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Post-release movement and habitat selection of reintroduced gaur (Bos gaurus gaurus) during exploration and post-settlement in central India

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Abstract

Understanding how reintroduced large herbivores adjust to unfamiliar landscapes is essential for evaluating reintroduction success and guiding post-release management. However, early post-release exploratory movements are often pooled with later space use, leading to inflated home-range estimates and misleading inferences about habitat selection. We examined post-release movement and habitat selection of reintroduced gaur in the Sanjay Tiger Reserve, central India, by explicitly distinguishing between exploratory and post-settlement phases. Using telemetry data from seven individuals, we quantified the duration of exploration, changes in home-range size and stability, site fidelity, and phase-specific habitat selection.

All individuals exhibited a prolonged exploratory phase characterised by rapid expansion of space use, followed by stabilisation and strong site fidelity, indicating successful settlement within the release landscape. Exploration persisted for 90–200 days, during which individuals used large and highly variable areas (33–440 km²). Following settlement, space use became more constrained and less variable among individuals. Habitat selection differed markedly between phases: during exploration, gaur broadly used the landscape, while selecting forested areas and higher elevations and strongly avoiding human settlements and agricultural land. After settlement, habitat selection became more focused, with increased selection for dense and moderately dense forest, rugged terrain, and proximity to rivers, alongside consistent avoidance of anthropogenic areas.

Our results show that prolonged post-release exploration in reintroduced gaur represents adaptive landscape learning rather than maladjustment. Ignoring this phase can misrepresent spatial requirements and habitat preferences, with direct consequences for reintroduction assessment, monitoring timelines, and habitat management. Phase-specific analyses are therefore critical for accurately evaluating large herbivore reintroductions and informing conservation planning in human-dominated landscapes.

Introduction

The gaur (*Bos gaurus*) is the largest extant bovine species and is classified as a globally vulnerable species due to extensive population decline driven by habitat loss, poaching and increasing human pressure across its range in South and Southeast Asia (Duckworth et al. 2016; Mahmood et al. 2021). As a megaherbivore, gaur exert strong ecological influences on tropical forest ecosystems by regulating vegetation structure, influencing nutrient cycling and the maintenance of habitat heterogeneity, thereby contributing to ecosystem functioning and biodiversity (Sankar et al. 2013; Mungi et al. 2023; Poudel et al. 2024). In India, the gaur population have undergone a significant reduction in both the abundance and distribution (Choudhury 2002), leading to extirpations from several protected areas in India, including Sanjay Tiger Reserve (STR) in central India (Sankar et al. 2001; Pabla et al. 2011).

To address such local extinctions and restore ecological processes, conservation translocations, including reintroductions, are increasingly employed as management tools (Griffith et al. 1989; Seddon et

al. 2007). However, reintroduction outcomes are highly variable, and many programs fail to achieve long-term establishment despite successful release (Fischer & Lindenmayer 2000; Moseby et al. 2011). A recurring cause of failure is inadequate post-release adjustment of translocated individuals to novel environments, which can manifest as excessive movement, poor habitat matching, or heightened exposure to anthropogenic risk (Berger-Tal & Saltz 2014).

Post-release movement behaviour plays a central role in determining whether reintroduced individuals successfully establish within the release landscape. Following release into unfamiliar environments, animals typically undergo an exploratory phase characterised by elevated movement rates and broad spatial displacement as they acquire information about resource distribution, shelter, risk, and conspecifics (Frair et al. 2007; Bilby & Moseby 2024). As familiarity with the landscape increases, exploratory movements are expected to decline, leading to the stabilisation of space use and the formation of a resident home range (Delgado et al. 2009; Berger-Tal & Saltz 2014). The duration and extent of this exploratory phase vary widely among species and individuals and are shaped by factors such as release strategy, landscape structure, resource availability, and social organisation (Le Gouar et al. 2012). Distinguishing exploratory movements from post-settlement behaviour is therefore essential for correctly interpreting post-release space use and habitat selection.

Movement ecology provides a quantitative framework for evaluating reintroduction outcomes by explicitly linking movement patterns to behavioural states and ecological processes (Berger-Tal & Saltz 2016). Metrics such as cumulative home-range expansion, home-range stability, and site fidelity can be used to identify transitions from exploration to settlement and to assess whether individuals have successfully integrated into the release landscape (Fieberg & Kochanny 2005; Sarkar et al. 2016). Importantly, failure to account for exploratory behaviour can lead to inflated estimates of home-range size and misleading inferences about habitat preference, particularly during early post-release periods.

Existing studies on gaur have primarily quantified overall home-range size and habitat use in established populations or over pooled post-release periods, without explicitly separating exploratory and post-settlement phases (Sankar et al. 2013; Prayoon et al. 2024). Consequently, there is limited understanding of how reintroduced gaur navigate unfamiliar landscapes immediately after release, how long exploratory movements persist, and how spatial behaviour changes once settlement occurs. Comparable phase-specific analyses have been conducted for other large herbivores, such as European bison (*Bison bonasus*) in Germany and Poland, revealing pronounced exploratory movements followed by stabilisation of space use (Schmitz et al. 2015; Sobczuk et al. 2023), but similar evidence for gaur is lacking.

The current reintroduction site, Sanjay Tiger Reserve (STR), had experienced the local extinction of its gaur population by the late 1990s, possibly due to predation by other wildlife, habitat degradation, and disruption of traditional migratory routes, with the last record in 1998 (Nigam et al. 2024). To restore the ecological role of this megaherbivore, a reintroduction programme was initiated in 2023 in accordance with IUCN guidelines (IUCN/SSC 2013). Fifty gaurs were captured from two geographically distinct

source populations within central India (i.e., from Kanha and Satpura Tiger Reserves; both sites are ~ 250 km apart) and translocated to STR to establish a genetically diverse founder population (Nigam et al. 2024).

In this study, we investigate the post-release movement ecology of reintroduced gaur in STR by explicitly distinguishing between exploratory and post-settlement phases. Our objectives were to (1) identify the behavioural characteristics of exploratory movement and post-settlement phases following release, (2) compare movement behaviour and home-range size between exploratory and post-settlement phases and (3) evaluate shifts in habitat selection between phases. We hypothesised that reintroduced gaur exhibits extensive space use and low habitat selectivity during the exploratory phase, transitioning to reduced home ranges and selective use of resource-rich habitats while avoiding anthropogenic disturbance following settlement. By integrating movement metrics, home-range analysis, and habitat selection models, this study provides one of the first phase-specific assessments of post-release spatial behaviour in reintroduced gaur and contributes empirical evidence to improve the design, monitoring, and interpretation of large herbivore reintroduction programmes.

Material and Methods

(a) Study Area:

Sanjay Tiger Reserve is located in the northeastern part of Madhya Pradesh, India (81˚ 28’ 30” to 82˚ 14’ 38” E and 23˚ 48’ 24” to 24˚ 7’ 38”) and covers an area of 1674.51 km². The reserve shares its southern border with Guru Ghasidas National Park, Chhattisgarh and is functionally connected to Bandhavgarh Tiger Reserve through a forest corridor, facilitating landscape-level connectivity for large mammals. Topography within STR is heterogeneous, comprising undulating terrain interspersed with plateaus, gorges, and relatively flat tracts. Elevation ranges from approximately 425 to 732 m above sea level. Vegetation is dominated by sal (*Shorea robusta*) forest, which constitutes nearly 80% of the forest cover, followed by mixed forest, bamboo-dominated forest, scrubland, and grassland (Chaudhuri et al. 2022). STR experiences substantial anthropogenic pressure due to the presence of villages within the core area and along the reserve periphery, resulting in a mosaic of natural and human-modified habitats.

(b) Translocation Procedure:

A total of 50 gaurs (38 females and 12 males) were captured using chemical immobilisation and translocated to STR from Kanha Tiger Reserve (n = 34) and Satpura Tiger Reserve (n = 16). Translocations were conducted in three batches during June 2023 and April 2024. The first batch comprised 28 individuals, followed by 16 individuals in the second batch and six individuals in the third batch. Following translocation, all individuals were initially kept in a 30-hectare soft-release enclosure for acclimatisation before release into the open forest. The mean duration of enclosure holding was 35 days (range: 23–52 days). This period allowed individuals to recover from capture stress, adjust to local

environmental conditions, develop social bonding and be closely monitored before release. During capture, 14 individuals were fitted with telemetry collars for post-release monitoring. Nine individuals were equipped with Very High Frequency (VHF) radio collars (Telonics Inc., USA), and five individuals were fitted with GPS–VHF–satellite collars (Vectronic Aerospace, Germany).

(c) Post-release monitoring and data collection:

Locations of VHF-collared individuals were obtained using homing-in techniques, whereby the VHF signal was followed until the animal or herd was visually located (Kenward, 1987; White & Garrott, 1990). Locations were recorded from a vehicle at distances of less than 10 m. VHF-collared individuals were monitored daily, with a minimum of one location per day and additional locations (two to three per week) for some individuals, depending on field conditions. Monitoring was conducted between 06:00 and 18:00 h across seasons. GPS satellite collars were programmed to acquire six fixes per day at four-hour intervals, with a mean horizontal accuracy of 2–10 m.

Individuals with a minimum of one year of post-release monitoring data were used for analysis. Thus, locations from seven individuals were retained in the present study, comprising five females (K9, K16, K30, K32, and S5) and two males (K31 and K36). Individuals K9, K16, K30, and K31 were monitored using VHF collars, whereas S5, K32, and K36 were equipped with GPS satellite collars.

Data analysis:

(a) Exploratory movement and site fidelity analysis

Exploratory movement was quantified using home-range accumulation curves. For each individual, 100% minimum convex polygon (MCP) home-range area was calculated at successive 10-day intervals using cumulative location data. MCP area was plotted against time to generate home-range accumulation curves. The exploratory phase was defined as the period during which cumulative MCP area continued to increase with additional locations and was considered complete once the curve reached an asymptote, indicating stabilisation of space use (Sarkar et al., 2016).

Site fidelity was quantified by dividing the post-settlement period for each individual into two equal temporal segments (Fieberg & Kochanny 2005). For each segment, utilization distributions (UDs) were estimated from location data using identical spatial resolution and smoothing parameters to ensure comparability. Overlap between the two UDs was then calculated using the Utilization Distribution Overlap Index (UDOI). UDOI incorporates both the degree of overlap and the intensity of space use. Higher UDOI values were interpreted as stronger site fidelity.

(b) Home range estimation:

Home ranges were estimated using fixed kernel density estimation (FKD; Seaman & Powell 1996). A manually selected bandwidth was applied following recommendations by Gitzen et al. (2006), with a

smoothing parameter of 1000 m used for all individuals to ensure comparability across estimates. Home-range size for each collared gaur was quantified using both the 100% minimum convex polygon (MCP) and the 95% isopleth of the FKD, while core areas were delineated using the 50% FKD isopleth. All home-range analyses were conducted in R version 4.2.1 (R Core Team 2023) using the adehabitatHR package (Calenge 2006).

(c) Habitat selection:

Habitat selection was analysed using use–availability resource selection functions (RSFs; Manly et al. 2007), with locations pooled across individuals to estimate population-level selection patterns separately for the exploratory and post-settlement phases. Pooling was adopted because the primary objective was to identify general phase-specific habitat associations relevant for reintroduction assessment and management, rather than to quantify individual-level variation. Individuals were therefore treated as sampling units contributing to a common availability domain within each phase.

Seven environmental variables were included based on their expected influence on gaur space use: elevation, terrain ruggedness index (TRI), distance to dense forest, distance to moderately dense forest, distance to human habitation, distance to agricultural fields, and distance to rivers (Prayoon et al. 2024; Poudel et al. 2024). All anthropogenic and habitat variables were modelled as distances, where negative coefficients indicate selection for proximity and positive coefficients indicate selection for avoidance (for distance to dense forest, moderately dense forest & agricultural fields) and positive coefficients indicate selection for proximity and negative coefficients indicate selection for avoidance (for distance to human settlement & agricultural fields).

Environmental layers were derived from the Shuttle Radar Topography Mission (SRTM 2013), Forest Survey of India forest cover maps (FSI 2017), global land-use land-cover datasets (Venter et al. 2022), and OpenStreetMap river layers. All distance variables were calculated as Euclidean distances. Collinearity among predictor variables was assessed before model fitting, and no strong correlations were detected. Habitat selection models were fitted separately for exploratory and post-settlement phases for each individual using the R package *amt* (Signer et al. 2019).

Results

(a) Exploratory movement and stabilization phase:

All monitored reintroduced gaur exhibited a consistent post-release movement pattern characterised by rapid early expansion of space use followed by stabilisation, indicative of settlement within the release landscape. Cumulative 100% MCP area increased sharply during the initial post-release period and subsequently approached an asymptote, beyond which additional locations resulted in minimal increases in explored area (Fig. 2).

Across individuals, the rate of cumulative area expansion was highest during the first 30–120 days following release. Thereafter, expansion slowed markedly, with stabilisation occurring between 90 and 200-days post-release. Although the timing of stabilisation varied among individuals, the temporal structure of exploration, rapid initial expansion followed by deceleration and eventual asymptote, was consistent across all monitored gaur. The total area explored before stabilisation varied widely among individuals, ranging from 33.15 km² to 439.75 km² (Table 2).

Sex-specific patterns were apparent in the explored area and stabilization. Females explored cumulative areas ranging from 30.21 to 439.75 km² and reached an asymptote between 90 and 200-days post-release (mean = 146 days). Males explored areas ranging from 64.98 to 366.95 km² and stabilised between 120 and 160 days (mean = 140 days). Despite these differences in magnitude and timing, both sexes followed broadly similar exploratory trajectories characterised by early expansion and subsequent stabilisation of space use.

(b) Site fidelity:

All individuals exhibited strong site fidelity following stabilisation of cumulative space use. Overlap between utilisation distributions calculated for successive halves of the post-settlement period was consistently high, indicating persistent use of the same areas and stable intensity of space use.

(c) Home range size across post-release phases:

Home-range size differed systematically between exploratory and post-settlement phases across individuals and estimators. During the exploratory phase, home ranges were large and highly variable among individuals (Table 2; Fig. 3). Female gaur exhibited mean exploratory home ranges of 204.06 km² (100% MCP) and 127.18 km² (95% FKD), with mean core areas (50% FKD) of 20.79 km². Male gaur showed comparable exploratory space use, with mean home ranges of 215.97 km² (100% MCP) and 147.23 km² (95% FKD), and mean core areas of 28.15 km².

Following settlement, most individuals exhibited reduced space use relative to the exploratory phase, although the magnitude and direction of change varied. Female post-settlement home ranges averaged 132.86 km² (100% MCP) and 89.90 km² (95% FKD), with mean core areas of 17.56 km². Male post-settlement home ranges averaged 141.84 km² (100% MCP) and 100.46 km² (95% FKD), with core areas averaging 20.53 km².

Table 2
Estimated home range (100% MCP and 95% FKD) and core area (50% FKD) of monitored reintroduced gaur during exploration and post-settlement

Gaur ID	Time required for asymptote (Days)	Site fidelity	Home ranges (km²)					
			Exploration			Post-Settlement		
			100% MCP (km²)	95% FKD (km²)	50% FKD (km²)	100% MCP (km²)	95% FKD (km²)	50% FKD (km²)
Females								
K9	200	Yes	92.60	61.64	7.10	129.02	117.34	17.61
K16	190	Yes	30.21	35.09	7.81	72.62	62.96	14.85
K30	90	Yes	96.97	115.51	14.69	53.14	51.08	11.84
K32	120	Yes	360.77	211.52	40.05	237.05	108.51	19.32
S5	130	Yes	439.75	212.15	34.29	172.45	109.59	24.18
Mean	146	-	204.06	127.182	20.788	132.856	89.896	17.56
Males								
K31	160	Yes	64.982	82.37	18.43	46.64	70.37	17.32
K36	120	Yes	366.948	212.09	37.89	237.05	130.55	23.74
Mean	140	-	215.97	147.23	28.15	141.84	100.46	20.53

Paired within-individual comparisons based on 95% FKD estimates showed that five of seven individuals reduced their home-range size after settlement, whereas two individuals (K9 and K16) exhibited increases in post-settlement home-range area (Fig. 4). Across all individuals, the mean paired change in 95% FKD home-range size between phases was − 40 km² (SD = 64.2 km²), indicating a general tendency toward contraction of space use following settlement.

A paired Wilcoxon signed-rank test did not detect a statistically significant difference between exploratory and post-settlement 95% FKD home-range sizes ($V = 5$, $p = 0.16$). Visual inspection of paired trajectories revealed greater dispersion in home-range size during the exploratory phase and tighter clustering following settlement, consistent with stabilisation of space use despite substantial inter-individual variation.

(d) Habitat selection across post-release phases:

Habitat selection during the exploratory phase of reintroduced gaur was significantly influenced by elevation, proximity to forest cover, and distance from anthropogenic features. Gaur showed a positive association with elevation ($p < 0.001$), indicating greater use of higher elevations relative to availability.

Distance-based predictors revealed significant selection for areas closer to dense forest ($p = 0.003$) and moderately dense forest ($p = 0.001$). In contrast, gaur selected areas farther from human settlements ($p < 0.001$) and agricultural fields ($p < 0.001$). Distance to rivers showed a weak negative association with space use ($p = 0.079$), suggesting a marginal tendency to remain closer to riverine areas. Terrain ruggedness did not significantly influence space use during exploration ($p = 0.736$) (Table 3).

The post-settlement phase was strongly structured by forest cover, anthropogenic features, terrain complexity, and proximity to rivers. Distance-based predictors indicated significant selection for areas closer to dense forest ($p < 0.001$) and moderately dense forest ($p < 0.001$). Gaur also selected areas closer to rugged terrain ($p < 0.001$) and rivers ($p < 0.001$). In contrast, space use was positively associated with increasing distance from human settlements ($p = 0.009$) and agricultural fields ($p < 0.001$), indicating avoidance of anthropogenic landscapes. Elevation did not significantly influence habitat selection during the post-settlement phase ($p = 0.552$) (Table 3).

Comparison between exploration and post-settlement phases revealed clear directional shifts in habitat selection (Fig. 5). Elevation influenced space use only during exploration, whereas selection for forest cover, rugged terrain, and river proximity strengthened after settlement. While avoidance of human settlements and agriculture was evident throughout both phases, it became more stable and less variable following settlement. Overall, gaur shifted from broadly exploratory movements with weak environmental constraints to more focused and predictable habitat selection centred on forested, rugged, and riverine landscapes after establishing home ranges alongside stabilized avoidance of human-modified landscapes.

Table 3
Habitat selection coefficients (β ± SE) and significance levels for reintroduced gaur during exploration and post-settlement phases.

Habitat Variable	Exploration (β ± SE)	p-value	Post-settlement (β ± SE	p-value
Elevation	0.334 ± 0.098	< 0.001	−0.049 ± 0.082	0.552
Distance to dense forest	−0.272 ± 0.091	0.003	−0.475 ± 0.045	< 0.001
Distance to moderately dense forest	−0.258 ± 0.079	0.001	−0.467 ± 0.064	< 0.001
Terrain ruggedness	−0.026 ± 0.078	0.736	−0.244 ± 0.061	< 0.001
Distance to rivers	−0.190 ± 0.108	0.079	−0.391 ± 0.103	< 0.001
Distance to human settlements	0.597 ± 0.180	< 0.001	0.322 ± 0.124	0.009
Distance to agriculture	0.882 ± 0.168	< 0.001	0.664 ± 0.100	< 0.001

Discussion

This study provides one of the first phase-specific assessments of post-release movement ecology in reintroduced gaur by explicitly distinguishing exploratory and post-settlement behaviour. All monitored individuals exhibited an initial period of extensive exploration followed by stabilisation of space use and strong site fidelity, indicating successful spatial integration into the release landscape. By quantifying the duration of exploration, changes in home-range size, and habitat selection across phases, our findings address a key gap in gaur reintroduction ecology and contribute empirical evidence relevant to the design and evaluation of large herbivore translocations.

Reintroduced gaur exhibited rapid spatial expansion immediately after release, with exploratory movements persisting for approximately three to six months. Such prolonged exploratory phases are consistent with expectations for large-bodied herbivores navigating unfamiliar and heterogeneous landscapes, where acquiring spatial information on forage availability, refuge, and risk entails substantial movement costs. Similar patterns have been reported in reintroduced European bison, which exhibited extensive early exploration followed by stabilisation of space use once familiarity with the release area increased (Schmitz et al. 2015; Sobczuk et al. 2023), as well as in translocated African elephants showing pronounced individual variation in exploratory behaviour (Pinter-Wollman 2009).

The wide range of cumulative areas explored before settlement (approximately 30–440 km²) highlights pronounced inter-individual variability in post-release responses. This variability likely reflects differences

in individual behavioural traits, social context, release timing, and prior experience, rather than sex alone. Although males and females showed broadly similar temporal patterns, males tended to explore large areas and, in some cases, required longer periods to stabilise. In sexually dimorphic and socially structured ungulates such as gaur, these differences likely arise from contrasting reproductive strategies and social organisation (Sankar et al. 2013). Adult males are largely solitary and must locate and monitor female groups, potentially necessitating broader exploratory movements, whereas females typically move within cohesive herds and may prioritise identifying suitable foraging areas and refugia for group persistence (Ashokkumar et al. 2011; Sankar et al. 2013). Comparable sex-biased exploratory behaviour has been reported in reintroduced gaur populations in Bandhavgarh Tiger Reserve (Sankar et al. 2015).

Importantly, prolonged exploration in this context should not be interpreted as maladjustment or failure. Instead, it appears to represent adaptive information-gathering behaviour that precedes settlement. All individuals eventually stabilised their space use and exhibited strong site fidelity, providing clear evidence of successful behavioural adjustment to the release environment.

Home-range sizes during the exploratory phase were consistently larger and more variable than those observed following settlement. This contraction of space use after stabilisation is consistent with theoretical expectations that increased familiarity with local resources reduces the need for extensive movement and lowers energetic and risk-related costs. Similar reductions in home-range size following settlement have been documented in reintroduced tigers in Panna Tiger Reserve (Sarkar et al. 2016) and in European bison populations monitored after reintroduction (Schmitz et al. 2015; Sobczuk et al. 2023).

Although paired statistical comparisons between exploratory and post-settlement home ranges were not significant, this likely reflects limited sample size rather than the absence of a biologically meaningful effect. The consistent tendency toward reduced space use across most individuals, coupled with decreased variance in post-settlement home-range size, supports the interpretation that gaur progressively anchored their movements within defined spatial bounds. The two individuals that exhibited increased home-range size following settlement may represent delayed establishment, social restructuring, or responses to local resource distribution. Such post-settlement adjustments have been reported in other large herbivores and do not necessarily indicate instability or failure to establish (Debeffe et al. 2013; Sobczuk et al. 2023).

Comparison with earlier gaur studies highlights the importance of phase-specific interpretation. Home-range estimates from reintroduced populations in Bandhavgarh Tiger Reserve (Sankar et al. 2013) are substantially smaller than the exploratory ranges reported here. Pooling exploratory and settled movements would therefore inflate home-range estimates and potentially misrepresent space-use requirements for reintroduced populations.

Habitat selection by reintroduced gaur differed sharply between the exploratory and post-settlement phases, reflecting a transition from broad-scale landscape assessment to more constrained, resource-driven space use following home-range establishment. Such phase-specific shifts are a well-recognised

feature of reintroduction dynamics and are widely interpreted as indicators of successful acclimatization to novel environments (Schmitz et al. 2015; Nelson et al. 2025).

During the exploratory phase, gaur selected higher elevations and areas proximal to dense and moderately dense forest while strongly avoiding human settlements and agricultural land. Selection for higher elevations likely reflects reduced anthropogenic disturbance and greater forest cover rather than elevation itself, as low-lying areas across South and Southeast Asia are disproportionately modified by agriculture and settlements (Poudel et al. 2024; Dhakal et al. 2025).

The consistent avoidance of settlements and agriculture during exploration suggests that reintroduced gaur rapidly perceive and respond to anthropogenic risk, even during initial dispersal. Similar patterns have been reported in Bandhavgarh, where agricultural land was avoided year-round despite its proximity to forest edges (Sankar et al. 2013), and in other large herbivore reintroductions, including European bison and banteng, suggesting that sensitivity to human disturbance may be largely innate rather than acquired post-release (Schmitz et al. 2015; Chaiyarat et al. 2023).

In contrast, distance to rivers exerted only a weak influence during exploration, implying that water availability did not strongly constrain movements at this stage. Temporary access to multiple water sources likely allowed gaur to prioritize security and cover over proximity to perennial rivers. Similarly, the absence of selection for terrain ruggedness suggests that exploratory movements were characterized by weak fine-scale habitat filtering and high behavioural flexibility.

Following settlement, habitat selection became more structured and predictable. Selection for dense and moderately dense forest persisted and intensified, emphasizing the central role of forest cover in providing forage, thermal refuge, and protection from disturbance (Owen-Smith 2008). This pattern closely matches habitat-use studies of reintroduced and resident gaur populations, which consistently identify closed-canopy forest and forest–grassland mosaics as core habitat components (Sankar et al. 2013; Poudel et al. 2024).

Elevation no longer influenced space use after settlement, indicating that once suitable forest conditions were secured, altitude itself did not constrain home-range placement. Instead, selection for rugged terrain emerged as significant, likely reflecting its role in reducing human access and enhancing refuge from disturbance. Similar associations between gaur occurrence and terrain complexity have been reported in Nepal, where slope and ruggedness were key predictors of suitable habitat (Dhakal et al. 2025).

Proximity to rivers became a strong determinant of space use during the post-settlement phase, suggesting increased dependence on stable water sources once home ranges were established. This shift mirrors findings from Bandhavgarh and Chitwan, where gaur consistently selected riverine forests and areas near perennial water, particularly during periods of localized resource limitation (Sankar et al. 2013; Poudel et al. 2024).

Avoidance of settlements and agricultural land persisted after settlement but exhibited reduced variability, indicating consolidation of risk-averse behaviour. Such stabilization of space use around safer core areas has been documented across reintroduced herbivores and carnivores and reflects the resolution of exploratory uncertainty as individuals refine habitat use to minimize energetic costs and anthropogenic risk (Schmitz et al. 2015; Nelson et al. 2025).

Implications for Practice:

Reintroduced gaurs exhibit a prolonged exploratory phase (≈ 3–6 months) characterized by extensive movements that represent adaptive landscape learning rather than maladjustment. Managers should therefore avoid evaluating reintroduction success, home-range size, habitat suitability, or conflict risk during this early period, as pooling exploratory and settled movements can inflate spatial requirements and misidentify core habitats. Post-settlement space use provides a more reliable basis for defining long-term habitat needs. After settlement, gaur consistently selected forested, rugged, and riverine habitats, while avoiding human settlements and agricultural land throughout both phases. These post-settlement habitats should be prioritized for protection, restoration, and connectivity planning. Immediate and persistent avoidance of anthropogenic areas highlights the need to minimize human disturbance around release sites and along exploratory pathways. Monitoring should be designed to detect transitions from exploration to settlement using home-range stabilization and site-fidelity metrics to inform adaptive management.

Declarations

Ethics Approval and Permits:

All animal capture, handling, immobilization, and collaring procedures were conducted in accordance with applicable national wildlife laws and ethical guidelines. Necessary permissions for capture and collaring of animals were duly obtained from the competent authority, Ministry of Environment, Forest and Climate Change (Wildlife Division), Government of India, vide permission letter number No. 1–37/2021 WL, dated 17th November 2021.

Competing Interests:

The authors declare they have no relevant financial or non-financial competing interests to disclose.

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Author Contribution

Ritesh Vishwakarma and Bhaskar Bhandari conceived and designed the study. Material preparation, data collection, data analysis, and drafting of the original manuscript were performed by Ritesh Vishwakarma and Bhaskar Bhandari. Hari Om, Rajesh Kanna Tamilarasan, Abhay Sengar, and Nitin Gupta provided field support during data collection. Arun Kumar Gorati contributed to data collection and analytical support. The study was supervised by Parag Nigam and Bilal Habib, who also contributed to funding acquisition and manuscript revision. Subharanjan Sen, Lakshman Krishnamoorthy, and Amit Kumar Dubey contributed to funding acquisition and obtaining field permissions. All authors reviewed and commented on previous versions of the manuscript, and all authors read and approved the final manuscript.

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Data Availability

The datasets generated and/or analysed during the current study are not publicly available because they contain sensitive location information for a Schedule I species, under the Wildlife (Protection) Act, 1972, Amendment, 2023 of the Government of India. disclosure of which could pose risks to the species and its habitat. Data may be made available from the corresponding author upon reasonable request and subject to scrutiny and approval by the Institutional Animal Ethics Committee and relevant statutory authorities.

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Figures

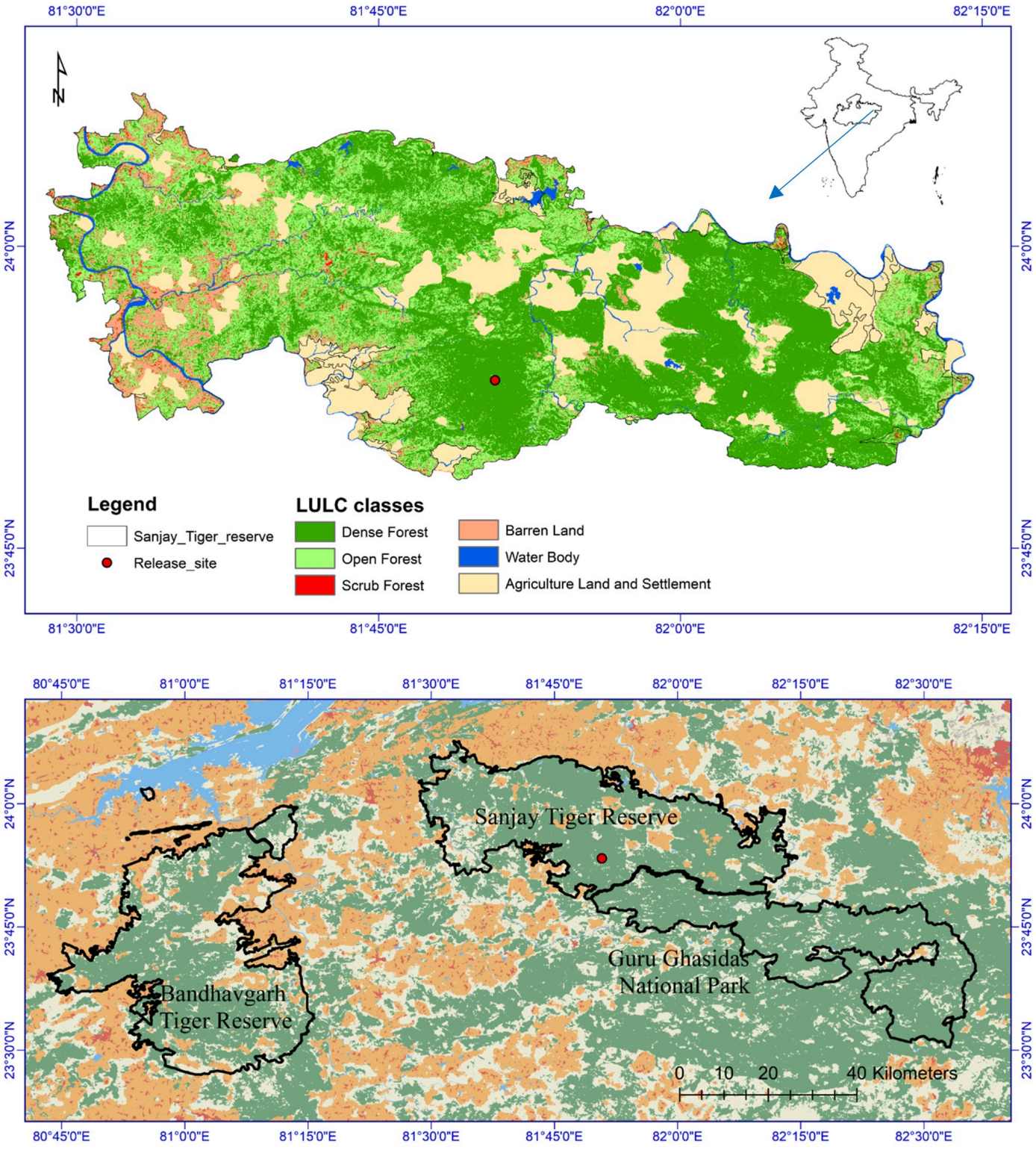


Figure 1

Map of the Sanjay Tiger Reserve (study site) representing the location of the release site and LULC classes and corridor connectivity with Guru Ghasidas National Park and Bandhavgarh Tiger Reserve.

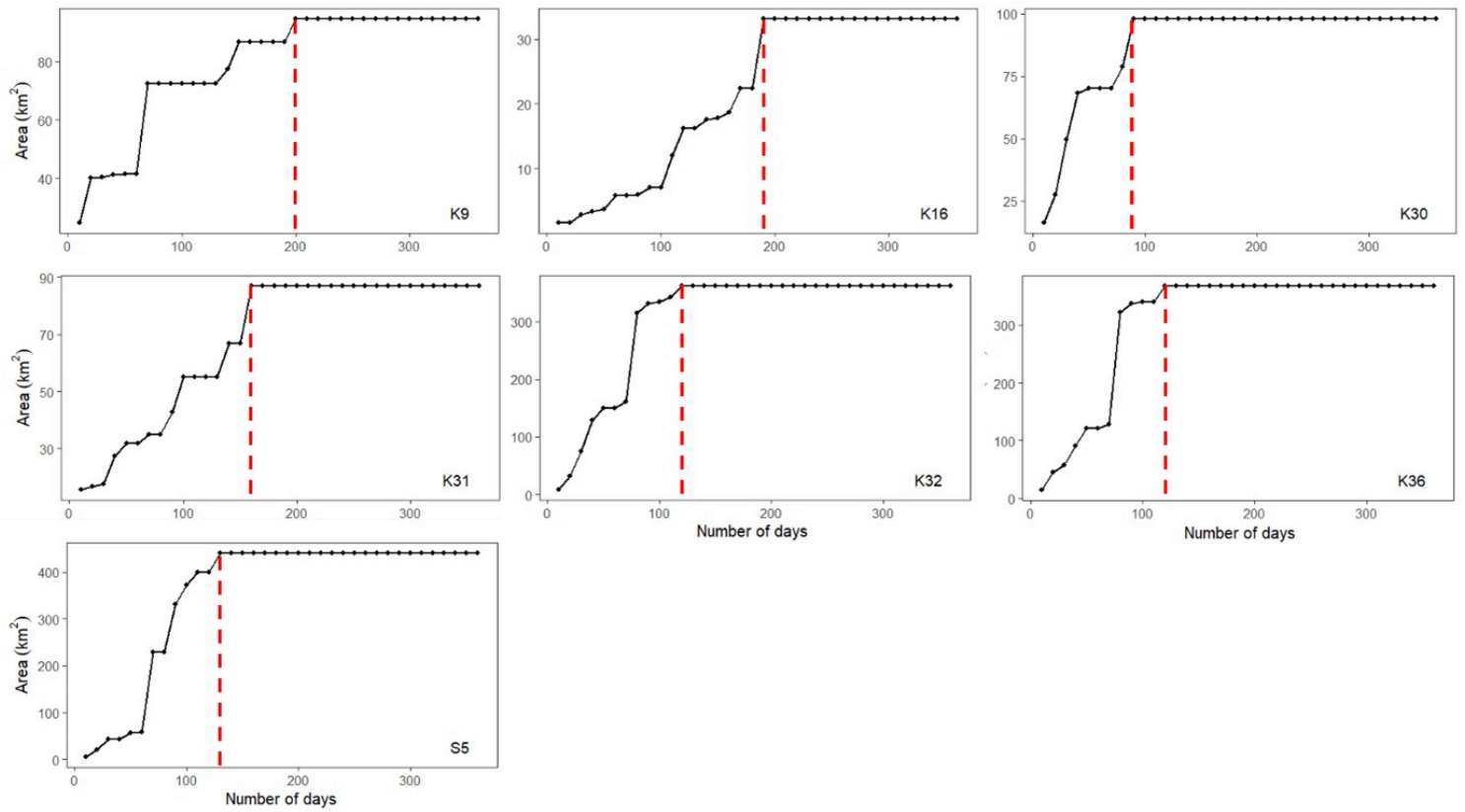


Figure 2

Estimated home range (100%) with respect to time period (10-day interval) and stabilization of home ranges of monitored reintroduced gaurs; the vertical red line represents the end of the exploratory period.

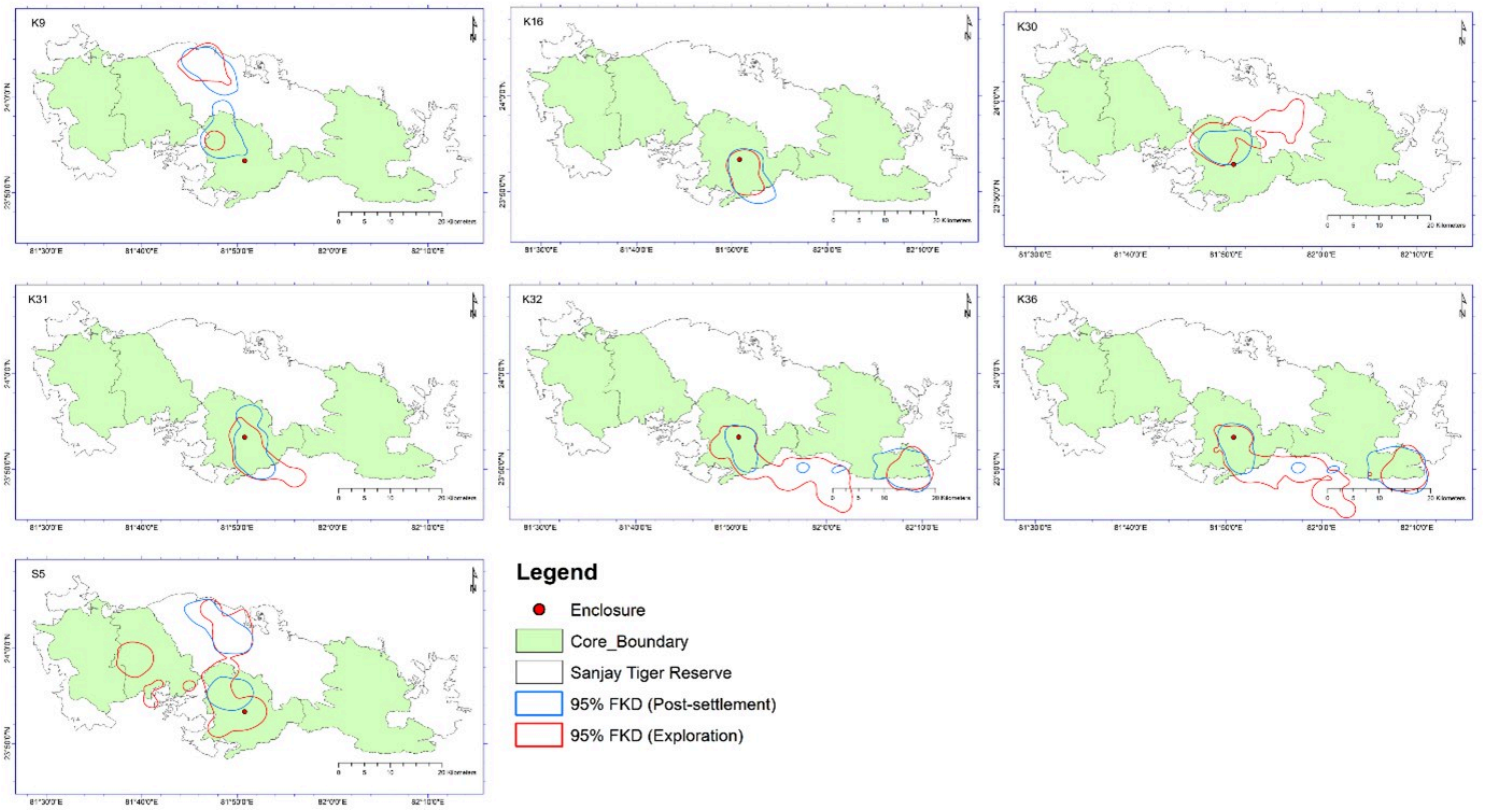


Figure 3

Home range characteristics (95% FKD) of monitored reintroduced gaur during exploration and post-settlement.

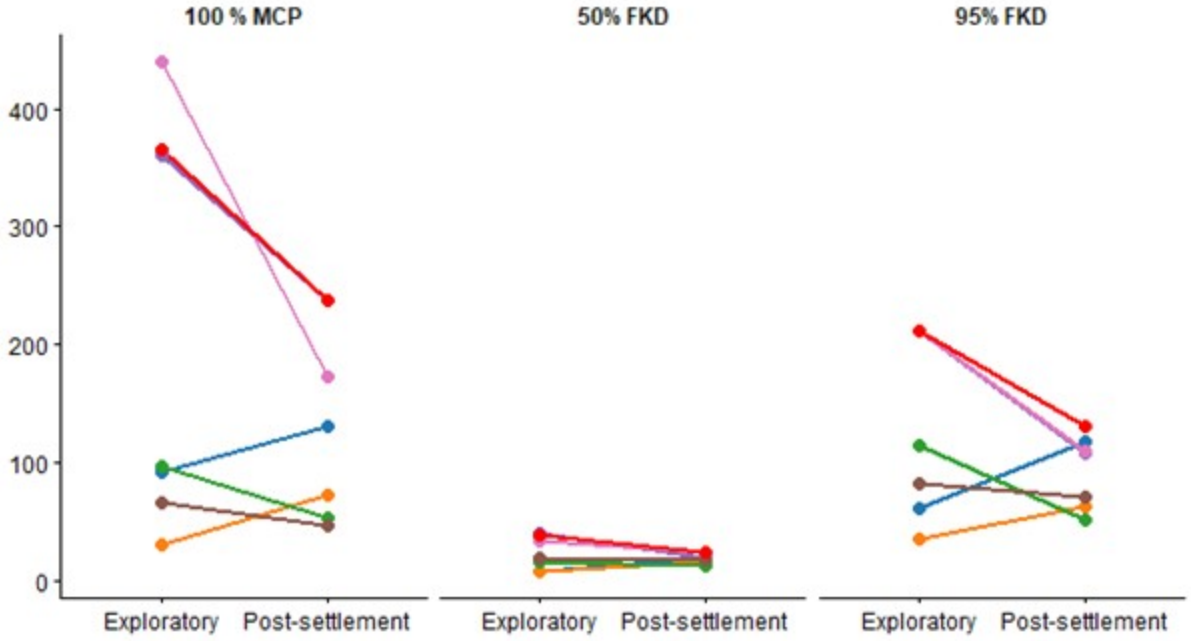


Figure 4

Paired comparison of individual home range size during exploratory and post-settlement phases for reintroduced gaur, estimated using 100% minimum convex polygon (MCP), 95% fixed kernel density (FKD), and 50% FKD. This paired presentation illustrates within-individual changes in space use following settlement. The colour in the graph denotes gaur individuals, *viz.*Blue (K9), Orange (K16), Green (K30), Purple (K32), Pink (S5), Brown (K31) and Red (K36).

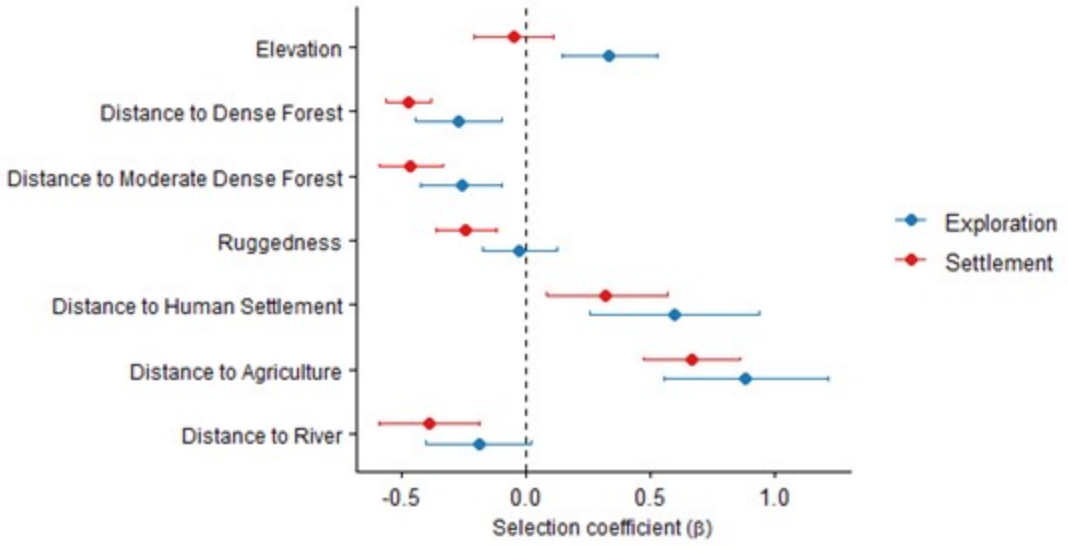


Figure 5

Comparison of resource selection coefficients (β ± 95% confidence intervals) for reintroduced gaur during the exploration and post-settlement phases.