Ecological determinants of occupancy and abundance of chinkara (Gazella bennettii) in Yadahalli Wildlife Sanctuary, Karnataka, India

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Chinkara (Gazella bennettii), the Indian gazelle, is a widespread antelope in the arid and semi-arid regions of the Indian subcontinent; however, the species has been relatively unexplored to the south of its distribution range. In 2016, with indefinite evidence of chinkara presence in Yadahalli Reserved Forest, Karnataka, India, the Forest Department notified the area as a Wildlife Sanctuary (WLS). We conducted a study to explore their possible existence and population status at Yadahalli WLS using a novel approach. We laid 2 sq. km grid cells in the Yadahalli WLS and divided it into four replicated sub-grids using GPS. We walked the grid cells and recorded the chinkara midden and deployed camera traps for direct detection and individual identity. We recorded site covariates, i.e. tree density, tree diversity, basal area, food tree density, cattle dung, goat and sheep droppings and distance from the boundary, and detection covariates, i.e. trail length. We performed occupancy modelling based on midden recordings using PRESENCE ver. 5.3. Through the effort of 62 grids with four spatial replicates, the detection probability of chinkara was found to be $0.68 \pm 0.03_{SE}$, and the estimated averaged occupancy was $0.51 \pm 0.37_{SE}$. The present study reveals a potential population of ~85 individuals in the Yadahalli WLS, which is the known southernmost population of the species in India. This study establishes the use of novel methods for monitoring of chinkara populations which will help in the development of a conservation action plan for the species and its habitat.

Keywords: Abundance, detection probability, Gazella bennettii, occupancy.

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protection (schedule 1) to the species under the Indian Wildlife Protection Act 1972 (ref. 17). The distribution of chinkara has been mostly studied in northern parts of India because of sporadic records from South India. In southern India, chinkara has been found to occur in certain parts of Karnataka12,18 and further south in the Coimbatore Forest Division, Tamil Nadu18. Subsequent studies did not record any population to the south of Pennar River, Andhra Pradesh, and a possible local extinction was supposed in large parts of Karnataka and Tamil Nadu12,19. Thus knowledge about chinkara has been scanty. Although the distribution map of chinkara by Rahmani13 depicts a possible historical range in Karnataka, the range map in the IUCN website does not include Karnataka. However recently, Desai20 reported the occurrence of chinkara from the Yadahalli Reserved Forest in Bagalkot district, which lies in the semi-arid region of Karnataka; this led to the reserved forest being notified as a Wildlife Sanctuary (WLS) in 2016. This was the first report in the last four to five decades about a possible occurrence of chinkara.

We conducted the present study to confirm the occurrence of chinkara based on the habitat covariates to further our understanding of the species at Yadahalli WLS. We employed methods suitable for this shy and elusive species in its natural habitat. Here, we report findings of the study conducted to assess the conservation status of chinkara in Yadahalli WLS using a methodology which could be standardized for further studies on the species throughout its distribution range.

Materials and methods

Study area

The Yadahalli WLS is located in northern Karnataka between 16°18′00″–16°23′47″N lat. and 75°24′00″–75°37′43″E long. (Figure 1). The sanctuary is spread over 96 sq. km. The temperature ranges between 14°C in December–January and 38°C in April–May and average annual rainfall is 580 mm (ref. 21). The vegetation of the study area includes southern dry mixed deciduous forest, southern thorn forest, southern thorn scrub, southern euphorbia scrub, babul forest and inundation babul forests22. The flora mainly consists of Chloroxylon swietenia, Albizia amara, Wrightia tinctoria, Anogeissus latifolia, Acacia nilotica, Mundulea suberosa and Diospyros melanoxylon as the dominant tree species23.

Field methods

The number of middens and the quantity of faecal deposits in an area indicate the occurrence and intensity of use by a species in that area. During our reconnaissance survey, we did not observe chinkara which is in agree-
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Figure 1. Map depicting location of capture, midden and probability of occurrence in each 2 sq. km grid at Yadahalli Wildlife Sanctuary, Karnataka, India.

Table 1. Predicted species response to each covariate based on our a priori hypothesis for chinkara

| Midden |  | P |
|--------|---|---|
| TR     | + | – |
| FDTR   | + | 0 |
| BA     | + | 0 |
| DIVE   | + | 0 |
| CATT   | – | 0 |
| GOAT   | – | 0 |
| DIST   | + | 0 |
| KM     | + | + |

TR, Tree density; FDTR, Food tree density; BA, Basal area; DIVE, Plant species diversity; CATT, Cattle dung density; GOAT, Goat drooping density; DIST, Distance from the boundary; KM, Trail length. ‘+’ signifies a positive effect on the response variable, ‘–’ signifies a negative effect and ‘0’ signifies that the covariate does not affect the response variable. ‘—’ Not applicable. \( \psi \) is the probability of occurrence and \( P \) is the species detection probability.

Statistical analysis

A priori hypothesis: Considering the biology of chinkara and habitat conditions, an a priori hypothesis was established to determine the parameters that might influence their detection and occupancy in the grid cells (Table 1). We categorized site-level covariates as ecological variables: tree density (TR), tree diversity (DIVE), basal area (BA) and food tree density (FDTR); anthropological variables: cattle dung (CATT), goat and sheep droppings (GOAT) and distance from the boundary (DIST). We used trail length (KM) as a covariate for detection probability.

Independent variables: Using plant data from each quadrat we calculated TR and FDTR by dividing the total number of individuals/area sampled \( \times 10,000 \) and BA using the formula \( (\text{GBH})^2/4\pi \). The plant species diversity (DIVE) was represented by Shannon–Wiener’s index using the formula

\[
H' = -\sum (n_i/N) \ln(n_i/N),
\]

for each grid cell. We listed five species as the most important food species for this study area based on the quadrats was 400 m across the diagonal line. Plant species having minimum 0.10 m girth were considered as trees, and height of the trees was measured using a hypsometer. The girth at breast height (GBH) for each stem more than 0.10 m was measured. Number and area covered by bushes in each quadrat were recorded. Taxonomic identification of the species was done following Flora of Karnataka by Saldanha. We also recorded the count of dung piles of livestock in quadrats. On the GIS platform, we measured the distance of the grid corner to the forest boundary and the nearest village.
Table 2. Detection probabilities for chinkara midden

| Model                        | $\hat{p}$ ± SE | AICc  | AICc  | $w_i$ | $K$ | Naïve occupancy |
|------------------------------|----------------|-------|-------|-------|-----|-----------------|
| $\psi(.)$, p(KM)            | 0.68 ± 0.03    | 225.20| 0.00  | 0.90  | 3   | 0.44            |
| $\psi(.)$, p(.)             | 0.70 ± 0.04    | 229.58| 4.38  | 0.10  | 2   |                 |

$\hat{p}$, Estimated species detection probability; AICc, Akaike information criterion corrected for small-sample bias; $\Delta$AICc, Difference in AICc values between each model and the model with the lowest AICc; $w_i$, AICc model weight; $K$, Number of parameters estimated by the model and KM, Trail length.

Table 3. Model for occupancy of chinkara using midden

| Model                        | $\psi$ | $\hat{SE}$ | AICc  | $\Delta$AICc | $w_i$ | $K$ |
|------------------------------|--------|------------|-------|---------------|-------|-----|
| $\psi$(BA + CATT + DIST), p(KM) | 0.5161 | 0.3710 | 170.95 | 0             | 0.6519 | 4   |
| $\psi$(BA + CATT), p(KM)      | 0.5125 | 0.0522 | 173.28 | 2.33          | 0.2033 | 4   |
| $\psi$(BA), p(KM)             | 0.5280 | 0.0347 | 173.96 | 3.01          | 0.1447 | 2   |
| $\psi$(DIST), p(KM)           | 0.4821 | 0.0486 | 210.33 | 39.38         | 0       | 2   |
| $\psi$(DIVE), p(KM)           | 0.5082 | 0.0471 | 212.76 | 41.81         | 0       | 2   |
| $\psi$(DEST), p(KM)           | 0.5087 | 0.0483 | 213.02 | 42.07         | 0.1447 | 2   |
| $\psi$(GOAT), p(KM)           | 0.5175 | 0.0502 | 217.12 | 46.17         | 0       | 2   |
| $\psi$(FDTR), p(KM)           | 0.4995 | 0.0479 | 224.32 | 53.37         | 0       | 2   |
| $\psi$(TR), p(KM)             | 0.4993 | 0.0479 | 224.32 | 53.37         | 0       | 2   |
| $\psi(.)$, p(KM)              | 0.4744 | 0.0643 | 225.50 | 54.25         | 0       | 2   |

$\psi$, Estimated occupancy parameter; $\hat{SE}$, Associated standard error.

Results

A total of 217.73 km was covered by walking in the 62 grids, during which we recorded the middens of chinkara in 30 grids. We recorded a total of 357 middens of chinkara in 60 sq. km (30 grid cells). The average visibility range around a midden was 3359 sq. m, which ranged between 198 and 20,700 sq. m². Largely, the middens were placed at ‘relatively open area’ within thick vegetation.

The analysis from 62 sites with four sampling occasions provided an estimated detection probability ($p$) of 0.68 ± 0.03 for the middens (Table 2). The distance walked (KM) in each sub-grid influenced the detection probability of middens, i.e. $w_i = 0.90$. Subsequent models were run with KM as a function of $p$. The estimated naïve occupancy was 0.40. The estimated occupancy for middens was $\psi(.)$, $p(.) = 0.51 ± 0.37$. Since $w_i$ of the top model was more than 0.5, we did not sum the AICc.
wt. and considered the top-ranking model as a predictor (Table 3). The occupancy of chinkara was positively correlated with BA: $\beta = 8.93 \pm 5.15$ and DIST: $\beta = 2.22 \pm 1.59$, while CATT had a negative influence $\beta = -2.57 \pm 2.15$ (Table 4). The site occupancy estimates were classified as low ($\psi = 0.00–0.25$), medium ($\psi = 0.25–0.50$), high ($\psi = 0.50–0.74$), very high ($\psi = 0.74–0.99$), and mapped, which shows that 33 out of 62 grids have a high probability, while 29 grids show relatively less probability of occupancy of chinkara in the study site (Figure 1).

GLM revealed BA as a significant determinant for relative abundance of chinkara. A model involving only BA was found to be the most suitable when compared with combinations of other covariates ($\text{AIC}_c = 163.14$; Table 5). Areas with high abundance of chinkara correspond to high BA ($\beta = 0.79 \pm 0.29$).

A total of 83 animals were identified in 72 sq. km of the area with a mean herd size of 1.20 ± 0.51SD individuals, which varied between 1 and 4. According to the Royle and Nichols model (27) ($\lambda = 0.29 \pm 0.06 SDS$ and $\psi = 1.50 \pm 0.39 SDS$), abundance in the sampled area was estimated to be 54.00. The individuals in each sampled grid were not detected in the neighbouring grids, except two adult males which were detected at the border of the adjoining grids. We multiplied site abundance with the mean herd size, which provided an estimate of 64 animals in 96 sq. km of the sanctuary.

### Discussion

Many of the antelopes have evolved and adapted for the plains, but also live in open scrub forests and productive landscapes. Chinkara is one among them known to extend from the Thar Desert to open scrub forests. Various studies have been conducted in different habitat types to estimate their density, like road surveys in desert areas and productive fields in Rajasthan13,14,28,29; line transects in the forested areas or protected areas with forest cover in Kutch and Gir in Gujarat, and Ranthambore Tiger Reserve in Rajasthan10–32; but there has been a lack of consistency in the results. Estimates using road surveys for different studies in Rajasthan varied highly (Table 6). Except in the Gogelao Enclosure in Nagaur33 and Ranthambore Tiger Reserve10, the estimated density of chinkara for all the sites was less than 3 individuals/sq. km, including the Yadahalli WLS. The present population density estimate indicates the existence of a sizable population in the Yadahalli WLS.

Results confirm the home range size of a herd or an individual chinkara in Yadahalli WLS to less than or equal to 2 sq. km, as the individuals were not found outside the border of the grids or neighboring grids. This is in agreement with Dookia16, who reported 2 sq. km of home range size in scrub forests of Rajasthan. Further, the Royle and Nichols model deduced a density of 0.88/sq. km, which corresponds to minimum population size derived from total count made using the photo-capture technique (0.86–0.99/sq. km).

Chinkara live in small herds of about 2–3 individuals, with mean herd size varying between 1.2 in Yadahalli, Karnataka and 2.60 in Ranthambore, Rajasthan34 and Kachchh, Gujarat32. However, a mean herd size of 5.01 was reported in Mayureshwara WLS, which is a small protected area notified to protect chinkara35. Probably, the high protection and limitations of the area have positively influenced the herd size in Mayureshwara WLS. Although the herd size in the present study is comparatively smaller, our estimates are highly reliable due to the use of infrared cameras used for camera-trapping technique.

The sex ratio was biased towards females in most of the range (Table 6); however, it was negative in Ranthambore (1:0.83) and Yadahalli (1:0.83), while adult female to fawn ratio did not differ between the sites (0.15–0.35). This requires further exploration to understand the population dynamics and survival rate of chinkara under different ecological conditions.

In Yadahalli WLS, the occupancy and abundance of chinkara were determined by the BA. However, the record of midden sites shows that they choose small, open areas which are the centre of their activities. As they feed on leaves from many shrubs and small trees, they were found more in the higher basal area, and further, they choose small, open areas within good forest cover. Thus, basal area is an important covariate which positively influences the occupancy and abundance of chinkara in Yadahalli WLS.

### Conclusion

This study establishes the presence of chinkara in the southern extremity of its distribution. Being an arid environment species with ~2 sq. km home range, the chinkara can have a healthy population even at low densities, making its monitoring difficult. This study demonstrates methodologies which can be employed to survey low-density populations of an elusive species through the use of camera traps and survey of middens. Further, these methods can also be employed for periodical monitoring.

### Table 4. Covariates influencing chinkara occupancy on basis of $\beta$-coefficients and standard error

| Covariate      | $\beta$-coefficient | SE  |
|----------------|----------------------|-----|
| Basal area (BA)| 8.93                 | 5.15|
| Distance (DIST)| 2.22                 | 1.59|
| Cattle (CATT)  | -2.57                | 2.15|
Table 5. Summary of the model selection procedure for covariates influencing relative abundance of chinkara with $R^2$ and corresponding $P$ values, $\beta$-coefficients and associated standard errors

| Covariates | $R^2$ | $P$  | $\Delta AIC_c$ | $\Delta AIC_c$ | K  | $\beta$-coefficient | $SE$  |
|------------|-------|------|----------------|----------------|----|---------------------|-------|
| BA         | 0.1780 | 0.000| 163.14         | 0              | 1  | 0.7914              | 0.2917|
| BA + DIST  | 0.1781 | 1.600| 165.13         | 1.99           | 2  | 0.4085              | 0.3574|
| BA + DIST + CATT | 0.1840 | 4.391| 166.87         | 3.73           | 3  | 0.2462              | 0.2483|
| TR         | 0.0797 | 0.000| 167.20         | 4.06           | 1  | 0.0028              | 0.0017|
| DIVE       | 0.0482 | 0.002| 168.41         | 5.27           | 1  | 2.4550              | 1.8720|
| CATT       | 0.0383 | 0.005| 169.79         | 5.65           | 1  | –0.0046             | 0.0040|
| FDTR       | 0.0098 | 0.160| 168.41         | 5.27           | 1  | 2.4550              | 1.8720|
| DIST       | 0.0072 | 0.229| 169.93         | 6.79           | 1  | 0.2188              | 0.4414|
| GOAT       | 0.0006 | 0.745| 170.75         | 7.03           | 1  | 0.0006              | 0.0040|
| BA + DIST + CATT + GOAT + TR | 0.2453 | 1.856| 172.06         | 8.92           | 7  | 0.1769              | 0.5569|

Table 6. Density and other variables of chinkara in other study sites

| Location                             | Method            | Density (km$^{-2}$) | Herd size | Ratio (M : F) | Ratio (F : fawn) | Reference   |
|--------------------------------------|-------------------|---------------------|-----------|---------------|-----------------|-------------|
| Thar Desert, Rajasthan               | Road survey       | 0.74                | 1–3       | 1 : 1.3       | –               | 12          |
| Thar Desert, Rajasthan               | Road survey       | 0.74                | –         | –             | –               | 28          |
| Thar Desert, Rajasthan               | Road survey       | 0.89                | –         | –             | –               | 29          |
| Thar Desert, Rajasthan               | Road survey       | 1.09                | –         | –             | –               | 14          |
| Thar Desert, Rajasthan               | Road survey       | 0.76                | 1 : 2.20  | –             | –               | 14          |
| Mayureshwara Wildlife Sanctuary, Pune| Road survey       | 48.4                | 5.01      | –             | –               | 35          |
| Gogelao Enclosure, Nagaur, Rajasthan | Line transect     | 49.6                | 5.01      | –             | –               | 33          |
| Kachchh, Gujarat                     | Line transect     | 0.005               | 2.55      | 1 : 1.46      | –               | 32          |
| Gir, Gujarat                         | Road strip count/line transect | 1.20          | 2.22      | –             | –               | 31          |
| Narayan Sarovar Chinkara Sanctuary, Gujar | –                   | 1.25                | –         | 1 : 1.35      | –               | 36          |
| Narayan Sarovar Chinkara Sanctuary, Gujar | –                   | 2.89                | –         | –             | 1 : 0.15        | 37          |
| Ranthambore, Rajasthan               | Line transect     | 5.60                | 2.5–2.6   | 1 : 0.83      | 1 : 0.35        | 30          |
| Cholistan Game Reserve, Pakistan     | –                  | 0.16                | 1 : 1.75  | –             | –               | 38          |
| Yadahalli WLS, Karnataka             | Photo-capture      | 0.88                | 1.20      | 1 : 0.83      | 1 : 0.24        | Present study|

of chinkara and other antelopes. As ungulate densities and vegetation are interdependent, their period monitoring will help understand the health of the ecosystem and establish management practices.

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