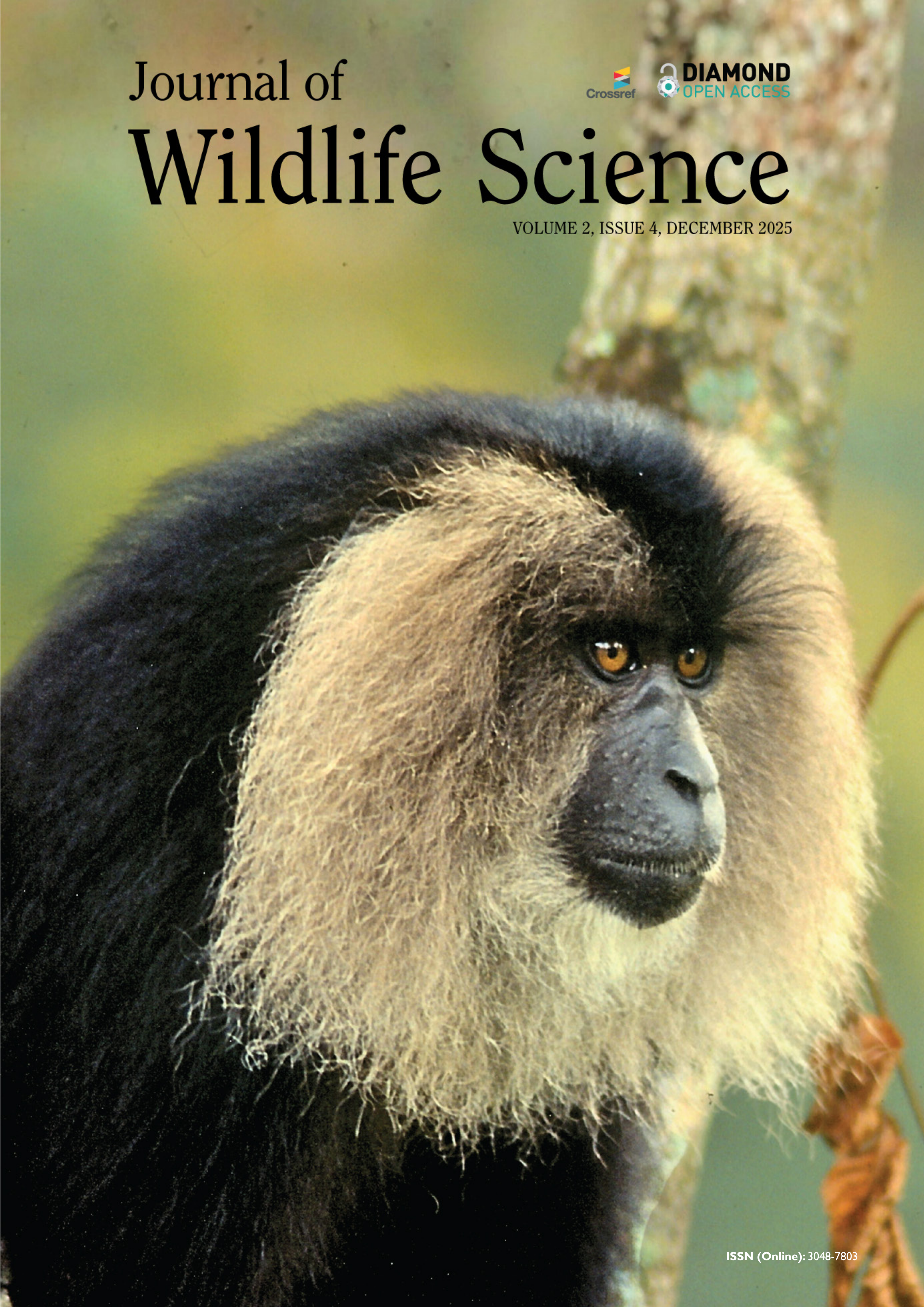
Crossref
DIAMOND OPEN ACCESS

Journal of Wildlife Science

VOLUME 2, ISSUE 4, DECEMBER 2025



ISSN (Online): 3048-7803

Journal of Wildlife Science

Published By: Wildlife Institute of India https://wii.gov.in/
Published On: 22 December 2025

Publisher's disclaimer: The Publisher, Journal of Wildlife Science (JWLS) or Editors cannot be held responsible for any errors or consequences arising from the use of the information contained in this journal. All claims expressed in articles published in JWLS are solely those of the authors and do not necessarily represent those of their affiliated organisations or those of the publisher, the editors and the reviewers. Any product that may be evaluated or used in the research published in JWLS or claim made by its manufacturer is not guaranteed or endorsed by the publisher.

Contact Information: For inquiries regarding submissions, editorial policies, or other matters related to JWLS, please contact:
Journal of Wildlife Science, Wildlife Institute of India,
PO Box # 18, Chandrabani, Dehradun – 248001 INDIA
Email: info@jwls.in

ISSN (Online): 3048-7803 **DOI (Volume 2, Issue 4):** https://doi.org/10.63033/JWLS.EWHG5456

Cover Image: Female of lion-tailed macaque (*Macaca silenus*), an endangered primate endemic to the Western Ghats of India. ©Werner Kaumanns

About the Journal

The Journal of Wildlife Science (JWLS) is dedicated to advancing wildlife science and conservation through rigorous, evidence-based research across taxa and ecosystems. The journal operates on a diamond open-access model, meaning neither authors nor readers incur fees for accessing or publishing in JWLS. In a departure from the traditional pay-to-publish or pay-to-read models, our mission is to foster open and free access to high-quality, peer-reviewed interdisciplinary research in wildlife science, conservation, and management. We provide an inclusive, author-friendly platform welcoming original articles, reviews, commentaries, policy briefs, and novel paper types like Methods Papers, Natural History Notes, and Academic Practices in Wildlife Science. Our unique peer review approach emphasises constructive mentorship between authors and reviewers to elevate quality while fostering a collaborative research community.

JWLS is a quarterly publication with an online-first feature (publishing online as soon as the article is accepted). Therefore, the authors can submit their latest findings, insights, and perspectives for publishing in JWLS at any time.

Aim and Scope

The journal does not categorise research based on taxonomic groups, allowing authors working on any wildlife taxa, ecological communities, or ecosystems to submit their work under a relevant theme.
https://jwls.in/author-guidelines.

Submission Guidelines

Authors interested in submitting their work to JWLS are encouraged to review the updated submission guidelines at https://jwls.in/author-guidelines.

Manuscripts should be submitted online through our submission system (https://www.editorialmanager.com/jwls/), and all submissions will undergo rigorous peer review.

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Content

Research Articles

Short Communications

Natural History Note

ISSN (Online): 3048-7803

JWLS

Volume 2, Issue 4 (December 2025)

TYPE Research Article

Mitigating linear infrastructure: Artificial canopy bridges as a key mitigating tool to reduce golden langur (*Trachypithecus geei*) road accidents in Assam, India

Jihosuo Biswas[1,2]*, Joydeep Shil[1,2]*, Kanmaina Ray[1,2], Mehtab Uddin Ahmed[1,2], Dharma Kanta Ray[1,2], Amulya Boro[1,2], Puja Muchahary[1,2], Benjamin Dorsey[3] & Honnavalli N Kumara[4]

[1] Primate Research Centre Northeast India, Guwahati-781012, Assam, India
[2] Conservation Himalayas Northeastern Chapter, Pandu, Guwahati-781012, Assam, India
[3] Asian Development Bank, PO Box- 3145, Revelstoke BC, Canada
[4] Salim Ali Centre for Ornithology and Natural History, South India Centre of Wildlife Institute of India, Coimbatore, Tamil Nadu, India.

EDITED BY
Mewa Singh
University of Mysore, Mysore, India.

*CORRESPONDENCE
Jihosuo Biswas
jihosuo@yahoo.com
Joydeep Shil
joydshil@gmail.com

RECEIVED 27 August 2025
ACCEPTED 29 September 2025
ONLINE EARLY 18 November 2025
PUBLISHED 22 December 2025

CITATION
Biswas, J., Shil, J., Ray, K., Ahmed, M. U., Ray, D. K., Boro, A., Muchahary, P., Dorsey, B. & Kumara, H. N. (2025). Mitigating linear infrastructure: Artificial canopy bridges as a key mitigating tool to reduce golden langur (*Trachypithecus geei*) road accidents in Assam, India. *Journal of Wildlife Science,* 2(4), 104-113.
https://doi.org/10.63033/JWLS.SZBG7452

FUNDING
This work was supported in part by the Bodoland Territorial Council Forest Department of Assam, People's Trust for Endangered Species, British Asia Trust, Re-Wild, CBOT and MBZSCF. The funding agencies were not involved in the design of the study, data collection, data analysis, decision to publish or preparation of any part of the manuscript.

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Abstract

Linear infrastructures like roads and power lines fragment the forest habitats used by golden langurs (*Trachypithecus geei*) in Assam, India. Artificial gaps in the forest canopy force these arboreal primates to descend to the ground, resulting in roadkill and other forms of anthropogenic mortality. From January 2023 to December 2024, a study in the Chakrashila–Amguri–Buxamara–Nayekgaon forest complex recorded 18 langur-vehicle collisions in the Nayekgaon-Choibari section of the State Highway-14 (SH-14), leading to seven deaths, five major injuries, and six minor injuries. To mitigate these risks, 15 artificial canopy bridges of four designs were installed along SH-14. During the monitoring, 112 instances of road and canopy bridge crossings by eight golden langur groups were recorded. Langurs used canopy bridges (74%, n = 83) significantly more than the road (χ^2 = 26.04, df = 1, p < 0.01). Among canopy bridges, pipe (69.9%) and ladder bridges (26.5%) were most effective, reducing ground-level crossings and probable collisions by ~74% during the study. Some power lines in the study area were insulated, providing additional pathways for their movement across the road. The initiative also integrates community outreach education to promote the conservation of golden langurs, providing incentives for restoring corridors through plantations, and maintaining them to mitigate conflicts. These interventions can restore fragmented habitat and, thus, corridor connectivity, reduce mortality risk, and are expected to enhance their persistence in the fragmented landscape.

Keywords: Colobine, collisions, corridor, fragmentation, habitat loss, population sustainability.

Introduction

Arboreal primates depend on undisturbed continuous canopies for their movement and dispersal within their habitats. However, canopy breakage and qualitative degradation of forest habitat by linear infrastructure - such as roads, power lines, and railway lines- severely disrupt their natural movement (Asensio *et al.*, 2021). Even within large forest patches, such breakages can isolate primate groups, and force animals to descend and adopt terrestrial movement to navigate across disconnected areas within their home ranges, thereby increasing the risk of road collisions, electrocution, and exposure to predators (Biswas, 2002; Lokschin *et al.*, 2007; Das *et al.*, 2009; Mass *et al.*, 2011; Donaldson & Cunneyworth, 2015). Lack of canopy connectivity can bring changes in diet (Onderdonk & Chapman, 2000; Das *et al.*, 2009), modifications in home ranges (Onderdonk & Chapman, 2000; Bicca-Marques, 2003; Shil *et al.*, 2021), increased physiological stress and higher parasite loads (Chapman *et al.*, 2006), and greater exposure to predators. Importantly, fragmentation restricts animal movement and gene flow between populations, which may further threaten the long-term viability of species (Biswas, 2002; Mass *et al.*, 2011). According to the IUCN Threats Classification Scheme (Version 3.2), 19.4% of all primate species are threatened by roads and railroads (Praill *et al.*, 2023). The rapid expansion of road networks - especially in and around primate habitat, including remote forested areas that serve as critical refuges - has exacerbated this threat. Consequently, wildlife-vehicle collisions (WVCs) involving primates are becoming increasingly common (Figure 1). Although many primates are primarily arboreal, roads often act as barriers that disrupt their natural movement.

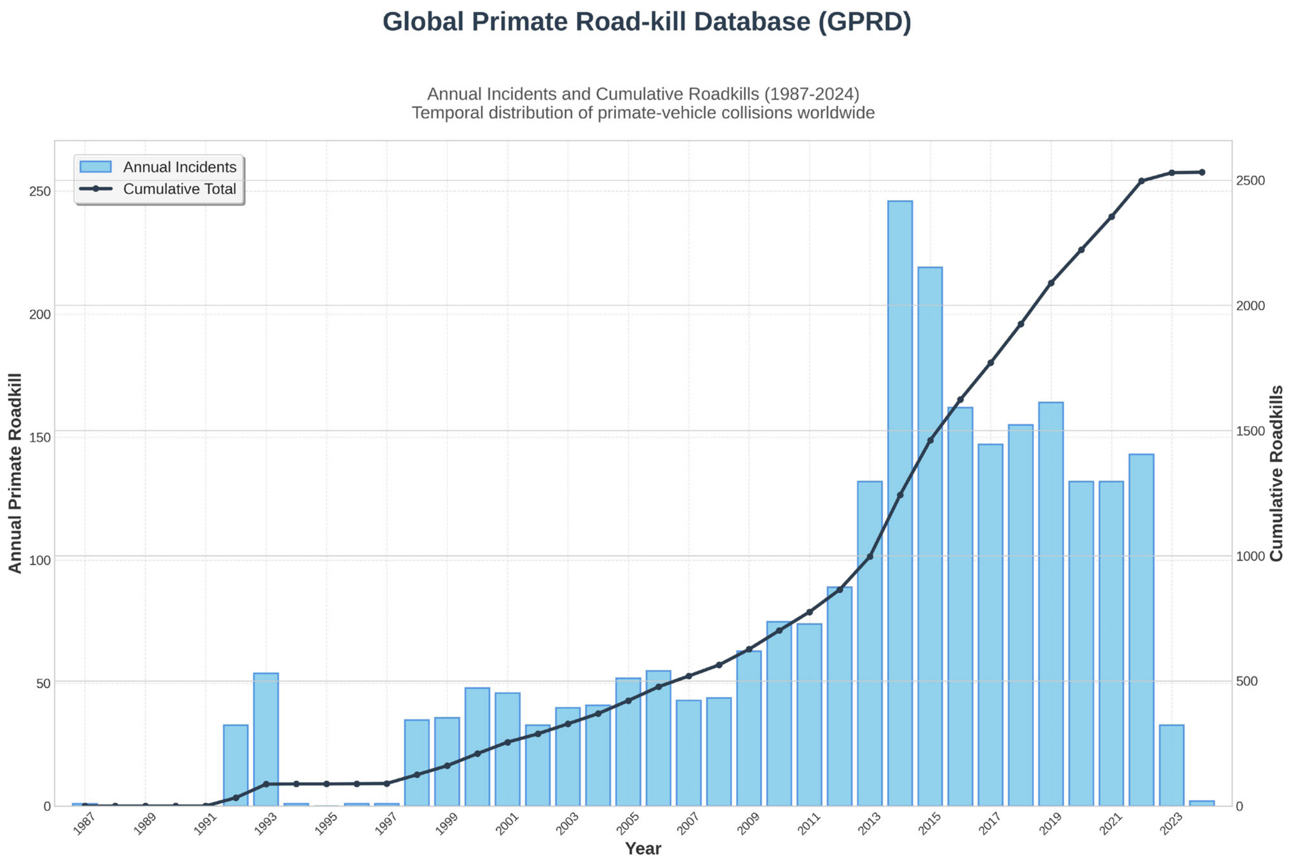


Figure 1: Report of the yearly number of primate road kills in the Global Primate Roadkill Database (GPRD), showing a gradual increase during 1987-2024 (bars), and an acceleration of records in the 2010s. The secondary axis provides the cumulative number of roadkill incidents (line). Data used are availed from The Global Primate Roadkill Database compiled by Praill *et al.* (2023) (accessed at: https://gprd.mystrikingly.com on 7 August 2025).

The golden langur (*Trachypithecus geei*) is an obligate canopy-dwelling primate endemic to the Indo-Bhutan border. It is found primarily in four districts of western Assam, India, and six districts of south-central Bhutan, making it one of the most 'range-restricted' primate species in South Asia (Biswas *et al.*, 2024; Thinley *et al.*, 2019). Across its range, the species faces habitat loss and population decline, with over half of its natural habitat lost in recent decades (Srivastava *et al.*, 2001). This decline is especially critical in the southern part of their range-particularly in Kokrajhar and Bongaigaon districts- where deforestation and the conversion of forests into agricultural fields and human settlements have fragmented once-continuous forests into smaller, isolated patches, jeopardising the long-term viability of these populations.

Recent population estimates suggest that the fragmented forests of Assam in its southern range support ~25% of India's golden langur population (Biswas *et al.*, 2024). However, several golden langur sub-populations of them have suffered a drastic decline or local extinctions in recent years due to extensive habitat fragmentation (Choudhury, 2002). Notably, the Kokrajhar district has lost five fragmented populations over the past few decades (Biswas *et al.*, 2019). Despite these setbacks, Kokrajhar district still retains six out of the twelve fragmented golden langur populations in India, harbouring roughly 15% of the national population (Biswas *et al.*, 2024). These populations were historically part of a contiguous habitat network, but have since become isolated due to habitat fragmentation (Biswas *et al.*, 2019), impeding population exchange and heightening the risk of local extinction (Frankham *et al.*, 2004).

Despite their isolation, these populations still retain relatively high genetic diversity, likely due to recent isolation (Ram *et al.*, 2016); however, they remain vulnerable to genetic fragmentation if the connectivity is not restored. Additionally, Aa substantial proportion of the golden langur population has begun adapting to human-altered environments, particularly village matrices (Medhi *et al.*, 2004; Shil *et al.*, 2021). The expansion of linear infrastructure within these fragmented habitats exacerbates these challenges by disrupting arboreal connectivity. This has resulted in increased road collisions, electrocutions, dog attacks, and mortality, and langurs straying into human settlements in search of food and refuge, all contributing to escalating human-langur conflict, further endangering the species (Chetry *et al.*, 2020; Shil *et al.*, 2021). These issues highlight the need for targeted conservation interventions to reduce risks and ensure the species' survival (Shil *et al.*, 2020). For several years, habitat fragmentation caused by linear infrastructure development has posed a significant threat to golden langurs and other arboreal primates elsewhere in Assam. In recent years, there has been a noticeable rise in incidents such as vehicle collisions, electrocutions, predator attacks, and langurs straying into human settlements in search of food and refuge, all contributing to escalating human-langur conflict (Biswas *et al.*, 2019; Chetry *et al.*, 2020; Shil *et al.*, 2021). Thus, the need to facilitating their movements artificially across linear infrastructure like roads has become inevitable.

Different animals respond to such facilitation differently, *e.g.*, elk took some time to use the newly created underpass in Arizona before using it regularly (Dodd *et al.*, 2007).

We implemented different types of artificial canopy bridges and evaluated their effectiveness in mitigating the impact of linear infrastructure on golden langur in a fragmented habitat in Assam, India.

Materials and Methods

Study area

The study site encompasses the fragmented forest complex of the Kokrajhar district of Assam, India, *viz.* Nayekgaon Proposed Reserve Forest (PRF) & Rubber Garden, Buxamara Reserve Forest (RF), Amguri PRF, and Chakrashila Wildlife Sanctuary (WLS), which is situated in the southern periphery of its distribution range (Figure 2). Historically, these forest patches were part of a larger, contiguous forested landscape. However, over the years, they have become increasingly fragmented and isolated due to deforestation and land-use changes. A key linear infrastructure SH-14 of the Kokrajhar–Bahalpur road passes through the Nayekgaon PRF–Rubber Garden–Amguri–Buxamara stretch, effectively bisecting the Chakrashila WLS-Amguri–Buxamara forest from the Nayekgaon PRF-Rubber Garden and Nadangiri RF. The rubber garden, a privately owned plantation, served as an important corridor connecting Chakrashila WLS-Amguri–Buxamara with Nayekgaon and Nadangiri. The general forest types in the region are Assam Valley semi-evergreen forests, northern secondary moist mixed deciduous forests, moist plain Sal forests, and rubber gardens dominated by Sal (*Shorea robusta*) and rubber (*Hevea brasiliensis*) mixed with some semi-evergreen and evergreen species (Bahuguna *et al.*, 2016).

Field methods:

Pre-ACB installation: We stationed three observers, comprising one research assistant and two community volunteers, on the road (SH-14) to monitor the golden langur movement along the road from January 2023 to November 2023. The observers recorded data between 07:00 hours and 17:00 hours, 16 to 20 days in a month, amounting to a total of 1768 hours of survey effort in this period. Once the langur group was spotted along the road, the group was observed until they moved away from the road. The time of crossing, number of individuals, path taken, substrate used, and the height of the animal during their movement were recorded.

Observers were stationed from June to August, 2023, two days a month, to signal passing the vehicles passing at high speed to reduce their speed at an accident-prone area, where there were high possibilities of animal crossings. Observers signalled a total of 50 vehicles when golden langur groups were active close to the roadside or attempting to cross and recorded the responses of the commuters. Vehicles' speed compliances were observed visually without a speedometer. Speed compliances were considered positive when vehicles used a full break or decreased their speed significantly. In September 2023, we erected two signage at both ends of the accident-prone area of the road to educate and signal the traffic. We further continued signalling vehicles to reduce their speed for two days a month, from September to November 2023. For comparison, observers signalled to another 50 vehicles while golden langur groups were near the roadside, keeping the signage in focus.

We recorded every langur collision with vehicles and other causes of their death along the road. Using this information, we identified the crucial location of animal crossings and possible animal collision sites. (Figure 6a and Figure 6b).

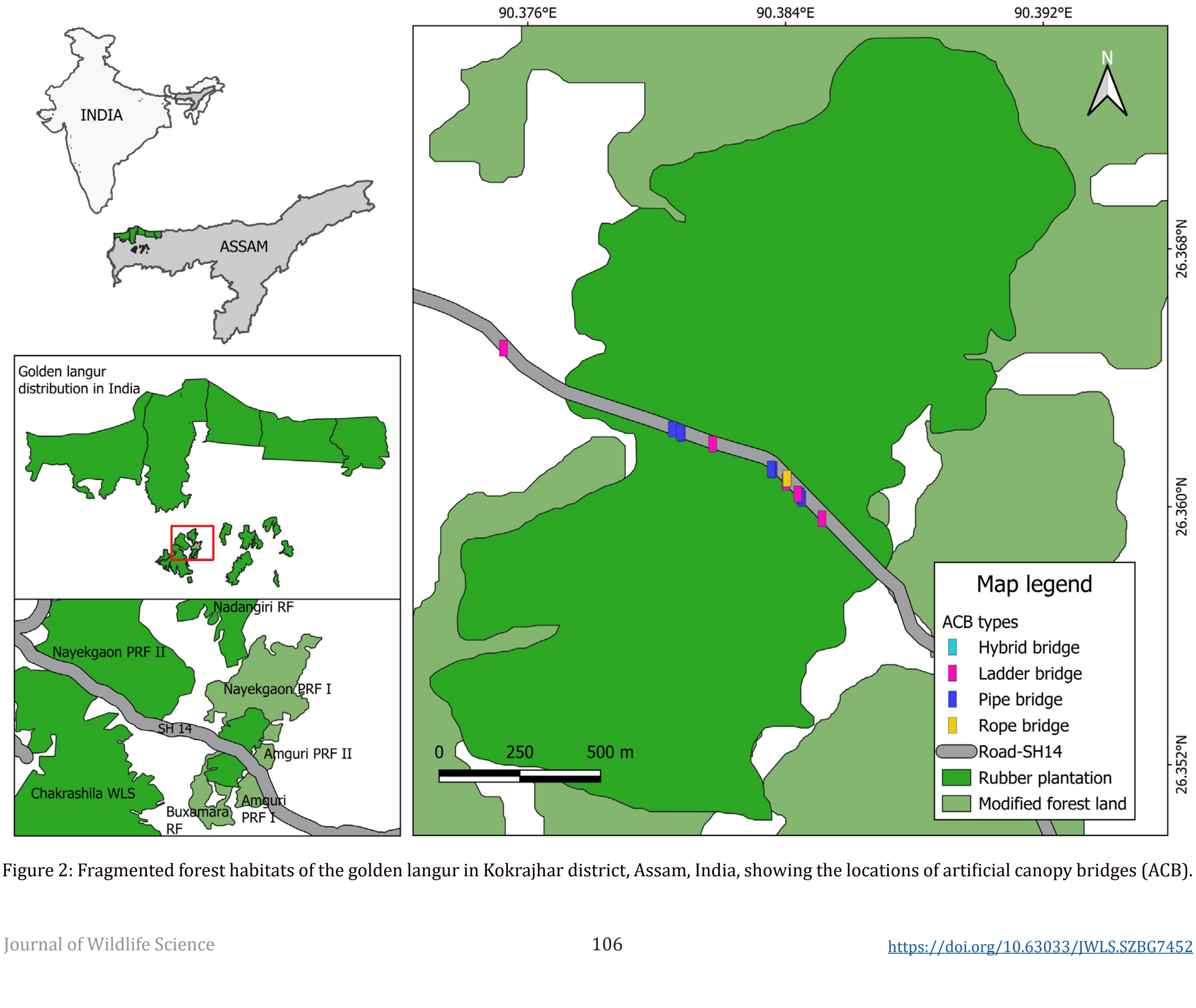


Figure 2: Fragmented forest habitats of the golden langur in Kokrajhar district, Assam, India, showing the locations of artificial canopy bridges (ACB).

 https://doi.org/10.63033/JWLS.SZBG7452

Installation of ACB: To construct the ACBs, we assessed the parameters like bridge length, anchor trees, canopy height, angle of the bridges, owner of the area, bridge type, and bridge viability to select the appropriate sites in the selected crucial locations. Considering the durability, strength, flexibility, and suitability for arboreal primates, we selected, i) 2.54 cm thick unplasticized polyvinyl chloride (UPVC) pipes, caps, ii) tie cables of varying size and strength, iii) insulated gym cables of varying size (6 mm, 5 mm & 4 mm), iv) adhesive, both side glue tape, v) 5.08 cm diameter high density polyethylene (HDPE) pipes, vi) 6 mm galvanizsed cable and 0.75mm steel wire, vii) 2.4 cm diameter nylon ropes, viii) bamboo poles and bamboo tubes, and ix) 20 mm insulated aluminium cable.

Bridge selection and construction: We initially used bamboo bridges to acclimatise the langurs to use the canopy bridges and later replaced this with the pipe bridges and ladder bridges (Table 1).

I. Bamboo bridge:
a. A 15-meter-long mature bamboo pole was installed on both anchor trees above the power line and securely fastened between them.

b. Bamboo poles measuring 3 cm in diameter were sliced into 10 cm lengths. These pieces were then threaded onto a 2.4 mm diameter nylon rope, forming a flexible yet sturdy bamboo chain. Once assembled, the rope cum bamboo chain bridge was installed between two anchor trees by securely fastening it to the branches. (Figure 6c)

II. Rope bridge: The bridges were constructed using thick yellow coloured nylon rope with a diameter of 2.4 cm, securely tied to pre-identified anchor trees. The ropes were fastened to branches at a height of approximately 1.5 to 2 meters above the electric lines crossing the road, thereby eliminating any risk of electrocution. (Figure 6d)

III. Pipe bridge: The bridges were constructed with HDPE pipes (5.08 cm diameter, typically used for water supply), combined with 2.4 cm diameter nylon rope and 4 mm galvanised wire. Considering the width of the canopy gap, the HDPE pipe was cut to the required length. A 2.4 cm diameter nylon rope and a 4 mm galvanised wire were inserted through the pipe, with an excess length of 6–8 meters on either end to allow the pipe to secure on the anchor trees. Two small holes were drilled at both ends and every 4 m of the HDPE pipe. The inserted rope and galvanised wire were tightly secured to the pipe with 0.75 mm steel wire at the drilled holes of the pipe. This provided additional stability and ensured that the rope remained firmly in place within the pipe. The bridge was lifted and positioned across the preselected canopy gap. The ropes were then securely fastened to strong branches on each side of the designated anchor trees. A total of eight pipe bridges were installed at the identified locations. (Figure 6e)

IV. Ladder bridge: We used a 2.54 cm diameter UPVC hose pipe of 50 cm length. Both ends of the pipe were closed with a cap using UPVC joining solvent. The bridge was constructed in the style of a horizontal "ship" ladder, with its total length varying from 12 m to 15 m according to the width of the road. The core structure comprised four parallel insulated gym cables. The two outer cables (6 mm thick) remained straight and were spaced approximately 50 cm apart to provide the bridge's main frame. The two inner steel cables (4 mm thick), that are commonly used in gym equipment, were arranged in an interlaced pattern, forming an "X" configuration between each step, spaced at intervals of 30 cm along the length of the bridge (see Figure 3a). At each end of every pipe, one 6 mm hole and one 4 mm hole were drilled using a drill machine, allowing the passage of both the outer and inner cables. In addition, at the midpoint of each pipe—corresponding to the "X" junction of the interlaced inner cables - one 6 mm hole was drilled at each end and another at the centre. The crossing point of the "X" configuration was secured at this junction using a thick rope clamp, ensuring overall stability and preventing cable movement during use. We constructed five ladder bridges in Siljan, Kokrajhar. (Figure 6f).

All of the bridges were placed at a height of nine to ten meters from the ground (Figure 3b).

Monitoring of ACB: Following the installation of all bridges, three observers and two community volunteers monitored the bridges from mid -December 2023 to December 2024, for the maintenance and management of the canopy bridges. They monitored the road crossings by langurs using ACBs and other crossing locations. Observers also periodically walked on either side of the road from the ACB for about 1.5 km to monitor the groups. The observers recorded data between 07:00 hours and 17:00 hours, ~ 20 days in a month, resulting in a total survey effort of 2216 hours. When a group of golden langur was detected crossing the road, the observers recorded date, start and end timings of the observation, group size, location, and crossing pattern.

We deployed 13 camera traps, comprising two Spartan cameras, five Reconyx cameras, and six Cuddeback cameras, across all ACB sites alternatively. All the camera traps were active simultaneously during the survey period without any gap.

We compared the number of langur deaths due to electrocutions, and collisions with vehicles before (January 2023 to November 2023) and after installing the canopy bridges (mid-December 2023 to December 2024). We compared the responses of vehicles to signalling and signages asking them to slow down to avoid a collision. We compared the number of road crossings made by the langurs using different canopy bridges using the Chi-squared test. We used QGIS 3.42 (QGIS Development Team, 2025) for map creation and used Python 3.13 (Python Software Foundation, 2025) for statistical analysis.

Results

When the langurs were on the roadside, observers signalled the high-speed vehicles (n = 50) to slow down. The signals were disregarded 92% (n = 46) of the time. The persisted signalling with signage resulted in an increased response from 8% to 18% by the moving vehicles. We identified 18 critical crossover points by the golden langurs on SH-14 on a 5.2 km stretch from Nayekgaon to Choibari. These crossover points were used by eight groups of golden langurs, of which seven were mixed groups while one was an all-male band. Before installing the canopy bridges, golden langurs crossed the road by walking on the ground on 71% of the occasions, while they altered their route to use the existing natural canopy on 29% of the occasions.

We installed 15 canopy bridges along the SH-14, comprising eight pipe bridges, five ladder bridges, one rope bridge and one hybrid bridge (developed by replacing the bamboo-pole bridge) (Table 1). The time taken by the langurs to get habituated to using the different ACBs varied depending on the materials used; however, they eventually adapted to using them. Golden langurs habituated to the bamboo pole bridge and rope bridge within 15 and 23 days of installation (Figure 6g & 8h), respectively. After the acclimatisation phase, the bamboo-pole bridge was replaced with a mixed bamboo-and-rope structure (hybrid bridge). In contrast, pipe bridges took slightly longer, with an average habituation period of 29 days (Figure 6i). During the acclimatisation phase, golden langurs quickly started using the bamboo canopy bridges over the rope bridge (Figure 6h). Ladder bridges initially required a longer habituation period

 https://doi.org/10.63033/JWLS.SZBG7452

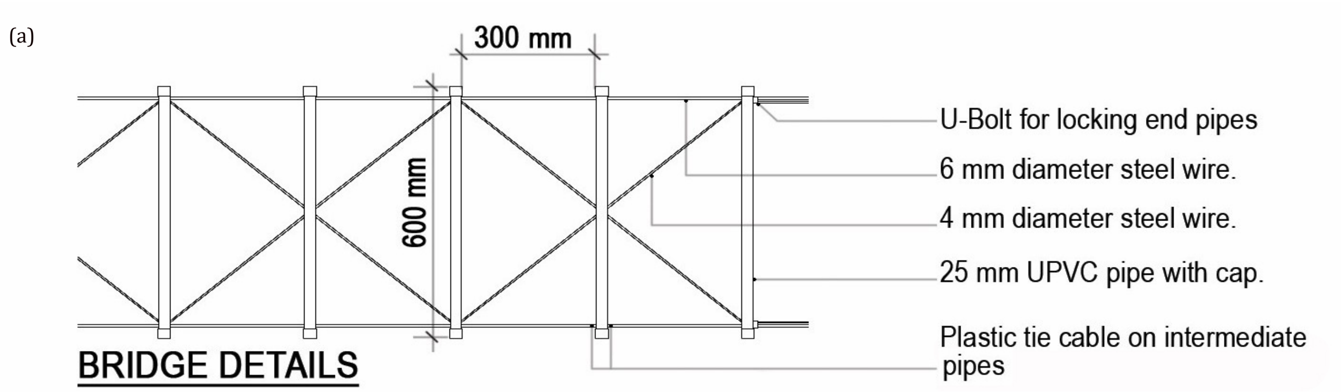
Table 1. Description of different canopy bridges, their limitations and advantages and the response of langurs.

Canopy bridge type	Description	Response of langurs	Limitations/ advantages
Rope Bridge	Initial installation: The bridges were constructed using thick yellow coloured nylon rope with a diameter of 2.4 cm, securely tied to pre-identified anchor trees. The ropes were fastened to branches at a height of approximately 1.5 to 2 meters above the electric lines. Modified bridge: Changed this to 20 mm thick insulated three-core aluminium wire coated in black plastic. This new material closely resembled natural climbers and was more visually neutral.	Langurs did not use the bridge even after 60 days. After the modification, langurs started to use the bridge after 27 days of installation. After the langurs acclimatised to using the artificial bridges, the structure was replaced with a plain rope bridge. The langurs continued to use the rope bridge for their movements.	Rope requires long acclimatisation by the langurs. the colour of the rope is important—it should be dark to blend with the natural environment. Relatively affordable. Modified bridge: The thickness, hardness, and weight of the insulated aluminium wire made it difficult to securely attach it to the terminal branches of the anchor trees, which were relatively delicate.
Bamboo pole bridge	A 15-meter-long mature bamboo pole was installed on both anchor trees above the power line and securely fastened between them.	Langurs started to use the bridge ~15 days after installation.	Availability of long bamboo poles, especially where canopy gaps exceeded 18 m, the bamboo poles' weight (approximately 15–18 kilograms) posed a safety risk. Any accidental fall could lead to damage or serious injury to langurs, vehicles and passengers. Limited durability of bamboo under outdoor conditions; the poles decomposed relatively quickly, requiring frequent maintenance or replacement. Thus, this can only be used during acclimatisation phase of the process.
Rope + Bamboo bridge	Bamboo slices of 10 cm lengths and 3 cm diameter were threaded onto a 2.4 cm diameter nylon rope, forming a flexible yet sturdy bamboo chain. Once assembled, anchor the rope cum bamboo chain bridge trees by being securely tied.	Langurs started using the bridge within 29 days of its installation.	Bamboo degradges quickly and requires replacement/repair. The weight of the bamboo poles may be an issue, particularly in longer bridges, influencing stability and durability. Given these factors, the hybrid bamboo and rope bridge design may be best suited for shorter canopy gaps, where frequent maintenance is feasible and the weight of the components does not compromise safety or structural integrity.
Pipe bridge	Constructed with high-density polyethylene (HDPE) pipes (5.08 cm diameter, typically used for water supply), combined with 2.4 cm diameter nylon rope and 4 mm galvanised wire. Made small holes every 4 m on a HDPE pipe of appropriate length. A 2.4 cm diameter nylon rope and a 4 mm galvanized wire were inserted through the pipe, with an excess length of 6–8 meters on either end. Two small holes were made at both ends and every 4 m of the HDPE pipe. The inserted rope and galvanised wire were tightly secured to the pipe with 0.75 mm steel wire at the holes of the pipe. This provided additional stability and ensured that the rope remained firmly in place within the pipe. The bridge was lifted and positioned across the preselected canopy gap. The ropes were then securely fastened to strong branches on each side of the designated anchor trees.	After the acclimatisation to use the pipe bridges, langurs started using them frequently.	The HDPE pipe is lightweight, durable and easy to install. Rope with wire provided additional stability and ensured that the rope remained firmly in place within the pipe.

 https://doi.org/10.63033/JWLS.SZBG7452

Ladder bridge	2.54 cm diameter UPVC hose pipe of length 50 cm. Both ends of the pipe were closed with a cap. Total length varying from 12 m to 15 m according to the width of the road. The core structure comprised four parallel insulated gym cables. The two outer cables (6 mm thick) remained straight and were spaced ~50 cm apart to provide the bridge's main frame. The two inner steel cables commonly used in gym equipment (4 mm thick) were arranged in an interlaced pattern, forming an "X" configuration between each step at intervals of 30 cm. The steps were spaced 30 cm apart along the length of the bridge. At each end of every pipe, one 6 mm hole and one 4 mm hole were drilled using a drill machine, allowing the passage of both the outer and inner cables. In addition, at the midpoint of each pipe—corresponding to the "X" junction of the interlaced inner cables - one 6 mm hole was drilled at each end and another at the centre. The crossing point of the "X" configuration was secured at this junction using a thick rope clamp.	Ladder bridge was the second highest used bridge by the langur.	Although, highly stable, but preparing the bridge was complicated.

(a)



(b)

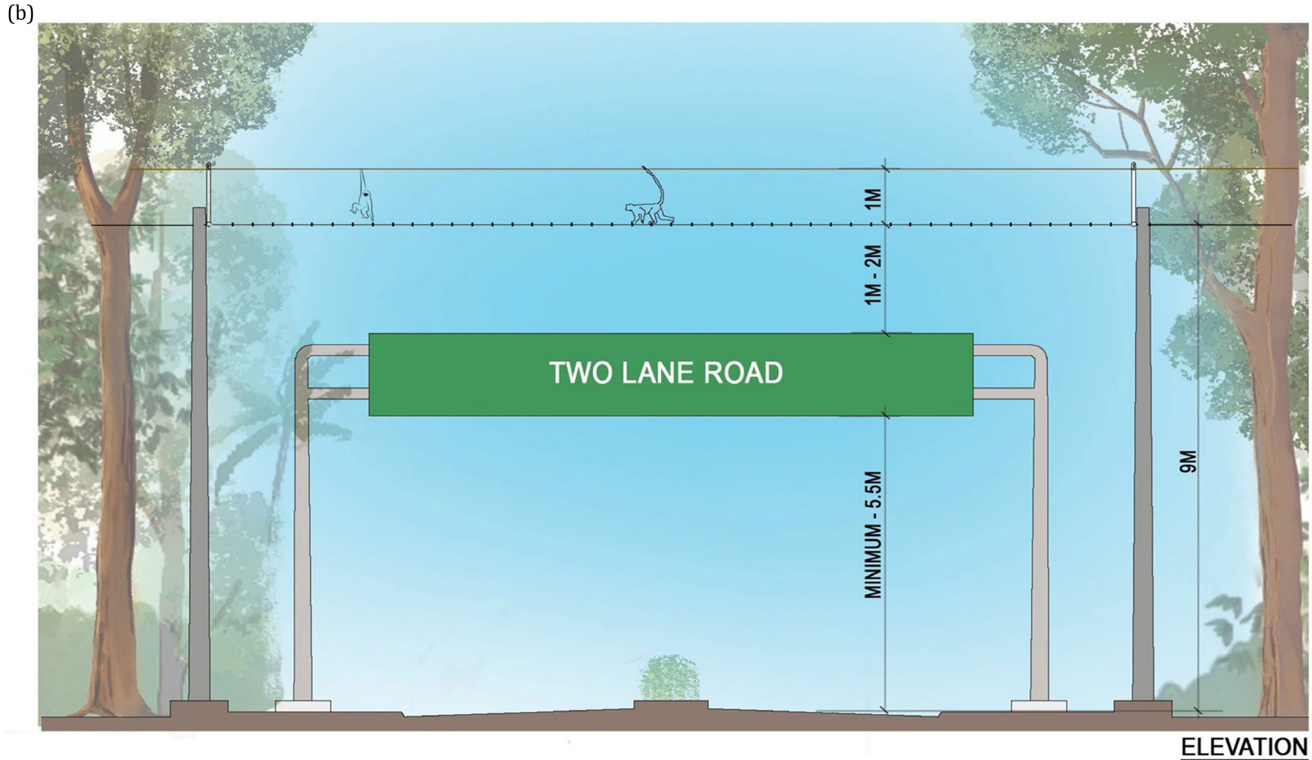


Figure 3: (a) Top view of the ladder bridge with the measurements. (b) Design for the ladder bridge for golden langurs.

nearly 90 days before the first observed crossing but this duration decreased to ~ 65 days in subsequent installations (Figure 6j).

We recorded 112 instances of golden langurs crossing the road during the monitoring period. Langurs used the canopy bridges (74.0 %, n = 83) significantly more than the road (25.8 %, n = 29) (χ^2 = 26.04, df = 1, p < 0.01). Further, out of 83 crossings using canopy bridges, 69.9 % (n = 58) were using pipe bridges, 26.5 % (n = 22) of the crossings were using ladder bridges, 2.4% (n = 2) of the crossings were using hybrid bridges and 1.2 % (n = 1) of the crossings were using rope bridges, (χ^2 = 102.69, df = 3, p < 0.001) (Figure 4).

Between January 2023 and December 2024, we documented a total of 18 golden langur road collisions on SH-14 (Figure 5a). Of those, 11 collisions leading to five deaths occurred before installing the canopy bridges, while two deaths due to seven collisions occurred after installing the canopy bridges. Out of 18 collision incidents in total, langurs were killed in seven incidents, sustained major injuries, that mainly included broken legs or the amputation of palms or tails in five incidents, and langurs escaped with minor injuries in the other six incidents. Meanwhile, there were three deaths of langurs in the five electrocution incidents in the period of pre canopy bridge installations, whereas we recorded five deaths in seven electrocution incidents in the period of post canopy bridge installations where electric power lines were not insulated.

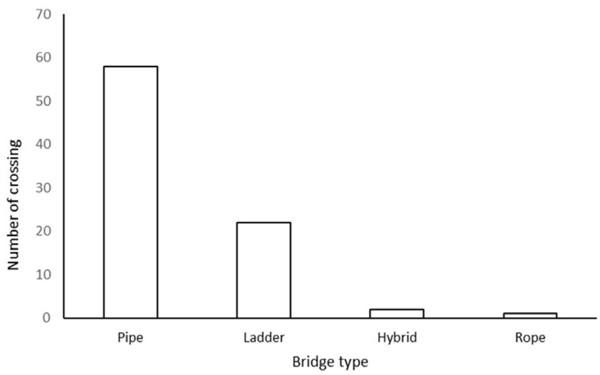


Figure 4: Frequency of use for different designs of artificial canopy bridges by the golden langur in Kokrajhar district, Assam, India.

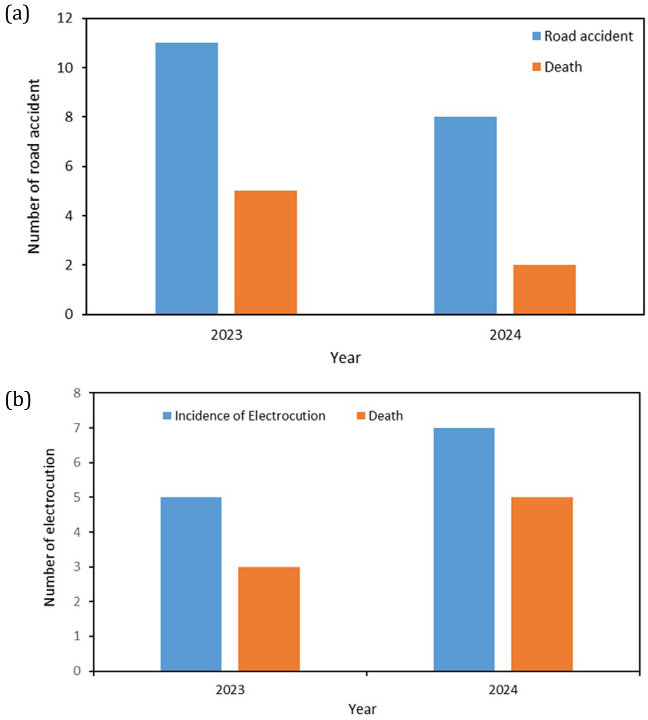


Figure 5: (a) Number of langur collisions with vehicles and deaths that occurred during the period of pre and post canopy bridge installations in Kokrajhar district, Assam, India. (b) Number of langur electrocution and their deaths during the period of pre and post canopy bridge installations in Kokrajhar district, Assam, India.

Discussion

Artificial canopy bridges (ACBs) substantially improved golden langur crossing by reducing their collisions with vehicles on 5.2 km stretch of SH-14 between Nayekgaon to Choibari. ACBs are increasingly used as a practical mitigation tool to restore connectivity, reduce mortality, and support conservation. Their effectiveness, however, depends on species-specific design, proper placement, and rigorous evaluation (Soanes *et al.*, 2024; van der Grift & van der Ree, 2015). In Australia, squirrel gliders (*Petaurus norfolcensis*) initially re-established movement using rope bridges and glide-poles (Soanes *et al.*, 2013). Later genetic analyses showed restored gene flow within five years, proving that aerial structures can reverse population fragmentation (Soanes *et al.*, 2018). The critically endangered Hainan gibbon (*Nomascus hainanus*) rapidly adapted to a rope bridge across a landslide, moving naturally and safely in Hainan, China (Chan *et al.*, 2020). In Kenya, “Colobridges” reduced road mortality among primates and proved sustainable with community involvement (Cunneyworth *et al.*, 2022). In Bangladesh, rare use of canopy bridges by slow lorises (*Nycticebus bengalensis*) confirmed that even cryptic, nocturnal species can benefit from ACBs (Maria *et al.*, 2022). After recording the high mortality of lion-tailed macaque (*Macaca silenus*) in Puthuthotam in Anamalai Hills, a few canopy bridges were installed (Jeganathan *et al.*, 2018), however, the estimation of their efficiency in reducing the ground movement of lion-tailed macaque and change in the rate of their roadkill is not available. At Hollongapar Gibbon Wildlife Sanctuary (Assam), targeted planting created a natural canopy bridge, later used by western hoolock gibbons (*Hoolock hoolock*) (Chetry *et al.*, 2022). Earlier work in Assam used ACBs for gibbons as temporary measures until forest regeneration closed canopy gaps (Das *et al.*, 2009). These evidence further reinforce the importance of ACBs in crucial crossovers of the animals.

ACBs will be efficient when integrated into wider landscape strategies: vegetation restoration to replace and complement artificial with natural bridges, speed management at hotspots, and power line insulation to reduce electrocutions (Chetry *et al.*, 2022; Clevenger & Huijser, 2011). Evidence suggests canopy bridges are relatively low-cost, community-manageable, and effective when combined with habitat restoration (Cunneyworth *et al.,* 2022). We observed that when only a nominal number of bridges were available, golden langurs tended to avoid using them, likely due to limited options. However, as the number and spatial distribution of artificial structures increased, providing a wider range of crossing points, the frequency of usage substantially increased. Ladder bridges initially required a longer habituation period, but this duration decreased in subsequent installations, suggesting that prior exposure helped facilitate faster adaptation.

There are some challenges we encountered in the implementation of the ACBs. During the study, five artificial canopy bridges were planned along SH-14 for golden langur crossings. However, the clearance of a rubber garden, which served as a habitat and transit route, led to the displacement of langur groups. This increased their ground crossings, collision risks, and straying into villages, highlighting the need for additional ACBs to mitigate these threats.

A: Golden langurs crossing the road.

B: Signage board and traffic signalling.

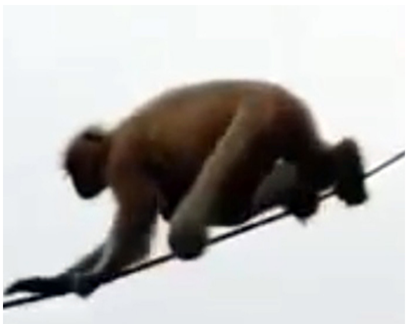
C: Bamboo cum rope (hybrid) bridge

D: Rope bridge (upper one)

E: High-density polyethylene (HDPE) pipes (6.08 cm diameter, typically used for water supply), 2.4 cm diameter nylon rope and 4 mm galvanised wire.

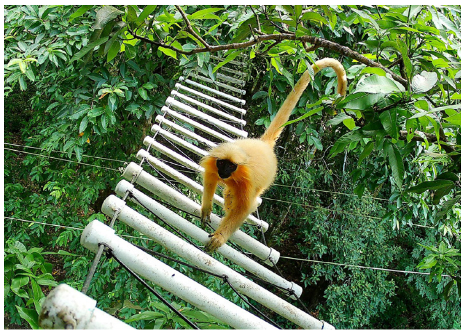
F: (i) 6 mm Gym cable & 2.54 cm diameter UPVC pipe (ii) Pierce holes at both ends and the centre

G: Bamboo cum Rope bridge (hybrid) used by golden langur



H: Rope bridge used by golden langur

I: Pipe bridge used by golden langur



J: Ladder bridge used by the golden langur

Figure 6 (A-J)

We facilitated the insulation of power lines in critical crossover stretches through the electricity department, which not only minimised electrocution risks but also facilitated their movement. However, the langurs have since become habituated to using power lines more confidently and now frequently move beyond the insulated stretches, where bare power lines pass through, leading to increased incidents of electrocution-related deaths and injuries (Figure 5b). For species such as the golden langur, whose substantial population (25%) is confined to fragmented habitats (Biswas *et al.*, 2024), ACBs provide immediate risk reduction while long-term restoration proceeds. For this, we have engaged local communities in joint monitoring of ACBs and creating natural canopies through extensive plantation of native tree species along critical stretches of the road and by restoring green corridors in the backyards. The initiative integrates education and community outreach to promote sustainable livelihoods, offering incentives for corridor maintenance and conflict mitigation. Multi-year monitoring and genetic analysis, where feasible, should be standard, ensuring that ACBs contribute not only to safe crossings but also to long-term conservation and connectivity (Soanes *et al.*, 2018; Soanes *et al.*, 2024).

Acknowledgment

We are thankful to the Department of Environment and Forest, Government of Assam, particularly the then PCCF (Wildlife) and Chief Wildlife Warden, Assam, Mr. Sandeep Kumar, the Council Head of the Department of Forest, BTC, Mr. Suman Mohapatra and Mr. Jayanta Kr Brahma, Divisional Forest Officer – Haltugaon Forest Division for providing the necessary permissions and logistical support. We gratefully acknowledge Dr. GV Gopi, Scientist-F and Head, Department of Endangered Species Management, Wildlife Institute of India for approving our designs. We also acknowledge the Range Forest Officer and forest personnel of Nayekgaon Range of Haltugaon Forest Division and Kokrajhar Wildlife Division for their assistance during fieldwork. We extend our gratitude to Ms. Bijoya Boro, General Manager, and all staff of the Assam Power Distribution Corporation Limited, as well as Mr. Simanta Das, Manager and all other staffs of Abhaya Rubber Plantation, for their generous support. We also thank the local communities residing in the fringe areas of the forest complex for their cooperation throughout the fieldwork. We are also deeply indebted to Dr. Santosh Kumar Sahoo and Ms. Aruna Negi of Conservation Himalayas for their support. Special thanks go to our dedicated field workers, particularly Mr. Bishop Kujur, Mr. Kamaleswar Sangma, Mr. Tipendra Sangma and Mr. Chandan Mahato, whose efforts were invaluable during construction and installation phase of the artificial canopy bridges.

This study was initiated with a small support from the BTC Forest Department, Kokrajhar. We extend our sincere gratitude to PTES for their partnership and generous financial support, which was instrumental in the successful implementation of this program. We also gratefully acknowledge additional support from BAT under their Coexistence SGP program, as well as from Re-Wild, CBOT, and MBZSCF. All research protocols reported in this manuscript were reviewed and approved by the Primate Research Centre NE India, Conservation Himalayas, and the Salim Ali Centre for Ornithology and Natural History.

ETHICS STATEMENT

The study was non-invasive and followed the guidelines for Best Practices for field Primatology. The research complied with a protocol approved by the Principal Chief Conservator of Forests and Chief Wildlife Warden, Assam, Council Head of the Department, Bodoland Territorial Council, and approved by the internal research monitoring committee, SACON (WII). The research adhered to the legal requirements of the Forest Department, Assam. The authors have no conflict of interest to declare.

CONFLICT OF INTEREST

Dr. H.N. Kumara holds editorial positions at the Journal of Wildlife Science. However, he did not participate in the peer review process of this article except as an author. The authors declare no other conflict of interest.

DATA AVAILABILITY

Data and codes are available from the corresponding author on request. All designs and data are the sole property of PRCNE.

AUTHOR CONTRIBUTIONS

Jihosuo Biswas: Conceptualization, Fund and resource raising, Designing, Project administration, Data curation, Implementation, Supervision, Investigation, Formal analysis, Writing – original draft, review & editing.
Joydeep Shil: Data curation, Implementation, Supervision, Investigation, Formal analysis, Writing – original draft, review & editing.
Kanmaina Ray: Data curation, Investigation, Implementation.
Mehtab Uddin Ahmed: Supervision, Data curation, Implementation.
Dharma Kanta Ray: Data curation, Implementation.
Amulya Boro: Data curation, Implementation.
Puja Muchahary: Data curation, Implementation.
Benjamin P Dorsey: Implementation, review & editing.
Honnavalli Kumara: Formal analysis, Writing – review & editing, Validation.

USE OF GENERATIVE AI STATEMENT

We declare that we have not used AI software for writing or analysing data for this article.

ORIGINALITY STATEMENT

We declare that this manuscript represents original research, without duplication from other studies, the published work of the authors or that it is not a salami-slicing paper from other major work by the author.

References

Asensio, N., Kachanan, J., Saralamba, C. & José-Domínguez, J. M. (2021). The impact of roads on the movement of arboreal fauna in protected areas: the case of lar and pileated gibbons in Khao Yai National Park, Thailand. *Journal of Tropical Ecology*, 37(6), 276-285. https://doi.org/10.1017/S0266467421000390

Bahuguna, V. K., Swaminath, M. H., Tripathi, S., Singh, T. P., Rawat, V. R. S., & Rawat, R. S. (2016). Revisiting forest types of India. *International Forestry Review*, 18(2), 135-145.

Bicca-Marques, J. C. (2003). How do howler monkeys cope with habitat fragmentation? in L.K. Marsh (ed.), *Primates in Fragments: Ecology and Conservation*, Kluwer Academics/Plenum Press, New York, USA, 283–303. https://doi.org/10.1007/978-1-4757-3770-7_18

Biswas, J. (2002). *Ecology and social behaviour of golden langur* (*Trachypithecus geei*) Khajuria, 1956. PhD thesis, Gauhati University, Guwahati, p.452

Biswas, J., Shil, J., Nag, S. & Bhattacharjee, P. C. (2019). *Consequences of habitat fragmentation on the Socio-Ecology and gastrointestinal parasitic load of Golden langur in Assam, India*. Technical Report PRC/32, Primate Research Centre, 109 Nehru Park, Jodhpur, Rajasthan, India. Submitted to SERB-DST, Government of India, p.102

Biswas, J., Shil, J., Sasi, R., Ahmed, M. U., Barman, K., Das, N., Basumatary, B. & Kumara, H. N. (2024). Ecological determinants of occupancy of golden langur *Trachypithecus geei* and its population characteristics in India, *Global Ecology and Conservation*, 53, e03003. https://doi.org/10.1016/j.gecco.2024.e03003

Chan, B. P. L., Tan, C. K. W., Hamblin-Jones, B. & Fellowes, J. R. (2020). First use of artificial canopy bridge by the world's most critically endangered primate: Hainan gibbon (*Nomascus hainanus*), *Scientific Reports*, 10, 15284. https://doi.org/10.1038/s41598-020-72641-z

Chapman, C. A., Wasserman, M. D., Gillespie, T. R., Speirs, M. L., Lawes, M. J., Saj, T. L. & Ziegler, T. E. (2006). Do food availability, parasitism, and stress have synergistic effects on red colobus populations living in forest fragments? *American Journal of Physical Anthropology*, 131(4), 525–534. https://doi.org/10.1002/ajpa.20477

Chetry, D., Phukan, M., Chetry, R., Boro, R.N., Das, A. K. & Bhattacharjee, P. C. (2020). Conservation Status of the Golden Langur *Trachypithecus geei* in Chakrashila Wildlife Sanctuary, Assam, India, *Primate Conservation*, 34, pp.167–173.

Chetry, R., Chetry, D., Singh, M., Das, N. & Medhi, R. (2022). A natural canopy bridge at the Hollongapar Gibbon Wildlife Sanctuary, Assam, India, *Primate Conservation*, 36, pp.47–55.

Choudhury, A. (2002). Golden langur *Trachypithecus geei* threatened by habitat fragmentation. *ZOOS' Print Journal*, 17(2), 699-703. https://doi.org/10.11609/JoTT.ZPJ.17.2.699-703

Clevenger, A. P. & Huijser, M. P. (2011). *Wildlife Crossing Structure Handbook: Design and Evaluation in North America*. Publication No. FHWA-CFL/TD-11-003, U.S. Federal Highway Administration, Washington, DC.

Cunneyworth, P. M., Donaldson, A., & Onyancha, F. (2022). Canopy bridges are an economical mitigation reducing the road barrier effect for three of four species of monkeys in Diani, Kenya. *Folia Primatologica*, 93(3-6), 217-234.

Das, J., Biswas, J., Bhattacherjee, P. C. & Rao, S. S. (2009). Canopy Bridges: An Effective Conservation Tactic for Supporting Gibbon Populations in Forest Fragments, in S. Lappan & D. J. Whittaker (eds.), The Gibbons. Developments in Primatology: Progress and Prospects, *Springer*, New York, NY, pp.467–475. https://doi.org/10.1007/978-0-387-88604-6_22

Dodd, N. L., Gagnon, J. W., Boe, S., Manzo, A. & Schweinsburg, R. E. (2007). *Evaluation of measures to minimize wildlife-vehicle collisions and maintain permeability across highways: Arizona Route 260*. Final Report, 540. Arizona Game and Fish Department, Research Branch, Arizona, USA.

Donaldson, A. & Cunneyworth, P. (2015). Case study: canopy bridges for primate conservation, in R. van der Ree, D. J. Smith & C. Grilo (eds.), *Handbook of Road Ecology*, John Wiley & Sons, West Sussex, UK, pp.341–343. https://doi.org/10.1002/9781118568170.ch41

Frankham, R., Ballou, J. D. & Briscoe, D. A. (2004). *A Primer of Conservation Genetics*, Cambridge University Press, p.236. https://doi.org/10.1017/CBO9780511817359

Jeganathan, P., Mudappa, D., Raman, T. S. & Kumar, M. A. (2018). Understanding perceptions of people towards lion-tailed macaques in a fragmented landscape of the Anamalai Hills, Western Ghats, India. *Primate Conservation*, 32(11), 205-215.

Lokschin, L. X., Printes, R. C., Cabral, J. N. H. & Buss, G. (2007). Power lines and howler monkey conservation in Porto Alegre, Rio Grande do Sul, Brazil, *Neotropical Primates*, 14(2), 76–80. https://doi.org/10.1896/044.014.0206

Maria, M., Al-Razi, H., Ali, A., Muzaffar, S. B. & Nekaris, K. A. I. (2022). Artificialcanopy bridge use by primates and other arboreal mammals in a fragmented tropical forest of northeast Bangladesh, *Folia Primatologica*, 93(3-6), 217–234. https://doi.org/10.1163/14219980-20211201

Mass, V., Rakotomanga, B., Rakotondratsimba, G., Razafindramisa, S., Andrianaivomahefa, P., Dickinson, S. & Cooke, A. (2011). Lemur bridges provide crossing structures over roads within a forested mining concession near Moramanga, Toamasina Province, Madagascar, *Conservation Evidence*, 8, 11–18.

Medhi, R., Chetry, D., Bhattacharjee, P. C. & Patiri, B. N. (2004). Status of *Trachypithecus geei* in a rubber plantation in Western Assam, India, International Journal of Primatology, 25(6), 1331–1337. https://doi.org/10.1023/B:IJOP.0000043965.38722.63

Onderdonk, D. A. & Chapman, C. A. (2000). Coping with forest fragmentation: the primates of Kibale National Park, Uganda, *International Journal of Primatology*, 21(4), 587–611. https://doi.org/10.1023/A:1005509119693

Praill, L. C., Eppley, T. M., Shanee, S., Cunneyworth, P. M. K., Abra, F. D., Allgas, N., Al-Razi, H., Campera, M., Cheyne, S. M. *et al.* (2023). Road Infrastructure and Primate Conservation: Introducing the Global Primate Roadkill Database, *Animals*, 13(10), 1692. https://doi.org/10.3390/ani13101692

Python Software Foundation (2025). Python (Version 3.13). Available at: https://www.python.org

QGIS Development Team (2025). QGIS Geographic Information System (Version 3.42). https://qgis.org

Ram, M. S., Kittur, S. M., Biswas, J., Nag, S., Shil, J. & Umapathy, G. (2016). Genetic diversity and structure among isolated populations of the endangered Gee's golden langur in Assam, India, *PLoS One*, 11(8), e0161866. https://doi.org/10.1371/journal.pone.0161866

Shil, J., Biswas, J. & Kumara, H. N. (2020). Influence of habitat conditions on group size, social organization, and birth pattern of golden langur (*Trachypithecus geei*), *Primates*, 61(6), 797–806. https://doi.org/10.1007/s10329-020-00829-y

Shil, J., Biswas, J., Nag, S. & Kumara, H. N. (2021). Persistence of *Trachypithecus geei* (Mammalia: Primates: Cercopithecidae) in a rubber garden in Assam, India, *Journal of Threatened Taxa*, 13(7), 18679–18686. https://doi.org/10.11609/jott.7273.13.7.18679-18686

Soanes, K., Goldingay, R. & van der Ree, R. (2013). Movement re-established but not restored: inferring the effectiveness of built crossing structures for gliding mammals, *Biological Conservation*, 159, 86–93. https://doi.org/10.1016/j.biocon.2012.10.016

Soanes, K., Rytwinski, T., Fahrig, L., Huijser, M. P., Jaeger, J. A. G., Teixeira, F. Z., van der Ree, R. & van der Grift, E. A. (2024). Do wildlife crossing structures mitigate the barrier effect of roads on animal movement? A global assessment, *Journal of Applied Ecology*, 61(2), 271–289. https://doi.org/10.1111/1365-2664.14582

Soanes, K., Taylor, A. C., Sunnucks, P., Vesk, P. A., Cesarini, S. & van der Ree, R. (2018). Evaluating the success of wildlife crossing structures using genetic approaches and an experimental design: lessons from a gliding mammal, *Journal of Applied Ecology*, 55(1), 129–138. https://doi.org/10.1111/1365-2664.12966

Srivastava, A., Biswas, J., Das, J. & Bujarbarua, P. (2001). Status and distribution of golden langurs (*Trachypithecus geei*) in Assam, India, *American Journal of Primatology*, 55(1), 15–23. https://doi.org/10.1002/ajp.1035

Thinley, P., Norbu, T., Rajaratnam, R., Vernes, K., Wangchuk, K., Choki, K., Tenzin, J., Tenzin, S. & Kinley *et al.* (2019). Population abundance and distribution of the endangered golden langur (*Trachypithecus geei*, Khajuria 1956) in Bhutan, *Primates*, 60(5), 437-448. https://doi.org/10.1007/s10329-019-00737-w

van der Grift, E. A. & van der Ree, R. (2015). Guidelines for evaluating use of wildlife crossing structures, in R. van der Ree, D. J. Smith & C. Grilo (eds.), *Handbook of Road Ecology*, John Wiley & Sons, Chichester, 411–419. https://doi.org/10.1002/9781118568170.ch15

ISSN (Online): 3048-7803

JWLS

Volume 2, Issue 4 (December 2025)

TYPE Research Article

Lion-tailed macaques in Indian zoos in the context of the global population

Nilofer Begum[1]*, Werner Kaumanns[1] & Mewa Singh[2]

[1]LTM-Research and Conservation, Eschenweg 5, 37130 Gleichen, Germany

[2]Biopsychology Laboratory, Institution of Excellence, University of Mysore, Mysuru, India

DIAMOND OPEN ACCESS Crossref Check for updates

EDITED BY
Honnavalli Kumara
Salim Ali Centre for Ornithology and Natural History, Tamil Nadu.

*CORRESPONDENCE
Nilofer Begum
niloferbegum3@gmail.com

RECEIVED 02 October 2025
ACCEPTED 24 November 2025
ONLINE EARLY 19 December 2025
PUBLISHED 22 December 2025

CITATION
Begum, N., Kaumanns, W. & Singh, M. (2025). Lion-tailed macaques in Indian zoos in the context of the global population. *Journal of Wildlife Science,* 2(4), 114-126.
https://doi.org/10.63033/JWLS.CXGU6570

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Abstract

This study analyses the development and status of the Indian captive population of the endangered lion-tailed macaque with reference to the global historical zoo population of the species. Lion-tailed macaques are endemic to South India and have been kept in zoos globally for more than a hundred years. In the year 2018, the global captive population comprised 516 individuals in 98 zoos spread over 30 countries. Recent studies reveal that the development of the historical and current populations has not been satisfactory due to low productivity and other problems. Our study intends to assess the potential of the Indian subpopulation for conservation breeding and whether it can be used to support the global core European population, and to function as a reserve for the wild population. It is found that the status of the captive population in India is poor and needs improvements in terms of size, structure, keeping systems, and management. We propose that the management of living conditions must consider the most critical aspect, which is the female-bonded social system in lion-tailed macaques. This would support breeding and welfare. To achieve this goal, it is proposed to closely cooperate with the European Association of Zoos and Aquaria's EAZA Ex-situ Programme (EEP) by exchanging know-how and introducing lion-tailed macaques from the EEP population. The management would profit from training systems for zoo personnel on all levels, with emphasis on the biology of lion-tailed macaques and their adaptive potential under the altered conditions in zoos. It is suggested to have a less centralised management system.

Keywords: Captive history, conservation breeding, EAZA Ex-situ Programme (EEP), Indian captive population, Lion-tailed macaque, zoo management.

Introduction

Lion-tailed macaques (*Macaca silenus*), endemic to the Western Ghats Mountain range of South India, are threatened by extinction. The species is classified as Endangered on the IUCN Red List (Singh *et al.*, 2020) and listed in Appendix I of the CITES (CITES, 2025). In India, the lion-tailed macaque is a highly protected species, categorised under Schedule I of the Wildlife (Protection) Act, 1972. According to Kavana *et al.* (2025), the total population in the wild is estimated 4,219 individuals, distributed across 237 groups. The population suffers from fragmentation and other human-induced alterations of their habitats, like tea plantations, settlements, roads, high-tension power lines, and hunting (Molur *et al.*, 2003; Kumara & Sinha, 2009; Singh *et al.*, 2020; Dhawale & Sinha, 2025). Two genetically distinct subpopulations of the species have been identified north and south of the 40 km long Palghat Gap (Ram *et al.*, 2015). Lion-tailed macaques have been kept in zoos for more than a hundred years (Lindburg, 2001; Begum *et al.*, 2022). In the year 2018, the global captive population comprised 516 individuals in 98 zoos spread over 30 countries (Sliwa & Begum, 2019). Recent studies by Begum *et al.* (2022, 2023) reveal that the development of the historical population has not been satisfactory due to low productivity and other problems. Low productivity was found to be influenced by management and husbandry systems which did not sufficiently consider the specific social way of living in permanent female-bonded groups with a modal size of 16–21 individuals in contiguous forests (see Kumar, 1987; Ramachandran & Joseph, 2000; Kumara & Singh, 2004; Kumara *et al.*, 2014; Sushma *et al.*, 2014; Singh, 2019). Management also did not consider that only males leave their natal groups and join other groups (see Kumar *et al.*, 2001). For details on the biology of the species, see Singh & Kaumanns (2005), Singh (2019), and Begum (2023). The global captive population decreased over the last decade to a core population in Europe of 322 individuals, and a few other (small) subpopulations, including the Indian population with about 51 individuals (status as of 2018; for details of the development, see Begum *et al.*, 2021, 2022, 2023). Especially, space problems in the American and

European populations led to a management of population size mainly *via* birth control (Lindburg *et al.*, 1997, Sliwa *et al.*, 2016; Rode-White & Corlay, 2024). It resulted in the attempted smaller populations but also produced problematic side effects in terms of perpetuating low productivity across these populations (see Penfold *et al.*, 2014). The proportion of ageing females growing into an infertile status increased. The formerly large American population decreased to a small number of non-productive individuals. Several descendants of the American population are found in Europe and in smaller subpopulations, but most probably not in the Indian one (see Sliwa & Begum, 2019). For a more elaborated and differentiated discussion of the potential effects of birth- control on population size (see Begum *et al.* 2022, 2023). The authors propose that the productivity of a population may be linked to a population's "natural" growth patterns and size.

The results of Begum *et al.* (2021, 2022, 2023) studies indicate that the historical captive population of the lion-tailed macaque probably experienced a loss of genetic and phenotypic diversity. To stop the decline and to support the captive population's long-term persistence (as a reserve for the threatened wild population), a new global management approach must be developed that allows more breeding in large female-bonded groups, despite the space problems European zoos suffer from. It seems that the Indian zoos have the potential to provide the necessary conditions in terms of space. Begum *et al.* (2021), therefore, proposed that Indian zoos should cooperate closely with the European Association of Zoos and Aquaria's EAZA Ex situ Programme (EEP), house lion-tailed macaques born in Europe, and serve as an interface between zoos and the wild for reintroductions. They can thus contribute to establishing a larger and more diversified global reserve population. The records available from the International Studbook for the Lion-tailed Macaque and from other sources reveal, however, a poor status of the Indian population and its living conditions, and a strong need for improvements. This especially should refer to the social system of lion-tailed macaques.

The present study aims to analyse the development and status of the Indian subpopulation, to discuss its potential for long-term survival and conservation breeding, and to propose necessary management improvements. Since the results of the investigation are placed and discussed in the context of the global historical captive population of the species, the global population is described briefly. The paper is oriented towards providing comprehensive materials for practical use and should contribute to the conservation of the species *via* captive propagation. The propositions should contribute to establishing a special management and breeding programme for the Indian lion-tailed macaque population. The establishment of the programme should be significantly supported by the Central Zoo Authority, considering contributions by the individual zoos. Furthermore, the already available husbandry guidelines for the lion-tailed macaque (Kaumanns *et al.*, 2006) should be used, as well as a number of other papers referring to the topic (Kaumanns *et al.*, 2013; Begum *et al.*, 2021, 2022, 2023; Begum, 2023). The existing husbandry guidelines (Kaumanns *et al.*, 2006) point to welfare-based management indicators, for example, the role of social living conditions, feeding ecology, arboreal life, and enclosure complexity.

The study is organised as follows: the first part briefly describes the global historical population, and the second and third parts focus in detail on the Indian historical and living populations, respectively.

Materials and methods

The study is based on the most recent edition of the International Studbook of the species as of 31st December 2018 (Sliwa & Begum, 2019). The terms "current" or "living" population in this study always refer to the status in 2018.

The Studbook provides information on the individual lion-tailed macaques kept globally and in Indian zoos with records from 1899 to 2018 (Sliwa & Begum, 2019). Data include identity, origin, births, deaths, reproductive output, transfers and locations. Group sizes could only be derived from the number of individuals per location. Additional information was taken from relevant publications, wherever available. Due to the small number of individuals in Indian zoos, limited descriptive statistics are used. Conservation and breeding potential are mainly discussed with reference to the reproductive output of the population and the living conditions currently provided, and deficiencies that need to be improved.

The International Studbook for the Lion-tailed Macaque is maintained as an electronic database using the software SPARKS (Single Population Analysis and Records Keeping System v 1.66) (Scobie & Bingaman Lackey, 2012). For analysing various demographic parameters, we used the population management programme PMx v 1.8.1.20250501 (Ballou *et al.*, 2025), available from the Species Conservation Toolkit Initiative (https://scti.tools). The data were organised and analysed using Microsoft Excel and R v 4.5.1 (R Core Team, 2025), and most figures were generated using GraphPad Prism 10.6.0 (GraphPad Software, 2025).

Results and discussion

The historical trend of the global captive population of lion-tailed macaque can be roughly divided in four periods (Figure 1). Between the end of the 19th century and about 1950, the number of individuals and births was small. Both increased slightly until the 1970s, followed by a significant increase till the 1990s, with the highest number of individuals (n = 561) recorded in 1994. From this "prime-time" onwards, the size of the population decreased. No further increase was due to a strong management-induced shrinking of the American subpopulation (see Lindburg, 2001) – "compensated" by an increase in the European subpopulation, which played a dominant role since the mid-1990s. The global population has been declining since 2011–2012, mainly due to management measures implemented in Europe (see Sliwa *et al.*, 2016). Among the smaller subpopulations, the Japanese population remained stable, while the size in India is shrinking (see later). As of 2018, Europe constituted 62% of the global population, followed by Japan and India, which comprise 15% and 10% of the population, respectively. The North American population has been reduced to a small, ageing population of 31 individuals.

The large populations were embedded in breeding programmes (Species Survival Plan SSP) in North America, and European Endangered Species Breeding Programme/ EAZA Ex situ Programme (EEP) in Europe in the years 1983 and 1989, respectively. In India, a breeding programme was established in the mid-2000s (CZA Guidelines, 2011).

The increase of the global captive population in its first decades was mainly contributed by wild-caught lion-tailed macaques. A total of 428 wild-born individuals (183 males, 209 females, 36 unknown sex) were recorded between 1899 and 2018 (Figure 2, Table 1). In the early period, India transferred 249 wild-born individuals to North America (n = 132, c.31%) and Europe (n = 117, c.27%), thus "establishing" these big populations. Smaller numbers of wild-born individuals were

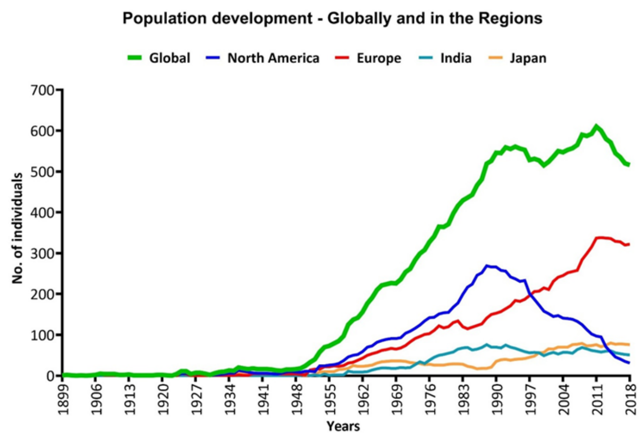


Figure 1: Development of the global population of lion-tailed macaques in captivity. Adapted with permission from Begum *et al.* (2022), published in Primate Conservation

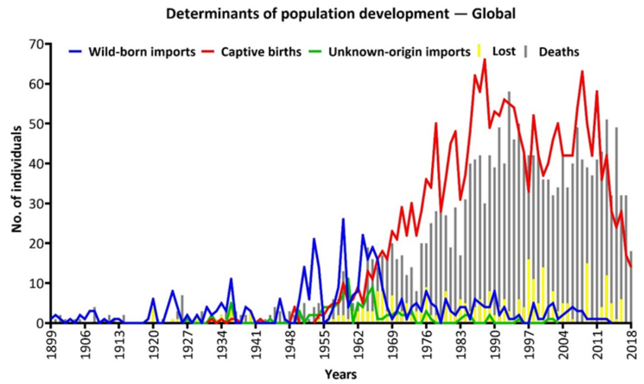


Figure 2: Population dynamics in the global captive lion-tailed macaque population over time. Adapted with permission from Begum *et al.* (2022), published in Primate Conservation

Table 1: Transfer of wild-caught individuals to zoos outside India between 1899 and 2018.

North America	132
Europe	117
Japan	21
Other smaller regions	9
Total	**279** (additionally 149 remained in Indian zoos)

transferred to Japan (n = 21, c.5%) and other regions (n = 9, c.2%). It seems that these transfers were executed by animal dealers. Indian zoos kept 149 wild-born individuals (c.35%). A number of individuals were transferred from North America and Europe to other countries, especially in Asia, establishing smaller peripheral populations. For an elaborated account of the transfers and exchanges of lion-tailed macaques between the various regions, see Begum *et al.* (2022).

From the 1970s onwards, further import of wild-caught individuals was voluntarily banned in zoos in North America and Europe, more breeding was propagated, and the proportion of individuals born into the population increased substantially (see Hill, 1971; Heltne, 1985; Kaumanns & Rohrhuber, 1995). Over the 119-year period (1899–2018), 2,195 births, 1,923 deaths, and 295 individuals lost to follow-up were recorded. North America (691 births) and Europe (1,044 births) together contributed to 79% of the individuals born in zoos globally. The number of births increased till about 1989, which was followed by a decrease due to management-induced population control in North America. The second increase in births in the global population from the early 2000s was contributed by increased breeding in Europe. Over the last decade, the number of births has been declining continuously as a result of birth control measures in Europe and declining birth rates in other subpopulations.

Patterns of management

North America and Europe

Till the 1970s, management and husbandry of captive lion-tailed macaques were mainly organised locally by individual zoos (see Lindburg, 2001; Begum *et al.*, 2022).

The 1980s brought significant collaborative efforts together following the first international symposium on lion-tailed macaques in Baltimore in 1982, leading to the publication of a Studbook in 1983, the establishment of the Species Survival Plan (SSP) in North America (1983), and the European Endangered Species Programme (EEP) in 1989. This resulted in systematic and conservation-oriented management and research in zoos. It included science-based improvements of physical and social living conditions. Breeding and improving breeding conditions were propagated. Progress was achieved in several international lion-tailed macaque symposia (see Singh *et al.*, 2009; Begum *et al.*, 2021).

The European and North American breeding programmes contributed the most to the global population, where both the subpopulations grew *via* captive breeding alone, without further imports (see Begum *et al.*, 2022). Since the end of the 1980s, however, these two large breeding programmes have developed different management strategies and goals. A key development in the 1990s was the management-induced shrinking of the North American subpopulation (steady-state management, Lindburg *et al.*, 1997), a decrease in their housing zoos, a reduction in group sizes, and export of individuals to other regions, resulting in a small (and non-productive) subpopulation (Figure 1). The European subpopulation, on the other hand, was managed by the EEP to grow steadily, and the establishment of large groups was propagated (Kaumanns *et al.*, 2013). Comprehensive overviews of the management of the American and European populations are presented in several publications (Lindburg *et al.*, 1997; Lindburg, 2001; Kaumanns *et al.*, 2001, 2013).

India

Conservation-oriented work in zoos in India is more recent compared to North America and Europe. A preliminary approach to a systematic breeding programme in India emerged in the 2000s. The Central Zoo Authority (CZA) in India identifies one large zoo in the distributional range of a target species as a coordinating zoo for breeding the selected species. The coordinating zoo is responsible for establishing the initial founding stock and developing off-display breeding centres as per designs approved by the CZA. This zoo is supposed to coordinate with a few more zoos (usually 2–4) that are also close to the species' distributional range and have been identified by the CZA as participating institutions in the programme. The participating zoos are responsible for maintaining satellite populations once sufficient numbers are bred at the coordinating zoo (see CZA Guidelines, 2011).

The breeding programme for the lion-tailed macaque in India deviates from the international programmes described above in terms of the management system as presented. It does not include all individuals of the Indian captive population and all zoos. It rather included three selected zoos (Vandalur, Mysore, and Thiruvananthapuram) in the range states (Tamil Nadu, Karnataka, and Kerala) of the species only (see above, CZA

https://doi.org/10.63033/JWLS.CXGU6570

Guidelines, 2011). The management of the lion-tailed macaque programme is also organised in a centralised manner by the CZA and Vandalur Zoo as the coordinating zoo, and to a limited extent by the two other participating zoos. Since the number of participating institutions is only three, many other zoos keeping lion-tailed macaques are excluded and are not managed systematically.

Lion-tailed macaques in many Indian zoos were often kept in small and barren enclosures (Mallapur *et al.*, 2005a, b; Begum, pers. observation). Zoos that participate in the breeding programme may keep individuals in off-exhibit areas, but may also use enclosures that are open to the public. The coordinating zoo is specifically financially supported by the CZA.

The Indian historical captive population

Historically, a total of 350 individuals were recorded in 36 Indian institutions, as derived from the International Studbook (Table 2; Sliwa & Begum, 2019). Most institutions kept only a few individuals. The list includes 28 individuals who were transferred to other regions (see later).

Population development

Although a few individuals in a few zoos were recorded since late 1949, the regular keeping of lion-tailed macaques in Indian zoos can be traced since 1959. A total of 350 individuals (152 males, 167 females, 31 unknown sex) have been kept so far, with a mean (±SD) of about 42 ± 24.83 individuals per year.

The population increased till the early 1990s and decreased continuously till 2000 (Figure 3). After a period of some increase during 2001–2008, the population has been declining overall (lambda, $\lambda = 0.909$). As of 2018, the population consists of 51 individuals in 10 zoos (Figure 3).

Historically, over about 70 years (1949–2018), approximately 53% of the lion-tailed macaques in Indian zoos were captive-born, 43% were wild-born, and 4% were of unknown origin (Table 3). Between 1950 and 2018, the mean number (±SD) of captive-born individuals was 19.75±14, and the mean number (±SD) of wild-born and unknown-origin individuals was 21.63±11.2.

Determinants of population development

The development of the Indian population was influenced by the integration of wild-caught and unknown origin individuals (n = 165), captive births (n = 185), and a few transfers (n = 28) to other regions (see Table 3, Figure 4). A total of 213 deaths and 33 individuals lost to follow-up were recorded. Births, as recorded continuously from 1969 onwards, increased until 1982, declined till 1998, increased again till 2007, and have

Table 2: Historical captive population of the Lion-tailed macaque in Indian zoos.

Institution mnemonic recorded in the Studbook – as assigned by Species360	Total individuals (m.f.u)*	Captive-born (m.f.u)*	Wild-born (m.f.u)*	Unknown-origin (m.f.u)*	Duration (in years) between 1st and last/ living individuals in 2018	No. of years between 1st and last/ living individuals in 2018	Total years when individuals were present
Acooli	4 (1.3.0)		4 (1.3.0)		1963	< 1	<1
Ahmedabad	3 (0.3.0)		3 (0.3.0)		1958-1989	31	16
Assam	9 (3.6.0)	1 (0.1.0)	8 (3.5.0)		1966-2014	48	37
Bannerghatta	6 (1.5.0)		5 (1.4.0)	1 (0.1.0)	1981-2018	37	15
Bhilai	7 (3.4.0)	7 (3.4.0)			1982-2013	31	31
Calcutta	9 (3.6.0)	3 (1.2.0)	6 (2.4.0)		1953-2008	52	21
Chatbir	15 (7.6.2)	6 (4.1.1)	7 (2.4.1)	2 (1.1.0)	1977-2018	42	42
Delhi	61 (21.29.11)	52 (18.23.11)	9 (3.6.0)		1959-2018	60	60
Guindy	9 (6.3.0)	2 (1.1.0)	7 (5.2.0)		1990-2009	19	19
Hyderabad	13 (6.7.0)	4 (3.1.0)	8 (3.5.0)	1 (0.1.0)	1964-2018	54	54
Jaipur	16 (6.9.1)	12 (4.7.1)	4 (2.2.0)		1978-2005	27	27
Jodhpur	1 (0.1.0)		1 (0.1.0)		1984-1992	8	8
Kanpur	12 (7.5.0)	7 (4.3.0)	5 (3.2.0)		1973-2003	30	30
Khandala	1 (1.0.0)	1 (1.0.0)			1980-1985	5	5
Kodanad	4 (4.3.0)		4 (2.2.0)		1988-2002	14	14
Lucknow	5 (3.2.0)	3 (1.2.0)	1 (1.0.0)	1 (1.0.0)	1988-2018	30	24
Madras (Vandalur)	83 (35.33.15)	64 (27.22.15)	18 (7.11.0)	1 (1.0.0)	1982-2018	36	36
Maharashtra	1 (1.0.0)	1 (1.0.0)			1977-1980	3	3
Mangalore	4 (1.3.0)		4 (1.3.0)		1992-2018	26	12
Mohotta	1 (1.0.0)		1 (1.0.0)		1982-1984	2	2
Mysore	32 (18.13.1)	8 (5.2.1)	24 (13.11.0)		1975-2018	43	38
Nandankanan	18 (10.8.0)	13 (8.5.0)	5 (2.3.0)		1966-2010	44	44

https://doi.org/10.63033/JWLS.CXGU6570

Parassinikadavu	5 (2.3.0)	0	5 (2.3.0)		1986-2016	30	15
Patna	10 (3.7.0)	6 (3.3.0)	3 (0.3.0)	1 (0.1.0)	1972-2017	45	25
Poona (Peshwe)	1 (1.0.0)		1 (1.0.0)		1984-2006	22	22
Pune	1 (1.0.0)		1 (1.0.0)		1984-2006	22	22
Shillong	3 (1.2.0)		3 (1.2.0)		1994-2000	6	3
Shimla	2 (1.1.0)	2 (1.1.0)			1986	< 1	<1
Shimoga	1 (1.0.0)		1 (1.0.0)		1990-1996	6	6
Sirmur	1 (0.1.0)			1 (0.0.1)	~ 1995	< 1	< 1
Thrissur	21 (11.10.0)	6 (3.3.0)	7 (4.3.0)	8 (4.4.0)	1959-2018	59	52
Tripura	1 (0.1.0)	1 (0.1.0)			1990-2000	10	10
Trivandrum (Thiruvananthapuram)	46 (25.20.1)	17 (9.7.1)	28 (15.13.0)	1 (1.0.0)	1963-2018	55	44
Vadodara	2 (1.1.0)			2 (1.1.0)	1986-1996	10	10
Veermata	14 (5.9.0)	7 (4.3.1)	7 (1.6.0)		1949-1995	46	24
Vocpkzoo	2 (1.1.0)	1 (1.0.0)			1980-1990	10	10

**The names of institutions are mnemonics assigned by Species360, as recorded in the International Studbook and the corresponding data recording software, SPARKS. Current names are included in brackets.*
***Letters "m", "f" and "u" refer to male, female, and unknown sex, respectively.*

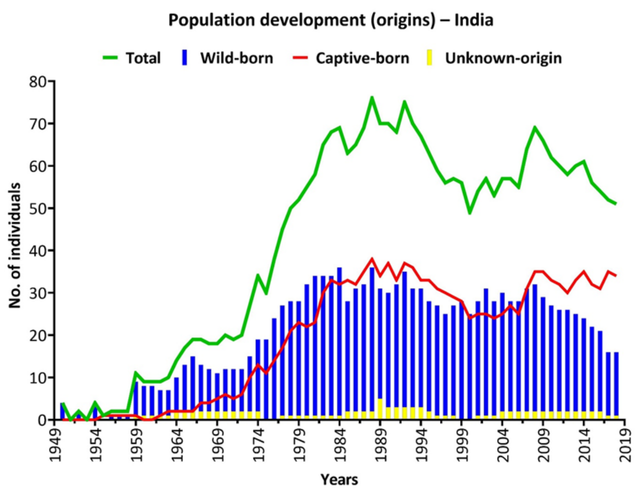


Figure 3: Development of the captive population of lion-tailed macaques in India.

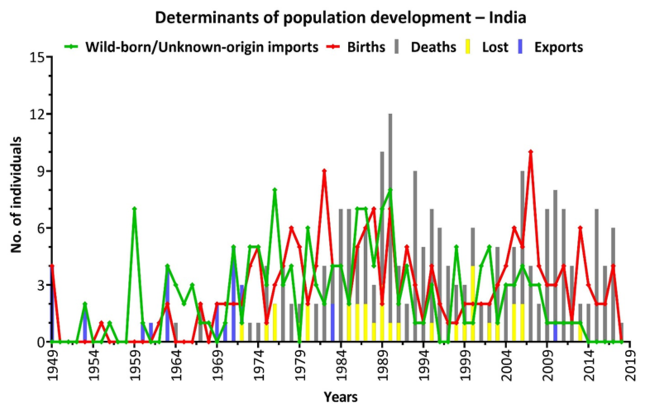


Figure 4: Annual numbers of births, imports of wild-born, and unknown origin individuals, deaths, exports, and lost individuals (based on 149 wild-born, 14 unknown origin, 185 captive-born, 213 dead, 33 lost to follow-up and 28 exported individuals) of the captive lion-tailed macaque population in India.

been decreasing since then. The mean (±SD) number of births per year (2.64±2.3) was consistently lower than the mean (±SD) number of deaths, lost to follow-up and exports (3.91±3.33).

Patterns of reproduction

An important reason for the poor development of the population was the low productivity of the individual females (see Figure 5). Between 1969 and 2018 (period of regular births), a mean (±SD) of 17.48±7.92 (median 15.5; range 5–34) adult females were recorded; however, a mean (±SD) of only 3.5±2.1 (median 3; range 0–10) adult females bred per year. The figure also reveals the increase in the number of females aged 5–20 years from the mid-1970s to mid-1980s, and a continuous decline until 2000. In the last two decades (1995–2018), the number of females of reproductive age remained less than 20 per year, and the number of breeding females exceeded five only at three times.

Table 3: Origins and exports of lion-tailed macaques from Indian zoos from 1949 onwards.

Historical population recorded in Indian zoos		Individuals exported to other regions from Indian institutions (male, female)	Individuals remaining in Indian zoos (male, female, unknown)
Captive-born	185	15 (8m, 7f)	170 (70m, 70f, 30u)
Wild-born	149	13 (9f)	136 (63m, 72f, 1u)
Unknown-origin	16		16 (7m, 9f)
Total	**350**	**28**	**322 (140m, 151f, 31u)**

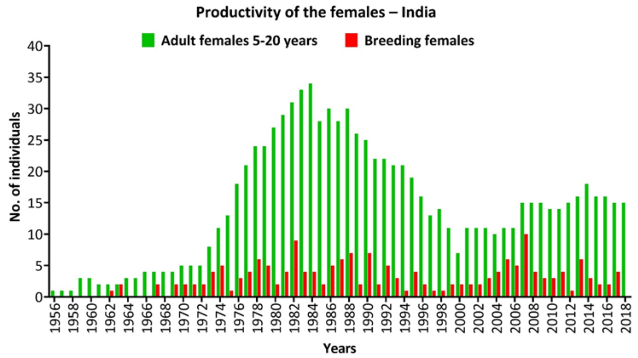


Figure 5: Annual number of adult females (5–20 years) and breeding females in the captive population of lion-tailed macaques in India.

Totally, 19% (n = 36) of the offspring born into the population died at less than 1 year of age (Figure 6), and another 12 offspring were lost to follow-up at less than 1 year after birth. Furthermore, another 11% (n = 20) either died (n = 17) or were lost to follow-up (n = 3) between the ages of 1 and 5 years. Therefore, about 26% of the captive-born individuals did not survive the first year of life, and a total of 37% of the individuals born were not available for breeding.

The number of institutions that kept lion-tailed macaques increased until about 1990 to 22 zoos and remained constant till 1995 (Figure 7). The numbers have been declining continuously, especially since 2001, reaching 10 zoos in 2017 and 2018, the lowest recorded in the last four decades (1977–2018).

The number of zoos in which breeding occured per year remained low (Figure 7). Between 1969 and 2018, a mean of 2.22±1.28 zoos (median 1, range 0–6) recorded births per year, with maximum six zoos with births in 1990. Since 1991, the

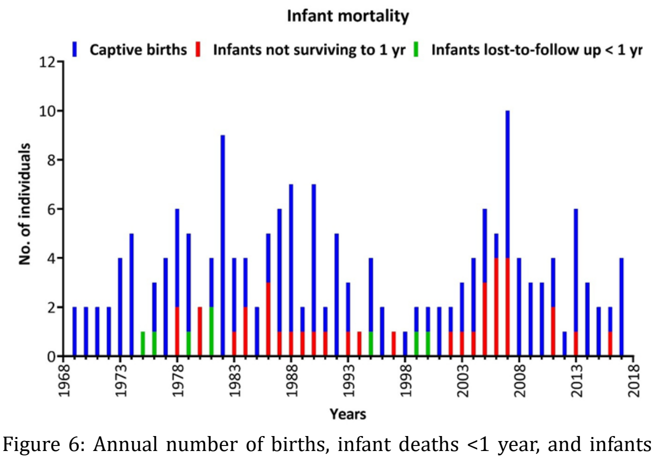


Figure 6: Annual number of births, infant deaths <1 year, and infants lost to follow-up < 1 year in the captive lion-tailed macaque population in India.

number of institutions with births has remained consistently low (0–4). The majority of the 185 births occurred in three zoos: Vandalur (c. 35%, n = 64), followed by, Delhi (c.27%, n = 49) and, Thiruvananthapuram (c.8%, n = 15), out of which Delhi zoo was a non-participant in the breeding programme, but contributed to births, especially in the 1970s (Table 4).

Another 39 infants were contributed by 16 females (including one that also bred in Thiruvananthapuram) across nine other zoos.

Reproductive output of the females

In the Indian historical captive lion-tailed macaque population,

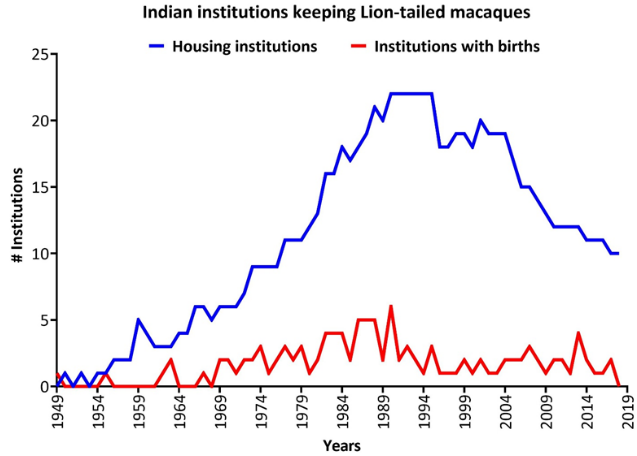


Figure 7: Indian institutions keeping lion-tailed macaques and recording births of individuals.

only 32% (n = 49) of the 151 females bred at all; this constitutes about 43% of the available adult females (n = 114) (see Table 5). When accounting for surviving infants only (n = 118), less than 29% (n = 43) of the females and about 38% of the adult females contributed to successful reproduction in the population. Females breeding in Indian zoos constituted only about 10% of the total 500 breeding females recorded in the global historical population.

There were large differences in the reproductive output between the females, ranging from 1 to 13 infants and 0 to 8 surviving infants. About 45% (n = 22) of the breeding females produced 1–2 infants per female lifetime, accounting for approximately 19% (n = 30) of the infants with known mothers. Only 12 females, forming 24% of the breeding females, produced five or more infants per female lifetime and contributed to 50% of the infants born to known mothers.

A total of 26% of the infants born to known mothers did not survive to the age of 1 year. Among the wild-born females, only 25% (n = 18) bred, contributing to 50 surviving infants.

Reproductive output of the males

The Indian captive historical population comprised 140 males, of which about 21% (n = 30) contributed to breeding at all, with fewer (c.19%, n = 26) contributing to surviving infants (Table 6). Based on the origin, 21% of the wild-born males and 24% of the captive-born males bred. Large differences in terms of individual reproductive output were found: 65% (n = 99) of the infants with known sires were produced by only seven males, which comprise about 23% of the breeding males recorded.

Composition of groups

Since the social way of life is an important aspect in the lives of primates, this is referred to by analysing the composition of the units in which lion-tailed macaques in the Indian population were kept. The “total historical colony size” refers to the overall number of individuals recorded in a zoo throughout its history. Out of the 36 institutions documented in the International Studbook, 24 had historical colony sizes of less than 10, including 17 zoos that kept fewer than 5 individuals in their captive history. In terms of group composition, 15 zoos either did not keep individuals of both sexes, or did not house both sexes together for more than a year. Most of these zoos kept a single individual at a time.

In the remaining 21 zoos that maintained heterosexual units, the median group size each year ranged from 2 to 13, with 20 zoos recording a size of 2 to 7 individuals (Table 7). In these

https://doi.org/10.63033/JWLS.CXGU6570

Table 4: Breeding of lion-tailed macaques in the three institutions participating in the conservation breeding programme and the non-participating Delhi zoo, India.

Zoos	Females recorded in the zoos historically (remaining in India)	No. of known dams	No. of births from known dams	Surviving infants (1year)	Infants surviving till 5 years
Vandalur	30	13	62	46	30
Thiruvananthapuram	19	7	9	8	8
Mysore	12	2	3	1	1
Delhi	26	12	47	37	31
Total		**34**	**121**	**92**	**70**

Table 5: Individual reproductive output of the females in the historical captive population of lion-tailed macaques in India.

	Wild-born	Captive-born	Unknown-origin	Total
Total females	72	70	9	151
Adult females (5+ years)	60	51	3	114
Breeding females	18	31		49*
Infants born	62	98		160
Surviving infants	50	68		118
Range of infants per breeding female	1–13	1–8		1–13
Range of surviving infants per breeding female	0–8	0–5		0–8

**Excludes one female that bred in India before transfer to North America, and includes one female that bred in 2 Indian zoos*

Table 6: Individual reproductive output of the males in the historical captive population of lion-tailed macaques in India.

	Wild-born	Captive-born	Unknown-origin	Total
Total males	63	70	7	140
Adult males (6+ years)	44	38	5	87
Breeding males	13	17		30
Infants born	47	105		152
Surviving infants	37	75		112
Range of infants per breeding male	1–13	1–21		1–21
Range of surviving infants per breeding male	0–13	0–15		0–15

heterosexual groups, over 71% (n = 15) had 2 to 4 members per year; five groups had 5–7 members, while only one group exceeded 8 members per year.

Most of the heterosexual units (n = 19) also experienced discontinuity and had periods during which either no individuals or only single-sex individuals were kept. Overall, most of these groups consisted of less than 5 members; keeping individuals in solitary conditions was, and is, not rare.

In order to describe and visualise the distribution of group sizes over the years, the empirical cumulative distribution function was applied. The analysis uses the number of individuals in heterosexual groups of two or more members, as recorded at the end of each year from 1959 to 2018. For the heterosexual groups, approximately 75% of the groups had fewer than seven members throughout the complete history of the population (Figure 8, Table 8).

Transfer of individuals between zoos

Population dynamics were influenced by the integration of wild-caught individuals (see above) and also by the transfer of individuals between zoos.

Females

A total of 15 captive-born females were removed from their natal groups and transferred to other zoos within India (additionally, seven females were transferred to five regions, Table 3).

The mean (±SD) age at removal of females from natal groups was 7.11±4.29 years. Six out of the 15 females were transferred at less than 5 years of age as young juveniles and infants. Among the transferred females, seven individuals bred at all: four bred in the new group, and three bred in the natal group before transfer. The latter produced 14 infants, of which 12 survived (see Figure 9). Of the 55 captive-born females remaining in their natal groups, 24 bred and contributed to 75 infants. Overall, about 80% (n = 78) of the infants, and 82% (n = 56) of the surviving infants produced by captive-born females were born in the respective natal group of the dam.

Wild-born (n = 18) and unknown-origin (n = 1) females were sometimes transferred to more than one zoo after capture from the wild. About 74% (n = 14) of these transferred wild-born and unknown-origin females did not breed at all. After capture from the wild, only one individual bred in both the first group and the new group, while four individuals bred in the new group only.

 https://doi.org/10.63033/JWLS.CXGU6570

Table 7: Composition of the heterosexual groups of lion-tailed macaques kept in Indian zoos.

Group size	Total zoos	Mean (± SD) no. of years with both sexes	No. of zoos that sometimes had no individuals or had one sex	Mean (± SD) no. of years with one sex	Mean (± SD) no. of years with no individuals
2 to 4	15	15.6±10.96	15	11.87±10.57	7.13±9.69
5 to 7	5	35.2±18.18	3	6.4±10.26	0
8 and more	1	33	1	3	1
Total	**21**	**21.09±15.15**	**19**	**10.14±10.37**	**5.14±8.73**

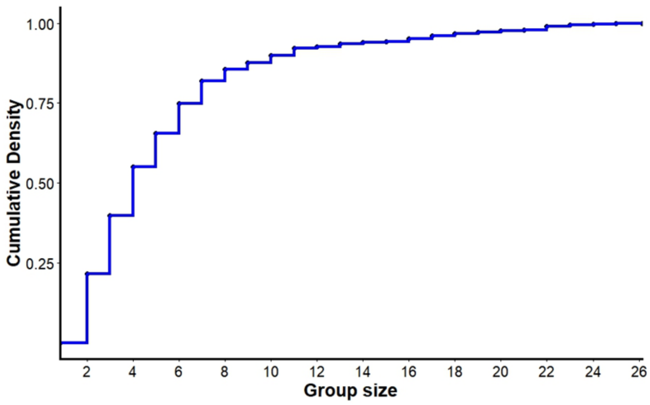


Figure 8: Distribution of sizes in heterosexual groups of captive lion-tailed macaques in Indian zoos.

Table 8: Distribution of group sizes in the Indian historical captive population of lion-tailed macaques.

Heterosexual units 1959–2018	Group size
Quantile 75%	7
Quantile 50%	4
Range	2–25

Males

Of the 70 males born into the population, about 29% (n = 20) were transferred from their natal zoos to other locations within India (Figure 10). Additionally, eight individuals were transferred to other regions; therefore, these individuals have been excluded from the analysis of male transfers in India. Half of the males (n = 10) were transferred at less than 5 years of age. The mean (±SD) age at dispersal was 5.28±2.80 years. Of the 50 males that remained in their natal groups, 11 bred to produce 83 infants, which is about 55% of all infants born to known sires and 79% of infants produced by captive-born males. A large percentage of infants in the few productive groups were likely to be produced by relatives.

Indian living population as of 2018

The Indian population, as of 2018, comprised 51 individuals (21 males, 24 females, 6 unknown sex) distributed across 10 zoos (see Sliwa & Begum, 2019). There are only four zoos with breeding units that comprise five or more individuals. The remaining six zoos keep units with fewer than three individuals, sometimes even one individual only.

The population consists of 16 wild-born (5 males, 11 females) and 34 captive-born individuals (15 males, 13 females, 6 unknown sex), as well as one individual of unknown origin. Wild-born individuals are housed in seven institutions, of which two zoos house lone individuals and two zoos house pairs (Table 9).

Age-sex composition

The age sex structure of the Indian population, as of 2018 refers to 51 individuals, including five individuals for whom birth date estimates were not known, but transfer dates to zoos were available (Figure 11). Based on these dates, the mean (±SD) ages of the individuals were as follows: females 14.65±9.2 years, males 11.8±6.12 years, unknown-sex 2.36±1.25 years.

The declining population trend and decreasing number of births are reflected in the unfavourable age-sex composition. As of 2018, there were only 10 individuals (1 male, 3 females, 6 unknown-sex) under the age of 5 years, accounting for about 19% of the population. Another 67% (n = 34; 19 males, 15 females) of the population was between the age range of 5 and 20 years, indicating some potential to breed, while 14% (n = 7; 1 male, 6 females) of the population was older than 20 years. With only a few individuals in the youngest age classes, the potential for future growth may be limited.

Seven zoos housed 14 females of breeding age (Table 10). Among the remaining three housing institutions, Delhi has a female under 5 years of age, who may breed in the future. Only two zoos have more than two females of breeding age. Furthermore, two zoos each house a single female of breeding age, and two other zoos maintain only pairs (see also Table 9).

Reproduction in the living population

A total of 16 (2 males, 14 females) individuals in the living population as of 2018 bred in four institutions (Table 11). Females from only one zoo (Vandalur) contribute to approximately 83% of the surviving infants. Furthermore, there are no living sires in other zoos.

The females in the population (living in 2018) produced a total of 41 infants, of which 29 survived to the age of one year. In terms of reproductive output per female, 9 out of the 14 breeding females had two or fewer surviving infants. About 36% (n = 8) of the females that reached adulthood were yet to breed (see Table 12). Among the 14 females that had bred, five were over 20 years of age. The average age of the remaining nine breeding females was 11.62 ±3.68 years, with an age range of 5–17 years. Additionally, four of these nine females had not bred in the last 5 to 8 years. In contrast, four females housed in Vandalur had bred regularly, producing 3 to 4 offspring per female at intervals of 1 to 2 years. They produced 13 infants, of which 11 survived.

The differences in the number of infants produced by the females are even more pronounced in the males. Only two males (c.9.5%) contributed to breeding, resulting in nine surviving infants (Table 13).

Genetic status

Since a future use of the population as a breeding and reserve population will require information on the living population's (in 2018) genetic status, it is briefly presented here (Table 14) together with the potential of the members of the population for breeding, *e.g.*, with reference to age.

 https://doi.org/10.63033/JWLS.CXGU6570

The development of the genetic status is influenced by the fact that 77% of the individuals in the population did not breed at all. This includes 79% of wild-born and 76% of captive-born individuals. Among those that did breed, there was considerable variation in lifetime reproductive output, especially among the males. This pattern is consistent across generations and among both wild and captive-born individuals. Low productivity and large variation in reproductive success also go together with the small number of founders (n = 16) from which the living population is derived, and their uneven contributions to the gene pool.

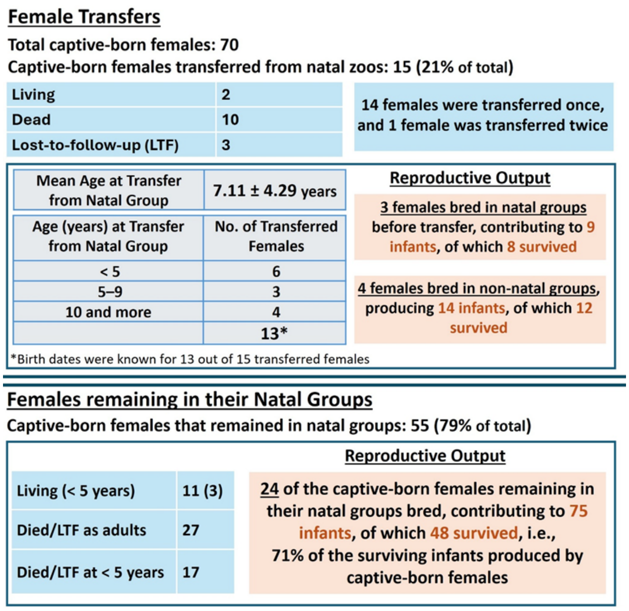


Figure 9: Female transfers and reproductive output of captive lion-tailed macaques in Indian zoos.

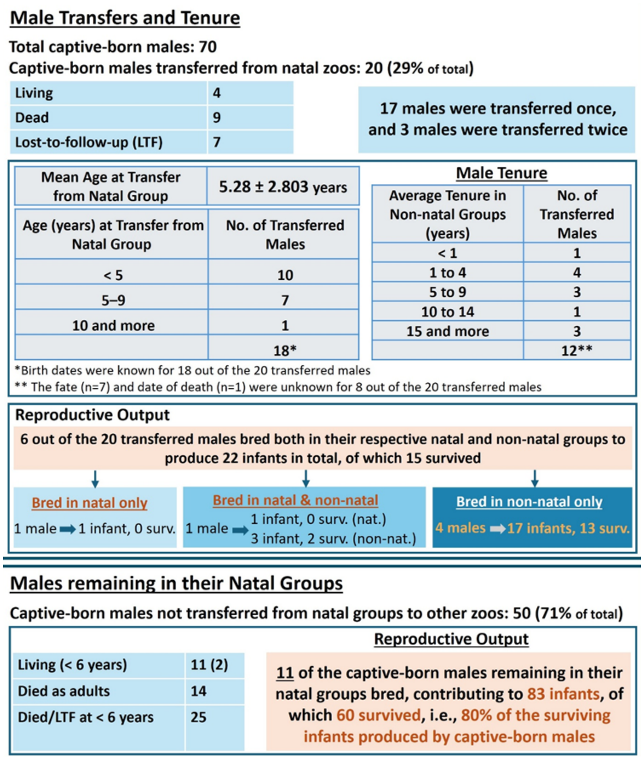


Figure 10: Male transfers and reproductive output of captive lion-tailed macaques in Indian zoos.

The only living wild-caught individuals in the global captive population are in the Indian zoos. There were four founders and 12 potential founders (wild-born individuals with no living descendants) in the living population (as of 2018). The average age of the founders was 19.77±9.39 years, and the average age of the potential founders was 16.29±9.48 years. Twelve wild-born individuals were less than 20 years of age; however, their breeding potential, in terms of social living conditions, needs to be assessed. For example, two potential founder females were housed alone in two zoos.

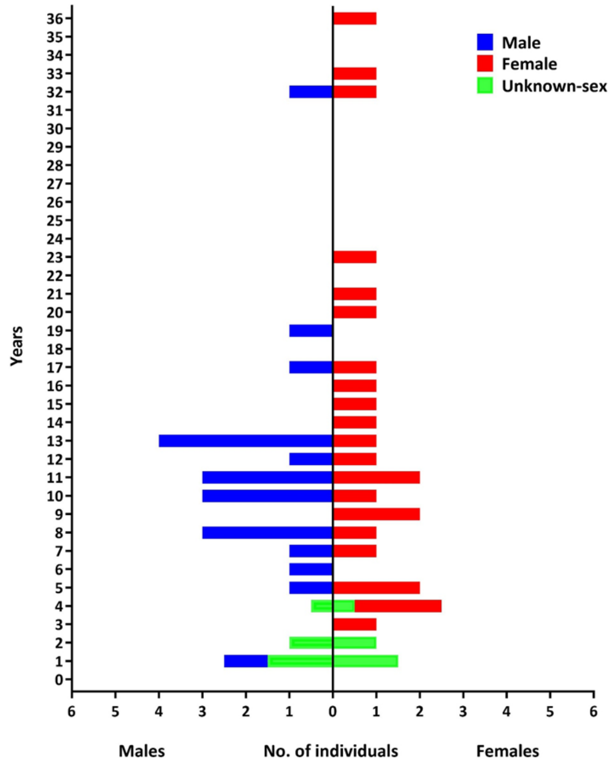


Figure 11: Age-sex composition of the captive lion-tailed macaque population in India as of 2018

Table 9: Living population of captive lion-tailed macaques in India as of 2018.

Institution	No. of individuals (m.f.u)*	Wild-born (m.f.u)*	Captive-born (m.f.u)*	Unknown origin (m.f.u)*
Bannerghatta	1 (0.1.0)	1 (0.1.0)		
Chatbir	1 (1.0.0)		1 (1.0.0)	
Delhi	5 (4.1.0)		5 (4.1.0)	
Hyderabad	2 (1.1.0)	1 (0.1.0)	1 (1.0.0)	
Lucknow	2 (1.1.0)		1 (0.1.0)	1 (1.0.0)
Vandalur	20 (5.9.6)	1 (0.1.0)	19 (5.8.6)	
Mangalore	2 (1.1.0)	2 (1.1.0)		
Mysore	7 (3.4.0)	3 (1.2.0)	4 (2.2.0)	
Thrissur	1 (0.1.0)	1 (0.1.0)		
Thiruvananthapuram	10 (5.5.0)	7 (3.4.0)	3 (2.1.0)	
Total	51 (21.24.6)	16 (5.11.0)	34 (15.13.6)	1 (1.0.0)

Letters "m", "f" and "u" refer to male, female, and unknown sex, respectively.

 https://doi.org/10.63033/JWLS.CXGU6570

Table 10: Distribution of captive lion-tailed macaque females aged 5-20 years (in 2018), in different zoos in India.

Zoos	No. of females
Vandalur	4
Mysore	4
Thiruvananthapuram	2
Lucknow	1
Mangalore	1
Thrissur	1
Bannerghatta	1

Table 11: Location of living breeders (in 2018) in the captive lion-tailed macaque population in Indian zoos.

Females			
Zoos where living females bred	No. of breeding females	No. of offspring produced	No. of surviving infants
Vandalur	8	33	24
Mysore	2	3	1
Thiruvananthapuram	3	4	3
Delhi	1	1	1
Total	**14**	**41**	**29**
Males			
Zoos where living males bred	No. of breeding males	No. of offspring produced	No. of surviving infants
Madras	2	10	9
Total	**2**	**10**	**9**

Table 12: Individual reproductive output of the females in the living population of the captive lion-tailed macaque in India as of 2018.

	Wild-born	Captive-born	Total
Total females	11	13	24
Adult females	11	11	22
Breeding females	6	8	14
Infants born	14	27	41
Surviving infants	10	19	29
Range of infants per breeding female	**1–7**	**1–8**	**1–8**
Range of surviving infants per breeding female	**0–6**	**1–4**	**0–6**

Table 13: Individual reproductive output of the males in the living population of the captive lion-tailed macaque in India as of 2018.

	Wild–born	Captive-born	Unknown origin	Total
Total males	5	15	1	21
Adult males	5	13	1	19
Breeding males	0	2	0	2
Infants born		10		10
Surviving infants		9		9
Range of infants per breeding male		4–6		4–6
Range of surviving infants per breeding male		4–5		4–5

Overall, the population retained 82.06% of gene diversity, which was lower than the recommended 90% for a captive population to be of conservation value (Soulé *et al.*, 1986; Ballou *et al.*, 2010). Moderate levels of relatedness among the individuals are reflected in the values of mean kinship (0.1794) and mean inbreeding (0.1781) (see Ballou *et al.*, 2010). The values of most of the genetic measures indicate a low potential of the population as a reserve, also at the level of genetics (see Lees & Wilcken, 2009; Leus *et al.*, 2011; Long *et al.*, 2011; Che Castaldo *et al.*, 2019).

Summary and conclusions

India only served as a resource for wild-caught lion-tailed macaques for American and European zoos in the first decades of the 20th century. The history of an Indian captive population of the species in zoos started in the 1950s, characterised by local management only, and a distribution over many zoos keeping few individuals only. Breeding occurred rarely. From the total of about 500 wild-caught lion-tailed macaques, almost equal proportions of individuals went to North America, Europe, and remained in India. They grew over the next decades in subpopulations of different sizes and composition: peak sizes were 269 (1988) in North America, 338 (2012) in Europe, 80 (2014) in Japan, and 76 (1988) in India. The living populations as of 2018 comprised 31 individuals in North America, 322 in Europe, 76 in Japan, and 51 in India.

The development of the subpopulations was influenced by different (systematic) management approaches as realised within breeding programmes. They were established in 1983 (North America), 1989 (Europe), and in the 2000s (India). The programmes in India differ from the SSP and the EEP version in terms of a strictly designed and controlled system managed by a "Central Zoo Authority". The nature of the breeding programme provides only a limited influence of local zoo staff, although they are directly dealing with the animals.

Whereas SSP and EEP intend to include all individuals kept in the region in question (*e.g.*, in North America or Europe) in the programme, in India, only a small proportion of the zoos and individuals, respectively, are included. For the lion-tailed

Table 14: Genetic status of the Indian population of captive lion-tailed macaque (in 2018) as provided by PMx.

Founders; Potential Founders (additional)	**16; 11**
% Pedigree Known; % Ancestry Certain	94.30%; 93.00%
Gene Diversity	0.8206
Founder Genome Equivalents (FGE), Potential FGE	2.79; 19.41
Population Mean Kinship	0.1794
Founder Genomes Surviving	7.16
Mean Inbreeding	0.1781

 https://doi.org/10.63033/JWLS.CXGU6570

macaque, the breeding programme presently comprises only three out of the 10 housing institutions.

The productivity of the Indian lion-tailed macaque population was low due to poor breeding conditions, and especially due to a low number of potentially productive females in species-typical breeding units and appropriate enclosures. According to Singh *et al.* (2006), a female lion-tailed macaque in the wild may give birth to up to five infants during her lifetime, but infants have a high survivorship rate. Field studies show that infant survivorship rate in the wild ranges from 0.80 to 0.973 (Kumar, 1987, 1995; Sharma, 2002; Krishna *et al.*, 2006). Our study reveals that in the Indian historical captive population, 68% of the females did not breed, and 26% of the infants born either died or were lost to follow-up within the first year of life. Among the captive females that reproduced, most had fewer than five infants, with 45% producing only 1–2 infants per female lifetime. Evidently, the productivity of the females is low. As was found in the global captive population (Begum *et al.*, 2022, 2023), a large percentage of the females did not breed at all – a pattern that has not been reported from the wild. Overall, the living and breeding conditions do not consider and allow for the realisation of the social and reproductive system of lion-tailed macaques. The Indian population is still (too) small and has an unfavourable age-sex composition. It does not have the potential to grow significantly and to develop sustainability. In the past, it depended on the integration of wild-caught individuals. With reference to the biology of lion-tailed macaques for successful breeding, larger groups with female-bonded structures are needed. To be able to carry out species-typical spacing patterns, groups would require large enclosures with some natural vegetation and richly furnished structures. Small night quarters in which lion-tailed macaques are kept for large parts of 24 hours of the day should be avoided. Under natural climatic conditions, safety during the night can also be realised *via* larger, airy subdivisions of the enclosures. Improved living conditions would increase the contribution of India to the global population growth *via* captive breeding. It has been low so far with 185 births, *i.e.*, 8.5% of total global births. Overall, the structure of the units in which the lion-tailed macaques were kept in various zoos did not correspond to the social system of the species and especially to the demographic structure of the groups in which they are found in the wild. Besides others, this includes the option to have long-term social relationships and the conditions to develop species-typical socialisation patterns. For the management of the Indian subpopulation, consideration of the social system of the species is of utmost importance for the development of a national management plan.

With reference to the actual number of lion-tailed macaques in the ten zoos that keep the species, only three zoos have the potential to contribute to breeding in terms of group size and the resulting social conditions. Seven institutions (in 2018) kept single or two individuals only – a setup that does not consider the natural (social) way of living of the species and animal welfare standards. As far as possible, small groups should be formed with these individuals. The process, however, would require highly professional management since there are no such group formations under natural conditions, and the individuals involved might have developed behavioural deficiencies during their suboptimal living conditions. For details on the process of group formation and social integration under captive conditions, see Kaumanns *et al.* (2006).

The three groups (with > 5 individuals) in zoos that participate in the breeding programme may have the potential to contribute to further breeding; however, as a starting set for a reserve population, they do not provide enough individuals. The groups, furthermore, are slightly inbred. Their further use requires exchanges of breeding males.

The poor status of the Indian population requires the integration of further lion-tailed macaques from Europe – preferably (small) groups of related females. They should be associated with wild-born males in India. To realise this, a programme to achieve appropriate living and management conditions in Indian zoos that intend to keep lion-tailed macaques must be developed. This would include an assessment of existing keeping conditions, proposing improvements, designing new keeping systems, and developing an appropriate conservation breeding programme. The latter must consider international standards. As a key component of a new approach, management by a competent zoo biologist or veterinarian as a programme coordinator is required. The person should be familiar with the biology of the species, be an experienced practitioner in husbandry and management, and be able to act in a responsible way. Management decisions should be in his/her responsibilities but discussed and supported by a committee of representatives of the participating zoos. The latter would help to consider local husbandry systems and problems. This approach proved to be successful in the European breeding programme (EEP) as experienced by the second author, who acted as the founding and long-term coordinator for the EEP for the lion-tailed macaque. It welcomes external scientific advisors, *e.g.*, field biologists. The quality of the work might be evaluated by experts who form a central zoo advisory board. On all levels, the use of scientific methods and knowledge is necessary. Contacts and know-how transfer with the relevant representatives and organisations of the scientific community are indicated. To establish such structures and to find the experts needed will be difficult in India since its zoo community and organisation so far does not support a more decentralised system that depends more on the responsibility of the individual zoos and their staff. The latter would be a condition for the development of professional expertise (see Singh *et al.*, 2012). It is essential to consider that as many – better all – members of a zoo population of a species, in this case lion-tailed macaque, are included and managed in a programme like it is propagated in the European breeding programmes. In the case of the Indian population of the lion-tailed macaque, coordination should be attempted to fully integrate all 51 individuals into a management plan and to interact with the European breeding programme to establish a population as proposed above.

Although the status of the captive population in Indian zoos is poor and might be difficult to improve towards a reserve population, efforts to achieve this goal are critical for the survival of the global captive population. Programmes for the reintroduction of this threatened primate species – endemic to South India – evidently must be realised *via* Indian zoos. To serve as an interface, they must develop the necessary expertise, keeping systems and a viable national captive population. The Indian community of conservation biologists seems to be motivated to support corresponding plans, as indicated by several publications (see Singh *et al.*, 2012; Kaumanns *et al.*, 2013; Begum *et al.*, 2021).

The analysis of the Indian population intends to contribute to the development of better global and national programmes. This study also demonstrates the special need for the existing international breeding programmes in the various regions to consider and care for the captive population of the species in its country of origin. Plans to transfer lion-tailed macaques and to improve the living conditions, training and know-how transfer for Indian zoos have not been materialised, consequently, and over longer time periods since the first international conference on lion-tailed macaques in zoos in Baltimore in 1982 (see Singh *et al.*, 2009).

The present study indicates very poor reproductive output of the Indian population, and related to this is a likely loss of genetic and phenotypic diversity. Therefore, the Indian captive population so far cannot be considered as a potential reserve. This is supported by the poor age-sex composition of the current population, especially due to the old age of the wild-born individuals. Furthermore, many females experience long periods of non-breeding. Living conditions that do not allow reproduction for extended time periods might negatively impact the future reproductive potential of individuals (see Penfold *et al.*, 2014).

The finding that there are two genetically different subpopulations of the lion-tailed macaque in the wild (Ram *et al.*, 2015) has not yet been properly considered for the global captive populations. The authors propose to treat the two genetic types as separate conservation units. Ram *et al.* (2015) found that most of the members of the Indian captive population are of the southern and a few of the northern type. A genetic analysis would be urgently needed for the European population.

All living wild-born lion-tailed macaques of the global captive population are kept in Indian zoos (Sliwa & Begum, 2019). This must be considered for the management of the global population.

The present study can be regarded as a model study that highlights the problems and management issues in a population of a highly threatened animal species. It can be used as a model for the analysis of captive populations for other primates and other threatened mammal species. Inappropriate living conditions and management in the past of a population decrease its potential to serve as a reserve. It refers to the adaptive potential of the species in question. The adaptive potential of a species kept in zoos should be regarded as a key aspect of conservation breeding (see Kaumanns *et al.*, 2020, 2025).

Acknowledgment

Nilofer Begum, Werner Kaumanns and Mewa Singh thank Prof. Dr. Hans-Jürg Kuhn, former Director of German Primate Center, Göttingen; late Prof. Dr. Gunther Nogge, former Director of Cologne Zoo; Prof. Dr. Heribert Hofer, former Director of the Leibniz Institute for Zoo and Wildlife Research, Berlin; and Dr. Alexander Sliwa, former EEP Coordinator for the lion-tailed macaque, Cologne Zoo, for supporting the Lion-tailed macaque project. Mewa Singh thanks the Indian National Science Academy for the Distinguished Professor award, during which this article was prepared.

CONFLICT OF INTEREST

Werner Kaumanns & Mewa Singh hold editorial positions at the Journal of Wildlife Science. However, they did not participate in the peer review process of this article except as authors. The authors declare no other conflict of interest.

DATA AVAILABILITY

The data used in the study is available in Sliwa & Begum (2019).

AUTHOR CONTRIBUTIONS

NB and WK conceptualised the idea and wrote the manuscript; data analysis has been done by NB. All authors contributed to the discussion and the finalisation of the manuscript. All authors have read and approved the final version.

References

Ballou, J. D., Lees, C., Faust, L. J., Long, S., Lynch, C., Lackey, L. B. & Foose, T. J. (2010). Demographic and genetic management of captive populations. In: Kleiman, D. G., Thompson, K. & Baer C. K. (eds.), *Wild mammals in captivity: Principles and techniques for zoo management.* University of Chicago Press. pp.219–252.

Ballou, J. D., Lacy, R. C., Pollak, J. P., Callicrate, T. & Ivy, J. (2025). PMx: Software for demographic and genetic analysis and management of pedigreed populations (Version 1.8.1.20250501). Chicago Zoological Society, Brookfield, Illinois, USA. http://www.scti.tools

Begum, N. (2023). P*rimates under altered living conditions: Development and conservation potential of the captive lion-tailed macaque Macaca silenus population*. PhD Thesis, Freie Universität Berlin. https://refubium.fu-berlin.de/handle/fub188/39329

Begum, N., Kaumanns, W., Sliwa, A. & Singh, M. (2021). The captive population of the lion- tailed macaque *Macaca silenus*. The future of an endangered primate under human care. Journal of *Threatened Taxa*, 13(9), 19352–19357. https://doi.org/10.11609/jott.7521.13.9.19352-19357

Begum, N., Kaumanns, W., Singh, M. & Hofer, H. (2022). A hun¬dred years in zoos: History and development of the captive population of the lion-tailed macaque *Macaca silenus*. Long term persistence for conservation? *Primate Conservation*, 36, 155–172. http://www.primate-sg.org/storage/pdf/PC36_Begum_et_al_100_years_captive_lion-tail_macaques.pdf

Begum, N., Kaumanns, W., Hofer, H. & Singh, M. (2023). A hun¬dred years in zoos II: Patterns of reproduction in the global historical captive population of the lion-tailed macaque *Macaca silenus*. *Primate Conservation*, 37, 134–154. http://www.primate-sg.org/storage/pdf/PC37

Central Zoo Authority. (2011). Guidelines/ norms for conservation breeding programme of the Central Zoo Authority. Central Zoo Authority, New Delhi. p.4 https://cza.nic.in/uploads/documents/CBP/Guidelines%20for%20the%20CBP.pdf

Che-Castaldo, J., Johnson, B., Magrisso, N., Mechak, L., Melton, K., Mucha, K., Terwilliger, L., Theis, M., Long, S. & Faust, L. (2019). Patterns in the long-term viability of North American zoo populations. *Zoo Biology*, 38(1), 78–4. https://doi.org/10.1002/zoo.21471

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). (2025). CITES Appendices I, II and III valid from 7 February 2025. https://cites.org/eng/app/appendices.php

Dhawale, A. K. & Sinha, A. (2025). Population dynamics of a lion-tailed macaque (*Macaca silenus*) population in a rainforest fragment in the southern Western Ghats of India. *American Journal of Primatology*, 87(9), e70075. https://doi.org/10.1002/ajp.70075

GraphPad Software. (2025). GraphPad Prism (Version 10.6.0 for Windows). Boston, Massachusetts, USA. https://www.graphpad.com/

Heltne, P. G. (ed.), (1985). *The Lion-tailed macaque: Status and conservation*. Alan R. Liss.

Hill, C. A. (1971). Zoo's help for a rare monkey. *Oryx*, 11(1), 35–38. https://doi.org/10.1017/S003060530000942X

Kaumanns, W. & Rohrhuber, B. (1995). Captive propagation in lion-tailed macaques: The status of the European population and research implications. In: Gansloßer, U., Hodges, J. K. & Kaumanns, W. (eds.), *Research and Captive Propagation*, Filander Verlag. pp.296–309.

Kaumanns, W., Schwitzer, C., Schmidt, P. & Knogge, C. (2001). The European lion-tailed macaque population: An overview. *Primate Report*, 59, 65–76.

Kaumanns, W., Krebs, E. & Singh, M. (2006). An endangered species in captivity: Husbandry and management of the lion-tailed macaque (*Macaca silenus*). *MyScience*, 1(1), 43–71.

Kaumanns, W., Singh, M. & Sliwa, A. (2013). Captive propagation of threatened primates – the example of the lion-tailed macaque *Macaca silenus*. *Journal of Threatened Taxa*, 5(14), 4825–4839. https://doi.org/10.11609/JoTT.o3625.4825-39

Kaumanns, W., Begum, N. & Hofer, H. (2020). Animals are designed for breeding: Captive population management needs a new perspective. *Journal of Zoo and Aquarium Research*, 8(2), 76–85. https://doi.org/10.19227/jzar.v8i2.477

Kaumanns, W., Begum, N. & Singh, M. (2025). Wild animals in zoos: A new paradigm is needed for zoos in the future. *Journal of Wildlife Science*, 2(3), 75–81. https://doi.org/10.63033/JWLS.IFNA7720

Kavana, T. S., Mohan, K., Erinjery, J. J., Singh, M. & Kaumanns, W. (2025). Distribution and habitat suitability of the endangered lion-tailed macaque *Macaca silenus* and other primate species in the Kodagu region of the Western Ghats, India. *Primates*, 66(1), 75–85. https://doi.org/10.1007/s10329-024-01152-6

Krishna, B. A., Singh, M. & Singh, M. (2006). Population dynamics of a group of lion-tailed macaques (*Macaca silenus*) inhabiting a rainforest fragment in the Western Ghats, India. *Folia Primatologica*, 77(5), 377–386. https://doi.org/10.1159/000093703

Kumar, A. (1987). *The ecology and population dynamics of the lion-tailed macaque (Macaca silenus) in south India*. PhD Thesis, University of Cambridge.

Kumar, A. (1995). Birth rate and survival in relation to group size in the lion-tailed macaques, *Macaca silenus*. *Primates*, 36(1), 1–9. https://doi.org/10.1007/BF02381911

Kumar, M. A., Singh, M., Kumara, H. N., Sharma, A. K. & Bertsch, C. (2001). Male migration in lion-tailed macaques. *Primate Report*, 59, 5–18.

Kumara, H. N. & Singh, M. (2004). Distribution and abundance of primates in rainforests of the Western Ghats, Karnataka, India and the conservation of *Macaca silenus*. *International Journal of Primatology*, 25(5), 1001–1018. https://doi.org/10.1023/B:IJOP.0000043348.06255.7f

Kumara, H. N. & Sinha, A. (2009). Decline of the endangered lion-tailed macaque, *Macaca silenus*, in the Western Ghats, India. *Oryx*, 43(2), 292–298. https://doi.org/10.1017/S0030605307990900

Kumara, H. N., Sasi, R., Suganthasakthivel, R., Singh, M., Sushma, H. S., Ramachandran, K. K. & Kaumanns, W. (2014). Distribution, demography, and conservation of lion-tailed macaques (*Macaca silenus*) in the Anamalai Hills landscape, Western Ghats, India. *International Journal of Primatology*, 35(5), 976–989. https://doi.org/10.1007/s10764-014-9776-2

Lees, C. M. & Wilcken, J. (2009). Sustaining the Ark: The challeng¬es faced by zoos in maintaining viable populations. *International Zoo Yearbook*, 43(1), 6–18. https://doi.org/10.1111/j.1748-1090.2008.00066.x

Leus, K., Lackey, L. B., van Lint, W., de Man, D., Riewald, S., Veld¬kam, A. & Wijmans, J. (2011). Sustainability of the European Association of Zoos and Aquaria bird and mammal populations. *World Association of Zoos and Aquariums Magazine*, 12, 11–14.

Lindburg, D. G., Iaderosa, J. & Gledhill, L. (1997). Steady-state propagation of captive lion-tailed macaques in North American zoos: A conservation strategy. In: Wallis, J. (ed.), *Primate Conservation: The Role of Zoological Parks, Special Topics in Primatology*, 1. American Society of Primatologists. pp.131–149.

Lindburg, D. G. (2001). A century of involvement with lion-tailed macaques in North America. *Primate Report*, 59, 51–64.

Long, S., Dorsey, C. & Boyle, P. (2011). Status of Association of Zoos and Aquariums cooperatively managed populations. *World Association of Zoos and Aquariums Magazine*, 12, 15–18.

Mallapur, A., Waran, N. & Sinha, A. (2005a). Factors influencing the behaviour and welfare of captive lion-tailed macaques in Indian zoos. *Applied Animal Behaviour Science*, 91(3-4), 337–353. https://doi.org/10.1016/j.applanim.2004.10.002

Mallapur, A., Waran, N. & Sinha, A. (2005b). Use of enclosure space by captive lion-tailed macaques (*Macaca silenus*) housed in Indian zoos. *Journal of Applied Animal Welfare Science*, 8(3), 175–186. https://doi.org/10.1207/s15327604jaws0803_2

Molur, S., Brandon-Jones, D., Dittus, W., Eudey, A., Kumar, A., Singh, M., Feeroz, M. M., Chalise, M., Priya, P. & Walker, S. (2003). Status of South Asian primates: Conservation Assessment and Management Plan (C.A.M.P.). Workshop Report 2003, Zoo Outreach Organization/CBSG-South Asia, Coimbatore. https://zooreach.org/downloads/ZOO_CAMP_PHVA_reports/2003PrimateReport.pdf

Penfold, L. M., Powell, D., Traylor-Holzer, K. & Asa, C. S. (2014). 'Use it or lose it': Characterization, implications, and mitigation of female infertility in captive wildlife. *Zoo Biology*, 33(1), 20–28. https://doi.org/10.1002/zoo.21104

Ram, M. S., Marne, M., Gaur, A., Kumara, H. N., Singh, M., Kumar, A. & Umapathy, G. (2015). Pre-historic and recent vicariance events shape genetic structure and diversity in endangered lion-tailed macaque in the Western Ghats: Implications for conservation. *PLOS ONE*, 10, e0142597. https://doi.org/10.1371/journal.pone.0142597

Ramachandran, K. K. & Joseph, G. K. (2000). Habitat utilization of lion-tailed macaque (*Macaca silenus*) in Silent Valley National Park, Kerala, India. *Primate Report*, 58, 17–25.

R Core Team. (2025). R: A language and environment for statistical computing. R foundation for statistical computing. Vienna, Austria. https://www.R-project.org/

Rode-White, G. & Corlay, M. (2024). Long-term management plan for the lion-tailed macaque (*Macaca silenus*) European Endangered Species Programme (EEP). Zoologischer Garten Köln, Köln, Germany and European Association of Zoos and Aquaria (EAZA), Amsterdam, Netherlands. p.17.

Scobie, P. & Bingaman Lackey, L. (2012). Single Population Analysis and Records Keeping System (SPARKS) (Version 1.66). International Species Information System (ISIS), renamed to Species360. Minnesota, USA.

Sharma, A. K. (2002). *A study of the reproductive behaviour of lion tailed macaque (Macaca silenus) in the rainforests of Western Ghats.* PhD Thesis, University of Mysore.

Singh, M. & Kaumanns, W. (2005). Behavioural studies: A necessity for wildlife management. *Current Science*, 89(7), 1230–1236. https://www. jstor.org/stable/24110976

Singh, M., Sharma, A. K., Krebs, E. & Kaumanns, W. (2006). Reproductive biology of lion-tailed macaque (*Macaca silenus*): An important key to the conservation of an endangered species. *Current Science*, 90(6), 804–811. https://www.jstor.org/stable/24089192

Singh, M., Kaumanns, W., Singh, M., Sushma, H. S. & Molur, S.(2009). The lion-tailed macaque *Macaca silenus* (Primates: Cercopithecidae): Conservation history and status of a flagship species of the tropical rainforests of the Western Ghats, India. *Journal of Threatened Taxa*, 1(3), 151–157. https://doi.org/10.11609/JoTT.o2000.151-7

Singh, M., Kaumanns, W., & Umapathy, G. (2012). Conservation-oriented captive breeding of primates in India: Is there a perspective? *Current Science*, 103(12), 1399–1400. https://www. jstor.org/stable/24089343

Singh, M. (2019). Management of forest-dwelling and urban spe¬cies: Case studies of the lion- tailed macaque (*Macaca silenus*) and the bonnet macaque (M. radiata). *International Journal of Primatology*, 40(6), 613–629. https://doi.org/10.1007/s10764-019-00122-w

Singh, M., Kumar, A. & Kumara, H. N. (2020). *Macaca silenus*. The IUCN Red List of Threatened Species 2020: e. T12559A17951402. https://doi.org/10.2305/IUCN.UK.2020-2.RLTS.T12559A17951402.en

Sliwa, A., Schad, K. & Fienig, E. (2016). Long-term management plan for the lion tailed macaque (*Macaca silenus*) European Endangered Species Programme (EEP). Zoologischer Garten Köln, Köln, Germany and European Association of Zoos and Aquaria (EAZA), Amsterdam, Netherlands. p.60

Sliwa, A. & Begum, N. (2019). *International studbook 2018 for the lion-tailed macaque Macaca silenus Linnaeus, 1758, (Edition 2018, Volume 9)*. Zoologischer Garten Köln, Köln, Germany.

Soulé, M., Gilpin, M., Conway, W. & Foose, T. (1986). The millenium ark: How long a voyage, how many staterooms, how many passengers? *Zoo Biology*, 5(2), 101–113. https://doi.org/10.1002/zoo.1430050205

Sushma, H. S., Mann, R., Kumara, H. N. & Udhayan, A. (2014). Population status of the endangered lion-tailed macaque *Macaca silenus* in Kalakad-Mundanthurai Tiger Reserve, Western Ghats, India. *Primate Conservation*, 28(1), 171–178. https://doi.org/10.1896/052.028.0120

ISSN (Online): 3048-7803

JWLS

Volume 2, Issue 4 (December 2025)

TYPE Research Article

Human-Carnivore Conflict: A cause of concern for District Kangra, Himachal Pradesh, India

Nitika Mehra[1] & Vinita Sharma[1]*

[1] Wildlife Conservation Research Laboratory, Department of Zoology, Central University of Jammu, Rahya-Suchani Bagla, District Samba, Jammu and Kashmir, India 181143

DIAMOND OPEN ACCESS Crossref

EDITED BY
Tapajit Bhattacharya
Durgapur Government College, Paschim Bardhaman, India.

*CORRESPONDENCE
Vinita Sharma
vinita302003@gmail.com

RECEIVED 23 July 2025
ACCEPTED 24 November 2025
PUBLISHED 22 December 2025

CITATION
Mehra, N. & Sharma, V. (2025). Human-Carnivore Conflict: A cause of concern for District Kangra, Himachal Pradesh, India. *Journal of Wildlife Science,* 2(4), 127-132.
https://doi.org/10.63033/JWLS.DJEZ4982

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Abstract

Human–carnivore conflict (HCC) is a major conservation and livelihood challenge in the Indian Himalayas. In Himachal Pradesh, leopards (*Panthera pardus*) and black bears (*Ursus thibetanus*) are widespread, but research has mostly focused on protected areas, leaving human-dominated landscapes understudied. This study investigates HCC in Kangra district, Himachal Pradesh, between January 2014 and August 2022, with emphasis on livestock depredation, human casualties, and spatio-temporal trends. Conflict records were compiled from four divisional forest offices (N=193) and supplemented with semi-structured interviews (N=86) to assess species involved, type of conflict, and compensation status. Results revealed that leopards were the primary cause of livestock depredation, targeting goats (57.42%) and sheep (26.45%), while black bears were more often involved in direct human encounters. The Nurpur Forest Division reported the highest number of cases (N=72) with 421 livestock deaths followed by Palampur (N=54), Dehra (N=51), and Dharamshala (N=24). Seasonal analysis showed conflict peaks in the rainy (N=59) and summer (N=58) seasons. Leopard depredation was highest in summer and rainy months, while black bear incidents peaked in autumn. Statistical analysis confirmed a significant upward trend in leopard attacks over the study period (R^2=0.74, p=0.0059). The findings highlight the growing intensity of HCC outside protected areas and underscore the need for mitigation strategies, including predator-proof livestock enclosures, awareness programs, and timely compensation to reduce retaliatory attitudes and promote coexistence.

Keywords: Conflict mitigation, Himalayan black bear, leopard, livestock depredation, Indian Himalayas.

Introduction

Since ancient times, humans and wild animals have competed for the same natural resources (Chauhan & Rajpurohit 1996; Madhusudan 2003; Distefano, 2005), which has now intensified into Human-Wildlife Conflict (HWC), threatening both biodiversity and human livelihoods. The conflict resulting in livestock loss and crop destruction leads to problems of food security and poverty (Gemeda & Meles, 2018). Large carnivores are among the most frequent conflicting species, with leopard, black bears, snow leopard, wolves, brown bears, and tigers often central to these conflicts, causing significant human and livestock losses across India (Madhusudan, 2003; Distefano, 2005; Suryawanshi *et al.*, 2013; Das, 2018; Sharma *et al.*, 2020; Sharma *et al.*, 2021), making human-carnivore conflict (HCC) a significant constituent of HWC. In the Indian Himalayas, an increase in human-leopard conflicts has been linked to changes in land use (Chauhan *et al.*, 2002). HWC presents a significant challenge across Himachal Pradesh (Sharma, 2024 a & b). The region holds considerable geomorphological and ecological importance, with its altitudinal variations supporting a diverse range of flora and fauna. But with the rapid transformation in land use changes and deforestation due to developmental activities, the state is facing numerous challenges that threaten its biodiversity. Moreover, the expansion of road networks and agricultural land has further led to an escalated confrontation with humans. Socially, the consequences of HWC are inextricably linked to human livelihoods and community dynamics (Hill, 2021).

Although leopard (*Panthera pardus*) and black bear (*Ursus thibetanus*) are widely spread throughout Himachal Pradesh, and several studies have focused on HWC in protected areas of the state (Mohanta & Chauhan, 2014; Rathore & Chauhan, 2014; Bhardwaj *et al.*, 2024; Kichloo *et al.*, 2024), little research has addressed non-protected landscapes where the majority of the population coexist. The region outside the protected area is often in conflict with the leopard and black bear (Sharma, 2024 a & b). About 94% of the human population in Kangra district resides in rural areas

(Census, 2011) and depends heavily on livestock. This region also serves as a migratory route for pastoralists (Sharma *et al.*, 2022). The traditional annual movement of the Gaddi community to ensure food availability for the livestock often increases the risk of predation by the large carnivores. These factors heighten the risk of carnivore attacks, yet systematic documentation outside protected areas remains scarce. Mahajan (2020) and Sharma (2024 a & b) highlighted the issue of leopard and black bear conflict across protected areas of Himachal Pradesh. In the present study, we try to identify conflict trends across non-protected landscapes of the district Kangra by examining human–carnivore conflict cases that occurred between January 2014 and August 2022, focusing on livestock depredation and human casualties. The findings of our study support conflict mitigation and long-term conservation planning. We hypothesize that human–carnivore conflict in Kangra has shown an increasing trend over the years. To test this, we examined conflict patterns across years, seasons, and forest divisions (FD) while assessing compensation effectiveness.

Methods

Study area

The state of Himachal Pradesh is well-known for its dense forests, rugged terrain, and high mountains. A key determinant of the district climate is its varying altitude, supporting an incredible diversity of wildlife. Among the 12 districts of Himachal Pradesh, Kangra district lies between 30° 22' 40" and 33° 12' 40" north latitude and 75° 45' 55" and 79° 04' 20" east longitude (Figure 1) with a geographical area of 5,739 km^2. It is bordered by the districts of Lahaul and Spiti to the northeast, Chamba to the north, Mandi to the south, Kullu to the east, and the Punjab state to the west. Kangra district is distinguished by its topography, characterized by intersecting mountain ranges that enclose broad to narrow valleys. Situated in the Shivalik and Lesser Himalayan zones, the district's landscape is defined by a series of nearly parallel hill ranges that progressively rise in height towards the northeast. The climate of the region has four distinct seasons: Summer (March-June), Rainy (July-September), Autumn (October-November), and Winter (December-February). In the low-lying valley areas, situated below 600 meters, the climate is hot and humid. At elevations between 2,000 and 4,500 meters, the district experiences a cold, temperate climate, with heavy snowfall during the winter months from December to February. During the monsoon season, from July to September, the landscape transforms, turning lush and green due to the abundant rainfall. According to the assessment for 2021, the district has a forest area of 2,357.27 km^2, which is 41.08 % of its total geographical area (Forest Survey of India, 2021). The Kangra forests are home to a wide variety of plants, including Chir (*Pinus roxburghi*), Banj oak (*Quercus leucotrichophora*), deodar (*Cedrus deodara*), Kharsu oak (*Quercus semecarpifolia*), Kail (*Pinus wallichaina*), spruce (*Picea sp*.), and fir trees (*Abies sp*.), as well as numerous species of wild animals, including the common leopard, black bear, jackal (*Canis aureus indicus*), sambar deer (*Rusa unicolor*), and nilgai (*Boselaphus tragocamelus*). The district has two protected areas, namely the Pong Dam Lake Wildlife Sanctuary (207.59 km^2), a Ramsar site of international importance that potentially offers a resting reserve for the migratory birds coming from the Trans Himalayan zone in the winter season, and the Dhauladhar Wildlife Sanctuary (982.86 km^2), unique in its high rainfall and rain shadow zones. The study area, having habitat for leopard and black bear, harbors a good population of both species, often resulting in conflict.

Data Collection and Methodology

Information on HCC incidences in the study area was collected through in-person interviews and official records from four divisional forest offices. Villages were purposively selected based on reported incidences of livestock depredation and human attacks recorded by divisional forest offices, as well as their proximity to forested areas. Within these villages, households were then selected using random sampling to ensure unbiased representation at the household level. The interviews were carried out between April and June 2022, and information was collected for the period January 2014-August 2022. A semi-structured questionnaire, comprising both open and closed-ended questions, was administered to 86 individuals, falling within the age group of 20-70 years, of whom 53 reported experiences of conflict during the study period. Verbal consent was obtained from all participants prior to the data collection, and no information that could identify individuals was recorded. From the questionnaire, we gathered details on the species involved in HCC, the type of victim (human or livestock), year and month of the attack, type of conflict, and residents' awareness of the compensation scheme. In addition, systematic data were collected in person from official records maintained by the Nurpur Forest Division, Dharamshala Forest Division, Dehra Forest Division, and Palampur Forest Division. A total of 193 reported cases were obtained from these offices. In cases where incidents were present in both primary (interview-based) and secondary (official record-based) datasets, the information from the secondary source was prioritized to maintain accuracy. The final dataset comprised 201 conflict reports from both sources.

This study focused on incidents involving leopards and black bears to assess the intensity of HCC in the region. To ensure data reliability, only cases with verifiable information were included. Spatial mapping was conducted using QGIS 3.16 Hannover. Based on reported cases, efforts were made to identify seasonal patterns of attacks, determine the most vulnerable periods, and assess trends over time. Furthermore, details of compensation payments were also collected from forest department records to evaluate the economic impact of such conflicts.

Data Analyses

The overall data collected on HCC incidents from January 2014 to August 2022 were analyzed in relation to time, area, incident type (injuries and fatalities for livestock as well as humans), and loss in terms of the most depredated livestock species with respect to the incidence. The quantitative data were analyzed using linear regression to assess the trends in HCC. A trend was deemed statistically meaningful if the coefficient of determination (R^2) was ≥0.65 and the p-value was ≤ 0.05 (Bryhn & Dimberg, 2011). We used the chi-square test (α=0.05) to check the seasonal difference in the number of attacks by both predators. To further illustrate conflict patterns, the species involved, and financial compensation, bar graphs and maps were employed for visual representation. For statistical analysis, the yearly data were analyzed for the years 2014-2021, and data were collected till August for the year 2022. In case of monthly data, the missing information for any period was straightforwardly not included for analysis, resulting in a total of 190 cases. This approach helped to reduce the bias in the conclusion.

Results & Discussions

Species Involved in Human-Wildlife Conflict

Leopards and black bears were identified as the primary conflict-causing species (Sharma, 2024 a & b) in the non-protected landscapes of district Kangra, Himachal Pradesh, which significantly contributed to livestock depredation and human casualties. In addition to these large carnivores, other mammalian species, including the rhesus monkey (*Macaca mulatta*), wild boar (*Sus scrofa*), nilgai, and sambar deer, were identified as primarily responsible for crop damage. A few instances of monkey and wild boar attacks on humans were also reported. From January 2014 to August 2022, leopards accounted for 181 cases and black bears for 20 cases out of total 201 conflict cases.

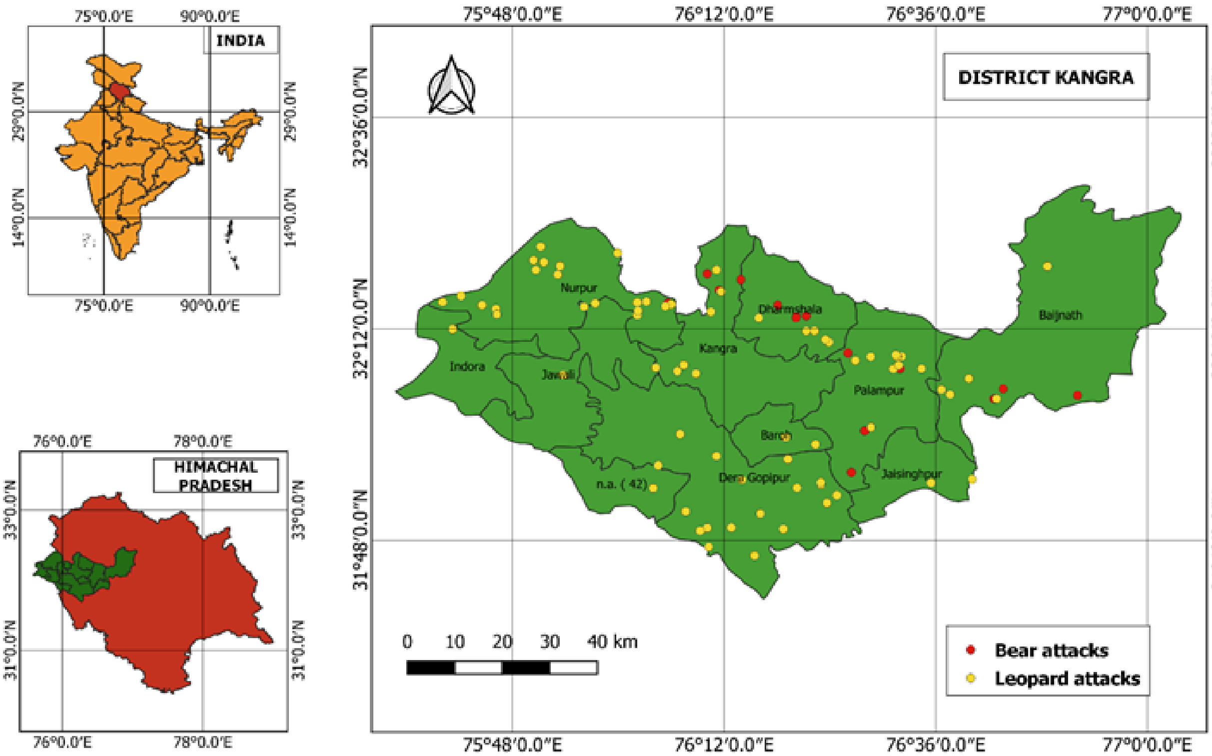


Figure 1. Locations of leopard and black bear attacks in the Kangra district the years 2014-2022.

Livestock depredation by leopards and black bears

Between January 2014 and August 2022, a total of 177 recorded attacks on livestock resulted in the death of 620 animals. Leopards preyed on goats, sheep, cows, horses, mares, mules, oxen, and buffalo (Table 1). Goats were the most frequently killed species (57.42%), followed by sheep (26.45%) and cows (10.81%). Black bears were responsible for nine attacks on livestock, resulting in the death of 20 animals, with goats and sheep accounting for 30% each, followed by oxen (20%), buffaloes (15%), and horses (5%).

The relationship between leopard attacks and bear attacks on different livestock types was not statistically significant (R^2= 0.442, $p>0.05$); however, a positive slope (0.0121) indicates

Table 1. Livestock predation by leopard and black bear in Kangra district during the years 2014-2022

Livestock type	Total livestock killed by leopard and black bear	Predation by leopard	Predation by black bear
Goat	362	356	6
Sheep	170	164	6
Cow	67	67	0
Horse, Mare & Mule	28	25	3
Buffalo	6	5	1
Ox	7	3	4
Total	**640**	**620**	**20**

that bear attacks tend to increase slightly as leopard attacks increase. In the case of leopard, the number of attacks decreased sharply as we move from medium-sized livestock (*e.g.*, goat and sheep) to large-sized livestock (*e.g.*, ox), showing a high preference for medium-sized livestock (R^2=0.787, $p<0.05$), whereas black bear shows a little variation in attacks for different livestock (Supplementary Table S1). Incidents of leopard and bear attacks have increased over time. The leopard attacks show a significant increase (R^2=0.742, $P<0.05$) while the black bear attacks have increased slightly over the years (Figure 2, Table 2).

Table 2. Regression of the number of leopard and black bear attacks with the years (2014-2022).

Animal of Conflict	R-square value	P-value	Inter-cept	Slope	Standard error
Leopard	0.742	0.005	-4662.61	2.321	3.61
Black bear	0.407	0.088	-838.25	0.417	1.32

Human Casualties

Black bear attacks were more prevalent on humans than on livestock. A total of eleven bear attacks were reported during the time frame on humans, further classified into severe injuries (N=7) and minor injuries (N=4). However, no human fatalities have been attributed to bear attacks. Leopard attacks on human resulted in minor injuries (N=4) and one death. In the present study, it was observed that humans were more prone to attacks by black bears rather than by leopards in the study area.

Forest Division-wise Human-Carnivore Conflict Incidences

The highest number of reported attacks (N=72) was recorded in the Nurpur FD, where 421 livestock deaths occurred. This was followed by the Palampur FD (N=54) with 116 livestock deaths; Dehra FD, and Dharamshala FD reported N=51 and N=24 attacks, respectively (Figure 3). Among human casualties, the Nurpur FD recorded one fatal leopard attack, while the Dehra FD and Palampur FD reported one and two cases of minor

 https://doi.org/10.63033/JWLS.DJEZ4982

injuries, respectively. Some cases of livestock depredation were also reported among migratory livestock, as pastoralists used the Nurpur region as a migratory route to the Chamba district (Supplementary Figure S3) during the summer months. Notably, in Dehra FD, all recorded HCC cases involved leopards, whereas in the Nurpur FD, Palampur FD, and Dharamshala FD, both leopards and black bears were responsible for conflicts.

Seasonal Trends in Human-Carnivore Conflict

The number of reported HCC incidents increased from 15 cases in 2014 to a peak of 34 cases in 2020 (Figure 2). The highest number of attacks by both large carnivores was recorded in 2020, after which the cases declined in 2021 and remained lower until August 2022 (Figure 2). There was a significant difference in the seasonal pattern of the number of attacks ($\chi2=13.4234$, df=3, P=0.0038). Seasonal analysis revealed that the highest number of attacks (N=59) occurred during the rainy season (July–September), followed by the summer season (March–June) with 58 reported incidents. Winter (December–February) and autumn (October–November) recorded 34 and 39 cases, respectively (Figure 4). The month of November had the highest number of reported cases (Supplementary Figure S1). Leopards exhibited the highest depredation rates during the summer (N=55) and rainy (N=55) seasons, followed by winter (N=32) and autumn (N=29). Conversely, black bears were most active during autumn (N=10), followed by the rainy season (N=4), summer (N=3), and winter (N=2).

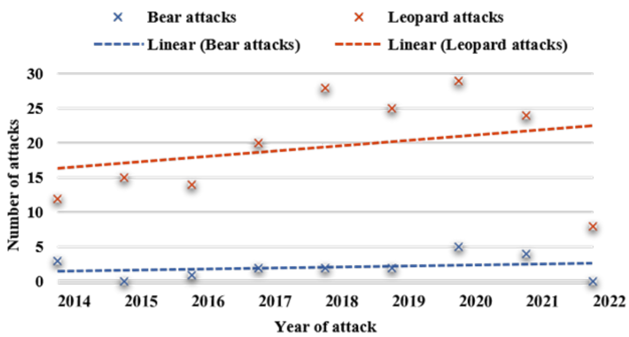


Figure 2. The trend in the yearly numbers of leopard and black bear attacks from 2014 to 2022 in Kangra district.

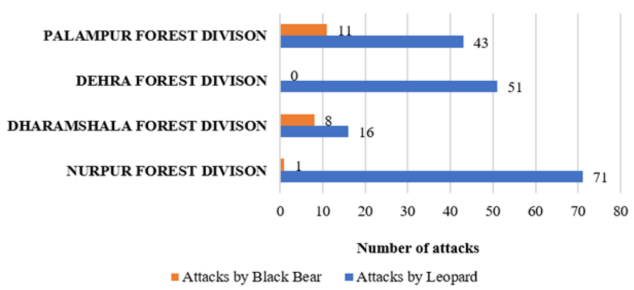


Figure 3. The distribution of leopard and black bear attacks on livestock during the year 2014-August 2022 across forest divisions in Kangra district, Himachal Pradesh.

Compensation paid against incidences of HCC:

The Indian government uses ex-gratia payments as a policy measure to compensate individuals affected by HWC. State governments determine payments on a per-incident basis. Monetary compensation for the loss of lives and livelihoods is a major tool used by the government for reducing HCC. The compensation rates of the state have increased over time, with the revised list having nearly double the compensation rates (Supplementary Table S2). The forest department paid a total of 25,90,583/- rupees in compensation for leopard and black bear attacks reported to four divisional offices between January 2014 and August 2022. Black bear conflicts costed 6,74,102/- rupees, whereas leopard conflicts accounted costed 19,16,481/- rupees in compensation.

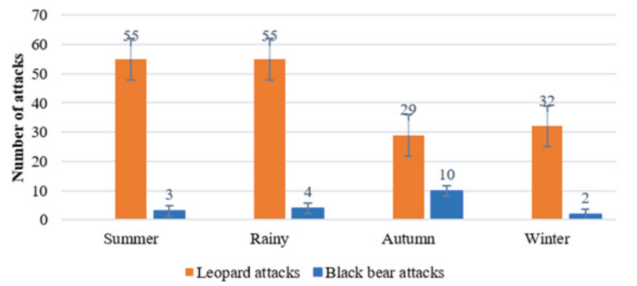


Figure 4. The seasonal pattern of attacks by leopard and black bear in the Kangra district during 2014-August 2022.

The revised rates reflect an effort to adjust for inflation over time, matching the rising costs of living, medical care, and livestock values. Compensation for human death increased from 1.5 lakh in 2014 to 4 lakh rupees in 2018, a substantial increase aimed to support the affected families. Also, the payments for permanent disability were doubled. The livestock categories like goat and sheep saw significant upward revisions, with rates tripled for large animals like horses, mules, buffaloes, and camels. Overall, these revisions acknowledge that static rates lose their adequacy over time due to inflation. Without revision, families affected by human–wildlife conflict would face an even heavier burden as medical treatment and replacement costs rise. However, some gaps remain. For instance, the compensation rate for grievous injuries remained unchanged, even though healthcare costs have risen steadily. This underlines the need for regular, comprehensive reviews of compensation policies to ensure that support provided to affected communities remains meaningful in real terms.

During in-person interviews with local inhabitants, it was found that though the compensation policies exist, there is a lack of awareness among people. It was also observed that even when people were aware of such policies, they usually refrained from applying for compensation, as the procedure and the additional associated costs involved were sometimes higher than the compensation received. Some respondents refrained due to past experiences of delay in receiving compensation. Based on our analysis, we suggest that continuous awareness programs regarding the application procedure and benefits of applying for compensation should be conducted in the villages closer to the forested area or high-conflict zones to encourage locals to apply for compensation. Ensuring timely reimbursement of compensation will improve public trust in the compensation scheme. These efforts will be effective in changing people's perception of the compensation schemes and promoting reporting of conflict cases.

Limitations

Despite providing valuable insights, this study has certain limitations:

- Data Constraints – The study relied on departmental records from four forest divisions and a limited number of resident interviews. Incomplete official records or underreporting by affected individuals could have led to an underestimation of conflict cases.
- Potential Biases – Response bias in interviews, where participants may provide socially desirable answers, might have influenced the findings.
- Unaccounted Conflict Cases – Attacks on dogs were frequently mentioned during interviews, but were not included in the study, as compensation schemes do not cover them. This suggests that the actual level of HC may be higher than reported.

Conclusion

The present study examined the extent and patterns of human–carnivore conflict (HCC) in the Kangra district of Himachal Pradesh. Leopards and black bears are widely distributed across the state (Sharma, 2024 a & b), and both species are frequently involved in conflicts with humans. However, this study revealed a pronounced disparity in conflict frequency, with leopards accounting for 90.05% of reported cases, while black bears contributed only 9.95%. This difference may be attributed to the leopards' wider distribution and their greater spatial overlap with human settlements and livestock, resulting in more frequent encounters (Charoo *et al.*, 2011). On the contrary, a low bear conflict rate may reflect their more localized distribution and differing foraging preferences. Apart from the livestock and human attacks, crop depredation is the most common type of human-bear interaction reported (Charoo *et al.*, 2011; Rawal *et al.*, 2024). Seasonal variations also influenced the conflict patterns. Leopard depredation was highest during summer and monsoon months, while black bear attacks peaked in autumn, particularly during October and November. This seasonal increase in bear-related incidents coincides with their pre-hibernation foraging period when they actively search for food in upper-altitude regions (Bashir *et al.*, 2018). These findings align partially with previous studies; for instance, Naha *et al.* (2018) reported peak leopard attacks in Pauri Garhwal between March and July, indicating regional differences possibly driven by local ecological and climatic factors. We reported spatial variation in conflict intensity across forest divisions. The Nurpur and Palampur FD recorded the highest number of leopard attacks, likely due to their connectivity with neighboring conflict-prone regions such as Chamba, Hamirpur, and Mandi Districts (Kumar & Chauhan, 2011; Athreya, 2015). Such landscape connectivity enables leopards to move freely across administrative boundaries, contributing to the persistence of conflicts. Livestock rearing—particularly of goats, sheep, and cattle—forms the backbone of the local economy, especially among the Gaddi community (Hill, 2021). However, a steady decline in livestock numbers between 1997 and 2019, coupled with increasing predator attacks, has intensified socio-economic challenges in the region (Sharma *et al.*, 2022). It is important to note that the present study primarily relied on conflict cases reported by local residents, excluding data from migratory pastoralists, which may limit the completeness of conflict estimates. Future research should focus on understanding the migratory patterns of pastoralist communities and their livestock to identify specific risks associated with seasonal movement. In addition, integrating community-based conservation strategies—such as improved compensation schemes, livestock insurance, and the use of predator deterrents—could play a vital role in reducing conflicts. Effective management of human–wildlife conflict in Kangra will require an approach that simultaneously considers ecological, spatial, and socio-economic dimensions to promote coexistence and long-term conservation outcomes.

Recommendations

The increasing trend in HCC, particularly with leopards, highlights the need for proactive management strategies. Strengthening compensation mechanisms, implementing community-based mitigation measures, and further research on pastoralist vulnerabilities could help reduce conflicts. Future studies should also consider larger sample sizes and alternative data sources, such as camera traps and GPS tracking, to improve conflict documentation. HCC varies across different spatial and temporal scales, making it impractical to adopt a single, universal mitigation strategy. Therefore, location-specific and species-specific measures must be developed to enhance conflict management efforts. A multi-pronged approach integrating habitat conservation, livestock protection, and community involvement is essential for long-term conflict mitigation. Future research should also focus on developing sustainable coexistence models for human and wildlife populations.

TO DOWNLOAD SUPLEMENTARY MATERIAL, CLICK **HERE.**

Acknowledgment

We are thankful to the staff of the respective Divisional Forest Offices, Himachal Pradesh for helping us obtain reliable information for this investigation. Moreover, we are grateful to the locals of the region for sharing conflict-related information during the interviews. We are also grateful to the Council of Scientific and Industrial Research for providing a Research fellowship to the first author. We are also thankful to the administration of the Central University of Jammu for providing the necessary administrative and laboratory support.

CONFLICT OF INTEREST

The authors declare no competing interests.

DATA AVAILABILITY

The data supporting the findings of this study are available from the author upon reasonable request.

AUTHOR CONTRIBUTIONS

All authors contributed to the study design. Data collection and analysis were performed by NM. The idea was convinced by both authors (NM, VS). The first draft of the manuscript was written by NM. VS suggested the necessary modification in the first draft of the manuscript. All authors read and approved the final manuscript.

References

Athreya, Vidya (2015). *Study of human leopard conflict in Himachal Pradesh.* An interim report-Wildlife Conservation Society-India and Wildlife Wing, Forest Department, Government of Himachal Pradesh.

Bashir, T., Bhattacharya, T., Poudyal, K., Qureshi, Q., & Sathyakumar, S. (2018). Understanding patterns of distribution and space-use by *Ursus thibetanus* in Khangchendzonga, India: Initiative towards conservation. *Mammalian Biology*, 92(1), 11-20. https://doi.org/10.1016/j.mambio.2018.04.004

Bhardwaj, S., Thakur, S., Singh, A. P. & De, K. (2024). Livestock Depredation Pattern by Common Leopard: A Case Study from Great Himalayan National Park Conservation Area. *National Academy Science Letters*, 1-5. https://doi.org/10.1007/s40009-024-01470-9

Bryhn, A. C. & Dimberg, P. H. (2011). An operational definition of a statistically meaningful trend. *PLoS One*, 6(4), e19241. https://doi.org/10.1371/journal.pone.0019241

Office of the Registrar General & Census Commissioner, India (2011). Census of India 2011: A-01: Number of villages, towns, households, population and area (India, states/UTs, districts and Sub-districts) - 2011. *Census of India*. Census tables | Government of India [Access on 29/09/2023]

Charoo, S. A., Sharma, L. K., & Sathyakumar, S. (2011). Asiatic black bear–human interactions around Dachigam National Park, Kashmir, India. *Ursus*, 22(2), 106-113. https://doi.org/10.2307/41304062

Chauhan, N. P. S. & Rajpurohit, K. S. (1996). *Study of animal damage problems in and around protected areas and managed forest in India Phase I: Madhya Pradesh, Bihar and Orissa.* Wildlife Institute of India, Dehradun, India.

Chauhan, N. P. S., Kavita, A. & Kamboj, N. (2002). *Leopard–Human Conflicts in Pauri, Thailisen, Chamoli and Pithoragarh: Project Report.* Dehradun, India: Wildlife Institute of India.

Das, C. S. (2018). Pattern and characterisation of human casualties in Sundarban by Tiger attacks, India. *Sustainable Forestry*, 1(1). https://doi.org/10.24294/sf.v1i2.873

Distefano, E. (2005). *Human-Wildlife Conflict worldwide: collection of case studies, analysis of management strategies and good practices.* Food and Agricultural Organization of the United Nations (FAO), Sustainable Agriculture and Rural Development Initiative (SARDI), Rome, Italy. Available from: FAO Corporate Document repository. http://www.fao.org/documents

Gemeda, D. O. & Meles, S. K. (2018). Impacts of human-wildlife conflict in developing countries. *Journal of Applied Sciences and Environmental Management*, 22(8), 1233-1238. https://doi.org/10.4314/jasem.v22i8.14

Hill, C. M. (2021). Conflict is Integral to Human-Wildlife Coexistence. *Frontiers in Conservation Science*, 2, 734314. https://doi.org/10.3389/fcosc.2021.734314

Forest Survey of India (2021). *India State of Forest Report 2021.* Forest Survey of India (Ministry of Environment Forest and Climate Change), Kaulagarh Road, Dehradun, India. ISBN 978-81-950073-1-8

Kichloo, M. A., Sohil, A. & Sharma, N. (2024). Living with leopards: an assessment of conflict and people's attitudes towards the common leopard *Panthera pardus* in a protected area in the Indian Himalayan region. *Oryx*, 58(2), 202-209. https://doi.org/10.1017/S0030605323001278

Kumar, D., & Chauhan, N. P. S. (2011). Human-leopard conflict in Mandi district, Himachal Pradesh, India. *Julius-Kühn-Archiv*, (432), 180.

Madhusudan, M. D. (2003). Living Amidst Large Wildlife: Livestock and Crop Depredation by Large Mammals in the Interior Villages of Bhadra Tiger Reserve, South India. *Environmental Management*, 31(4), 466–475. https://doi.org/10.1007/s00267-002-2790-8

Mahajan (2020). *Human-wildlife conflict on rise in Himachal Pradesh.* The pioneer. https://www.dailypioneer.com/2020/state-editions/human-wildlife-conflict-on-rise-in-himachal-pradesh.html

Mohanta, R. & Chauhan, N. P. S. (2014). Anthropogenic threats and its conservation on Himalayan Brown Bear (*Ursus arctos*) habitat in Kugti wildlife sanctuary, Himachal Pradesh, India. *Asian Journal of Conservation Biology*, 3(2), 175-180.

Naha, D., Sathyakumar, S., & Rawat, G. S. (2018). Understanding drivers of human-leopard conflicts in the Indian Himalayan region: spatio-temporal patterns of conflicts and perception of local communities towards conserving large carnivores. *Plos one*, 13(10), e0204528. https:// doi.org/10.1371/journal.pone.0204528

QGIS.org (2021). QGIS Geographic Information System. Open-Source Geospatial Foundation Project. http://qgis.org

Rathore, B. C. & Chauhan, N. P. S. (2014). The food habits of the Himalayan Brown Bear *Ursus arctos* (Mammalia: Carnivora: *Ursidae*) in Kugti Wildlife Sanctuary, Himachal Pradesh, India. *Journal of Threatened Taxa*, 6(14), 6649-6658. https://doi.org/10.11609/JoTT.o3609.6649-58

Rawal, A. K., Timilsina, S., Gautam, S., Lamichhane, S., & Adhikari, H. (2024). Asiatic black Bear–Human conflict: A case study from Guthichaur rural municipality, Jumla, Nepal. *Animals*, 14(8), 1206. https://doi.org/10.3390/ani14081206

Sharma, A., Parkash, O. & Uniyal, S. K. (2022). Moving away from transhumance: The case of Gaddis. *Trees, Forests and People*, 7, 100193. https://doi.org/10.1016/j.tfp.2022.100193

Sharma, L. K. (2024a). *Population estimation and assessment of human-wildlife conflicts for conservation and management planning of Common Leopard and Asiatic Black bear in Himachal Pradesh.* p.61.

Sharma, L. K. (2024b). *Human-Wildlife Conflict Management Baseline Survey and development of comprehensive strategy for its mitigation in selected district of Himachal Pradesh*, Final Technical Report, Zoological Survey of India and Himachal Pradesh Forest Department. p.127

Sharma, M., Thakur, D. & Thakur, A. (2022). Dynamics of livestock population in Himachal Pradesh. *Indian Journal of Dairy Science*, 75(1). https://doi.org/10.33785/IJDS.2022.v75i01.015

Sharma, P., Chettri, N. & Wangchuk, K. (2021). Human–wildlife conflict in the roof of the world: Understanding multidimensional perspectives through a systematic review. *Ecology and evolution*, 11(17), 11569-11586. https://doi.org/10.1002/ece3.7980

Sharma, R. K., Gupta, A., Singh, R. Sripal, R., Nagpal, T., Rajendran, T. (2020). *Human-Wildlife Conflict Management Strategy in Pangi, Lahaul, and Kinnaur Landscapes, Himachal Pradesh.* GEF-GoI-UNDP SECURE Himalaya Project.

Suryawanshi, K. R., Bhatnagar, Y. V., Redpath, S. & Mishra, C. (2013). People, predators and perceptions: patterns of livestock depredation by snow leopards and wolves. *Journal of Applied Ecology*, 50(3), 550-560. https://doi.org/10.1111/1365-2664.12061

ISSN (Online): 3048-7803
JWLS
Volume 2, Issue 4 (December 2025)

TYPE Short Communication

Status and ecological significance of *Terminalia arjuna* (Roxb.) Wight & Arn., a keystone species in the riparian forest of Moyar River valley in Mudumalai Tiger Reserve, Southern India.

Iyanar Sekar[#1], Thirumurugan Vedagiri[*#1,3], Malavika S Nair[1], Thekke Thumbath Shameer[1], Siva Ranjani S[1], Arunkumar P[2] & Senbagapriya S[1]

[1] Advanced Institute for Wildlife Conservation, Tamil Nadu Forest Department, Vandalur, Chennai, Tamil Nadu, 600 048, India
[2] Masinagudi Division, Mudumalai Tiger Reserve, Tamil Nadu
[3] Department of Botany, Madras Christian College (Autonomous), Tambaram East, Chennai 600 059, India
[#] Joint first authors

DIAMOND OPEN ACCESS Crossref Check for updates

EDITED BY
Chandra Prakash Kala
Indian Institute of Forest Management, Bhopal, India.

*CORRESPONDENCE
Vedagiri Thirumurugan
thirumurugan771@gmail.com
adlpccf.aiwcrte@tn.gov.in

RECEIVED 02 July 2025
ACCEPTED 12 September 2025
ONLINE EARLY 28 October 2025
PUBLISHED 22 December 2025

CITATION
Sekar, I., Vedagiri, T., Nair, M. S., Thekke, T. S., Ranjani, S. S., Arunkumar, P. & Senbagapriya S. (2025). Status and ecological significance of *Terminalia arjuna* (Roxb.) Wight & Arn., a keystone species in the riparian forest of Moyar River valley in Mudumalai Tiger Reserve, Southern India. *Journal of Wildlife Science,* 2(4), 133-140.
https://doi.org/10.63033/JWLS.RKVL6975

FUNDING
This work was supported by the Mudumalai Tiger Conservation Foundation, Udhagamandalam (Proc. No.151/2023 (MTCF) for funding the project

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Abstract

Terminalia arjuna (Roxb.) Wight & Arn. is a keystone species that supports vital ecosystem services in riparian forest and associated faunal communities in the Moyar River valley. The study assessed the ecological significance of these trees in five forest ranges of Mudumalai Tiger Reserve (MTR). A total of 10,127 trees (92.9% live and 7.1% dead) were enumerated. Its distribution ranged from 292m to 933m AMSL with high basal area (7,612.26 m^2), biomass (93,589.6 t) and carbon stock (46,794.8 t). We observed nests of White-rumped vulture *Gyps bengalensis* (n= 56) and Malabar giant squirrel *Ratufa indica* (n= 157) on these trees. This study highlights the importance of conserving large trees like *T. arjuna* due to their ecological significance and role in climate change mitigation.

Keywords: Carbon stock; Malabar giant squirrel, nesting sites; Western Ghats; White rumped vulture.

Introduction

Terminalia arjuna (Roxb.) Wight & Arn., locally called as "Marutham" or "Neer Marudhu", is an endemic plant species to the Indian subcontinent with a severely fragmented population (Sunil *et al.,* 2019; WFO 2025). *T. arjuna* trees are often considered as 'Large old trees' due to their large size, associated faunal communities and their invaluable ecosystem services. Large old trees are often referred to as "Keystone structures", supporting other biodiversity, livelihood of local community by offering economic and social benefits and contributing significantly to the climate change mitigation by carbon sequestration and storage (Manning *et al.,* 2006; Lindenmayer *et al.,* 2012; Lindenmayer & Laurance, 2017, Kauppi *et al.,* 2015; Hauck *et al.,* 2023). Large trees serve as shelter and nesting sites and food for many key species such as elephants, tigers, and leopards in tropical dry forest (Manning *et al.,* 2006; Lindenmayer 2017), and their canopies serve as shelters and nesting sites, particularly for raptors (Gibbons & Lindenmayer, 2002; Lindenmayer & Laurance, 2017). The decline of the large trees adversely impacts the ecosystem, and leads to the loss of many associated fauna and flora (Lindenmayer, 2017).

Large old trees hold immense ecological and cultural significance globally, but detailed regional studies on these keystone species, particularly from Asia, are negligible (Bar-Ness, 2013; Arzoo *et al.,* 2022). A few studies have focused on specific landscapes, *e.g.,* areas along the River Cauvery in Karnataka (Sunil *et al.,* 2010; Nagaraja *et al.,* 2014; Sunil *et al.,* 2019). *T. arjuna* plays a pivotal role in diverse ecosystems, underscoring its importance (Nagaraja *et al.,* 2014; Sunil *et al.,* 2019). A broader understanding of its ecology, distribution pattern, and carbon storage capacity is crucial but lacking, especially from India. Regional studies are very limited, especially in critical wildlife habitats.

The Moyar River Valley (MRV), located within Mudumalai Tiger Reserve (MTR), Tamil Nadu, is a dry tropical landscape, renowned for its rich biological diversity supporting numerous flagship species of flora and fauna. It is also known as one of the prime landscapes supporting the populations of tigers and elephants in the country (Thirumurugan *et al.,* 2021; Qureshi *et al.,* 2023; PE-MoEFCC-WII, 2024). Moreover, this landscape supports substantial vulture nesting colonies, particularly on the Segur plateau and MRV, where the *T. arjuna* trees are abundant along the riparian stretches. Sathya & Jayakumar, (2017) and Nagarajan & Bhaskar (2023) mapped the distribution of *T. arjuna* in MRV. Nesting population of vultures on *T. arjuna* trees have been previously studied by Venkitachalam & Senthilnathan, (2018), Anoop *et al.,* (2018), and Samson *et al.,* (2024) in MRV. Though there is a limited number of studies for understanding the status, distribution, and ecological significance of these key species in riverine habitats, including studies on associated or dependent faunal communities. Hence, the present study focused on i) assessing the population, distribution, and carbon storage of *T. arjuna* and ii)enumerating its ecological role and importance by documenting the nesting observations of White-rumped vulture (*Gyps bengalensis*) and Malabar giant squirrel (*Ratufa indica*) in the riparian forest of Moyar River valley in MTR.

Study Area

The Mudumalai Tiger Reserve (MTR) (Figure 1A) covers an area of 688.59 km², with its core area alone spanning 321 km² (NTCA 2025), situated in the Nilgiris Mountain of the Western Ghats and shares borders with other protected areas such as Bandipur Tiger Reserve, Sathyamangalam Tiger Reserve (STR), and Wayanad Wildlife Sanctuary (Baskaran & Boominathan, 2010). MTR is an integral part of Nilgiri Biosphere Reserve, the first Biosphere Reserve recognized by UNESCO in India (Daniels 1993), renowned for its rich biodiversity, and the diverse landscape experiences (Pushpakaran & Gopalan, 2014). According to Champion & Seth (1968), forest types of MTR is classified as Southern Tropical Dry Thorn Scrub Forest (6A/DS1), Southern Tropical Dry Deciduous Forest (5A/C3), Southern Tropical Moist Mixed Deciduous Forest (3B/C2), Southern Tropical Semi-Evergreen Forest (2A/C2), Moist Bamboo Brakes (2E3), and Tropical Riverine Forest (5/B1 & 4E/RS1). The present study was conducted in five forest ranges, such as Segur, Masinagudi, Nilgiri Eastern Slopes (NES), Theppakadu, and Singara in MTR.

Methods

The present study assesses the population status, distribution, and ecological significance of *T. arjuna* using a field inventory method (Avery & Burkhart 2015). During the study period, all individual trees on either side of the Moyar River and its tributaries (within 200-300 m perpendicular distance along the total stretch of 77.6 km length of river) in the Mudumalai Tiger Reserve, Tamil Nadu, were measured between February and July 2024. The status of each tree was marked either as live or dead, and the tree circumference was measured (in cm.) at girth at breast height (GBH) (1.37 m). Each tree was marked with a unique code to avoid double-counting and color-coded for identity. Geo-coordinates for all trees, photographs, and critical observations were recorded, and associated flora and fauna were documented. The flora (both native and invasive species) and faunal communities were documented within a 5-meter radius. Direct, indirect signs of faunal communities, nesting of birds and mammals, particularly the Indian giant squirrel and White-rumped vulture nests, were identified and documented. Vultures' nests were identified based on characteristics described by Venkitachalam & Senthilnathan (2018), Anoop *et al.,* (2018), and Samson & Ramakrishnan (2020). Nesting of the Indian Giant Squirrel was identified based on Baskaran *et al.,* (2011).

The basal area of each tree is a key indicator for tree density, biomass, and carbon storage (Babst *et al.,* 2014). Such indicators were calculated based on measurements using the standard formulas:

(1) Diameter at Breast Height (DBH) =
Girth at Breast Height (GBH)/π, and basal area (in cm. sq.) = π(DBH×DBH)/4 (Hein & Dhote, 2006; Thompson *et al.,* 2006). Trees were grouped into DBH classes and elevation classes (200 m to 1000 m) to assess age structure and vertical distribution.

(2) The carbon stock methods were estimated using standard protocols (Cairns *et al.,* 1997, IPCC, 2003; 2005; Chave *et al.,* 2009).

(3) Above-Ground Biomass (AGB) refers to the total mass of living plant material, including the entire shoot, branches, leaves, fruits, and flowers (Chave *et al.,* 2005). AGB (kg tree^{-1}) = $\rho \times \exp(-0.667 + 1.784 \ln(D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3)$. Where ρ is the wood density, D is DBH.

(4) Wood density of *T. arjuna* is calculated as 0.94 kg/m^3 by Zanne *et al.,* (2009).

(5) The Below-Ground Biomass (BGB) is the biomass of live roots, excluding fine roots having <2 mm diameter (Cairns *et al.,* 1997; IPCC, 2003) and BGB (kg tree^{-1}) = AGB × 0.26 (IPCC, 2005).

(6) Total biomass or living plant material in both above and below the soil was calculated based on the formula: Total biomass (kg tree^{-1}) = AGB (kg tree^{-1}) + BGB (kg tree^{-1}).

(7) Formula for total carbon stored in a tree: Carbon (kg tree^{-1}) = 0.5 × Total Biomass (kg tree^{-1}); wherein, 0.5 is a default conversion factor as 50% of its biomass is considered as carbon (IPCC, 2005).

(8) The total carbon dioxide (CO_2) sequestration by a tree was assessed based on the formula: CO_2 sequestered (kg tree^{-1}) = 3.67 × Carbon (kg tree^{-1}); wherein, 3.67 is the factor for CO_2 sequestration in trees (IPCC, 2005).

During the survey in Moyar, a total of 77.6 km distance was covered, and *T. arjuna* tree encounter rate (average number of trees per km) was estimated along 56 km stretch between 11.60828°N, 76.61684°E and 11.52538°N, 77.01463°E. The assessment mainly focused on the mainstem river of MTR, while minor streams and tributaries were excluded due to uneven distribution within these areas, and the survey was restricted to the state. Mapping of the spatial distribution of *T. arjuna* was carried out using ArcMap (Version 10.8). Data analysis and summarization (DBH and streams) were performed using R software (version 4.2.3, R core team 2024).

Results and Discussion

A total of 10,127 trees were counted in the entire study area (Figure 1B), out of which 9,415 trees were live (92.9%) and 712 trees were dead (7.1%) (Table 1). A total of 3,454 trees were recorded in the 56 km stretch of the mainstem of the Moyar river, wherein the tree encounter rate was estimated as 61.6 trees per km. (61.6±1.04 SE) *T. arjuna* is widely distributed in the riparian ecosystem along the MRV. It ranges from the highest elevation of 933 m to the lowest elevation of 292 m above mean sea level (AMSL) in MTR. DBH varied from 5 cm to 359 cm. *T. arjuna* covered a substantial total basal area of 7612.26 m², and it is stocking a total of 46794.8 tons carbon (Table 1). The tree presence and population in the present study are comparatively higher than the previous studies (Sunil *et al.,* 2010; Nagaraja *et al.,* 2014; Sunil *et al.,* 2019) in the neighboring landscapes.

The present study exhibits an exceptional carbon storage capacity of *T. arjuna* due to its large size. This large tree species

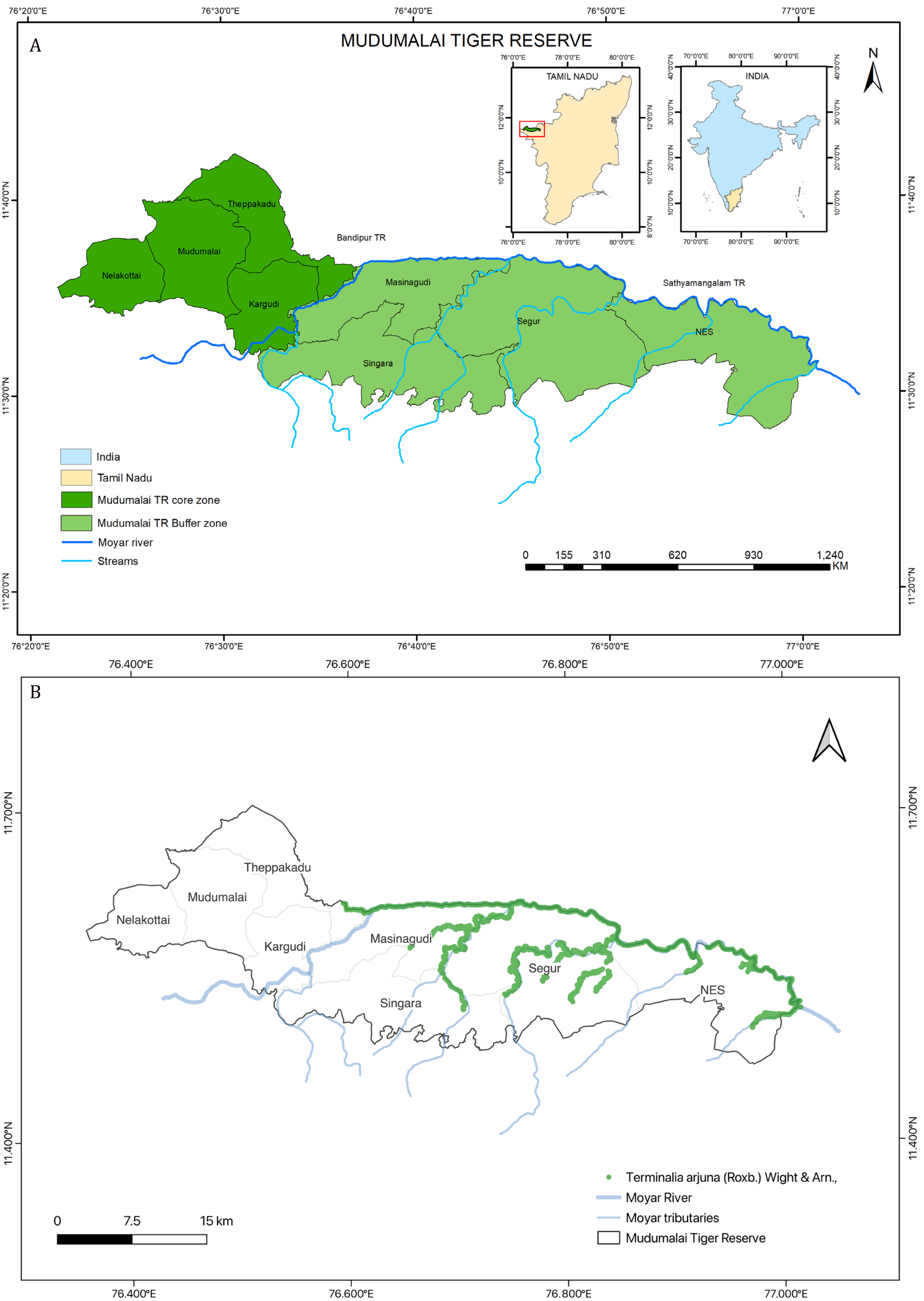


Figure 1 A: The study area map included different forest ranges along Moyar river and its tributaries in Mudumalai Tiger Reserve, Tamil Nadu. B: The distribution of *T. arjuna* trees along Moyar river in the Mudumalai Tiger Reserve.

Table 1: Details of quantitative summary of *T. arjuna* trees in the study area.

Habit		**Estimate**
Total individuals enumerated		10127
Tree condition	Live	9415
	Dead	712
Tree distribution elevation range		292–933m AMSL
Diameter at Breast Height range		5-359 cm
Average Diameter at Breast Height		74.35 cm
Total Basal area		7612.26 m^2
Above Ground Biomass		74277.5 t
Below Ground Biomass		19312.1 t
Total Biomass		93589.6 t
Carbon stock		46794.8 t
Carbon dioxide sequestration		171737 t
Average number of individuals in a 1 km stretch of *T. arjuna* habitat along Moyar River valley (Tamil Nadu portion)		61.6 individuals/ Km (61.6±1.04 SE)

with a high basal area contributes significantly to the potential carbon storage capacity in the MRV. The total carbon stock storage capacity of 93,589.6 tons (t) of total biomass amounting to 1,71,737 t of carbon dioxide sequestration in a single river valley of 77.6 km, highlights its significant role in mitigating climate change. Many other studies have also highlighted that these trees store large quantities of biomass and accumulate carbon in the riparian ecosystems (Chauhan *et al.,* 2019; Srinivas & Sundarapandian 2019; Kujur *et al.,* 2021).

Terrain type plays a significant role in tree distribution. Flat and stable terrain supports high tree distribution, as these areas have a favorable microclimate for growth and regeneration with greater soil depth and moisture retention. In contrast, the tree density was lower in stretches with rapid elevation change. The present study exhibits a healthy population with low mortality. Though, there are certain observations of drying branches and defoliation due to parasites and invasive species. The highest tree population was observed in the Segur Range (N= 4872), hn followed by Masinagudi Range (N= 2451). The lowest number of trees was observed in Singara Range (N= 53). Masinagudi and NES ranges (N= 1904) exhibited a fair presence of *T. arjuna* with very low tree mortality rate (<5%). On the other hand, no tree deaths were recorded in Theppakadu range, where all 135 individuals are alive (Figure 2). All five forest ranges showed a significant variation in different elevation ranges (Supplementary Figure S1). The highest number of trees was recorded in the elevation range between 300 m and 600 m AMSL (N=6622). Tree abundance was high in the elevation range between 400 m and 1000 m AMSL (N=7532), and *T. arjuna* had a widespread elevational distribution in Segur Forest Range. Tree Presence was low in the elevation range between 200 and 300 m AMSL (n = 159), observed in NES Range (Supplementary Figure S1).

Live trees had a similar median DBH (76.13±0.52) with dead trees DBH (75.18±1.86) in all the streams (Supplementary Figure S2), except Segurnallah stream and Siriyurallah stream. The Iyanmathi stream showed the largest range of DBH (11 to 286) for live trees (N = 56). Significantly, some of the trees in the Segur nallah stream and Siriyurallah stream had attained maximum DBH (318 and 259) before mortality. In some other streams, the median DBH of the dead trees was smaller than the DBH of the live trees, which indicates the presence of higher mortality in the smaller size classes. We noted that the DBH was almost equal for both live and dead trees in Edakkarapallam, Mukkuruthipallam, and Poochapallam streams (Supplementary Figure S2).

The number of trees in various size classes showed significant variation amongst the forest ranges. Masinagudi, Segur, and Theppakadu ranges showed an inverted 'J' shaped curve, indicating a healthy, regenerating forest with a considerable number of young trees (Supplementary Figure S3). In contrast, NES and Singara ranges showed a decline in the presence of smaller size class trees (5-50 cm DBH), indicating that these areas have slow recruitment and possible hindrance in the establishment of young trees. As the total number of trees in Singara range was too small (N= 53) to draw any conclusion, the situation of low recruitment in smaller size classes in the NES range needs further investigation. Invasive species such as *Prosopis juliflora*, *Lantana camara*, *Parthenium hysterophorus*, and *Chromolaena odorata* have caused severe degradation of native ecosystems in some ranges of STR (Sivakumar *et al.,* 2018). Presence of anthropogenic pressures such as lopping, cattle herbivory on edges, trampling of young plants, and severe invasion of *P. juliflora*, in the NES range may have led to the lower number of young trees with 0-50 cm of DBH. Several studies have documented the negative impact of *P. juliflora* in the Moyar river valley landscape (Sathya & Jayakumar 2017; Maheshnaik & Baranidharan 2018; Rajput *et al.,* 2019; Arandhara *et al.,* 2021).

T. arjuna has direct and indirect ecological associations with several floral and faunal communities in the riparian ecosystem (Figure 3). We observed association of *T. arjuna* with the plant species like: *Pongamia pinnata* (L.) Pierre, *Diospyros malabarica* (Desr.) Kostel. and *Syzygium cumini* (L.) Skeels (Supplementary Table T1), and wild animal species such as: *Axis axis* (Erxleben, 1777), *Crocodylus palustris* (Lesson, 1831), and *Elephas maximus indicus* Cuvier, 1798 (Supplementary Table T2). The Bengal tiger (*Panthera tigris tigris*) and leopards (*Panthera pardus*) use *T. arjuna* trees for sharpening their claws, and many mammals use the tree shade and rest beneath the trees; . These trees act as one of the most preferred nesting sites of Honey bees, as it provides space for large honeycombs, which also indicates their importance to pollinators. Tusk marks of the Indian elephant (*Elephas maximus indicus*) on these trees, basking of marsh crocodiles (*Crocodylus palustris*) near these trees in riparian habitat, the termites moulding on the dead tree trunks, and sloth bears (*Melursus ursinus*) feedings on these termites shows vital ecological interactions between animals and *T. arjuna*.

https://doi.org/10.63033/JWLS.RKVL6975

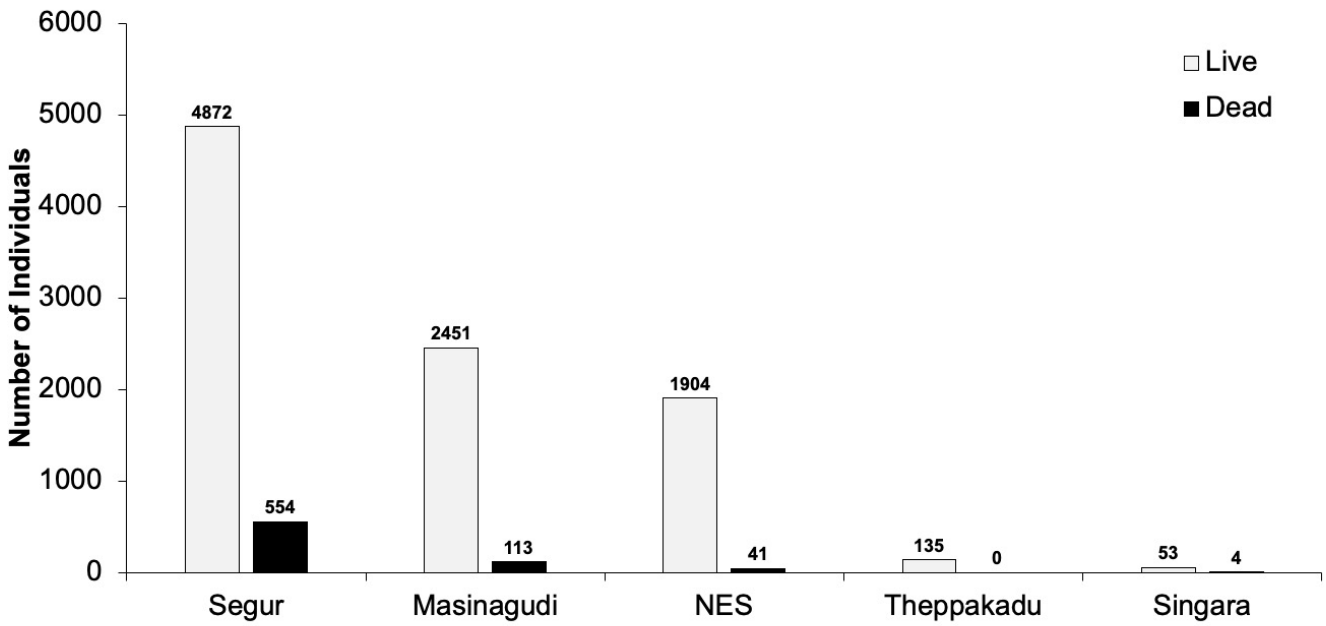


Figure 2: Distribution of live and dead *T. arjuna* trees in different forest ranges of the Mudumalai Tiger Reserve.

Figure 3: The direct and indirect sightings of faunal species associated with the *T. arjuna* tree.
a) White-rumped vulture (*Gyps bengalensis*) soaring.
b) The White-rumped vulture nesting and roosting on the *T. arjuna* tree.
c) Malabar giant squirrel (*Ratufa indica*).
d) A Malabar giant squirrel nest on *T. arjuna* tree.
e) Tiger claw scratch marks on the *T. arjuna* tree trunk, likely indicating territorial marking and claw sharpening behaviour.
f) Spot-bellied eagle-owl (*Bubo nipalensis*) roosting on *T. arjuna* tree.

 https://doi.org/10.63033/JWLS.RKVL6975

During the study, 56 nests of White-rumped vulture, a critically endangered species and 157 nests of Malabar giant squirrel were observed on *T. arjuna* trees in the Mudumalai Tiger Reserve (Figure 4, Supplementary Table T3). The observed 157 Malabar giant squirrel nest were higher than the earlier study (N = 83; Baskaran *et al.*, 2011). Sightings of White-rumped vultures are high in the Segur followed by Masinagudi ranges, whereas its nests were recorded as high in the Segur range (N = 44) followed by Masinagudi range (N = 13). Only one nest of White-rumped vulture was observed on a different tree species, Mitragyna parvifolia (Roxb.) Korth. Samson & Ramakrishnan (2020) also, recorded that the White-rumped vultures nests (N = 83) with preference of 97% *T. arjuna* trees and 3% nest on the trees of Spondias mangifera Willd. to build their nest; *T. arjuna* is preferred for shelter mainly because of its tall, large crown and wide canopy that provide protection from predators (Samson & Ramakrishnan 2020; Arockianathan, 2020).

The highest number of Malabar giant squirrel's nests on *T. arjuna* trees was observed from Segur range (N= 74), and the lowest was observed from Singara range (N= 01). The results were similar to earlier studies, *e.g.* Samson & Ramakrishnan (2020) observed 68 vulture nests, and Arockianathan (2020) observed 279 nests of Malabar giant squirrel in MTR.

Out of the total enumerated 10,127 individual trees in the present study, 92.9% were live and distributed in a wider elevational range between 292 m – 933 m, indicating a healthy population and widely fragmented in these landscapes. Carbon storage of 46,794.8 tons by these trees exhibits their importance in preventing CO_2 release and climate change mitigation. Limited branch death and defoliation showed its resilience to parasites, invasive species, and other disturbances. Observation of a large number of nesting sites of birds and mammals on *T. arjuna* showed its strong contribution to the ecological integrity.

This study identified and quantified some of the crucial associations of *T. arjuna*, providing crucial habitat for several native plant species and shelter and other services to wildlife in riparian areas, highlighting its high ecological significance to the landscape (Nagaraja *et al.,* 2014; Ramakrishnan *et al.,* 2014; Sunil *et al.,* 2019; Thirumurugan *et al.,* 2021; Nagarajan & Bhaskar, 2023). Though it is essential to adopt policies and management measures to invasive species, *P. juliflora*, in the Segur and NES forest ranges, as these invasions potentially disrupt the regeneration of *T. arjuna*. Anthropogenic disturbances should be restricted, and some of the activities like pollution and dumping waste must be regulated, particularly along the Segur and Masinagudi ranges, where the higher tree mortality rates were recorded. Establishing long-term monitoring plots to study factors affecting tree mortality and regeneration is highly recommended to conserve these large old heritage trees in the riparian ecosystems of Mudumalai Tiger Reserve.

TO DOWNLOAD SUPPLEMENTARY MATERIAL CLICK HERE.

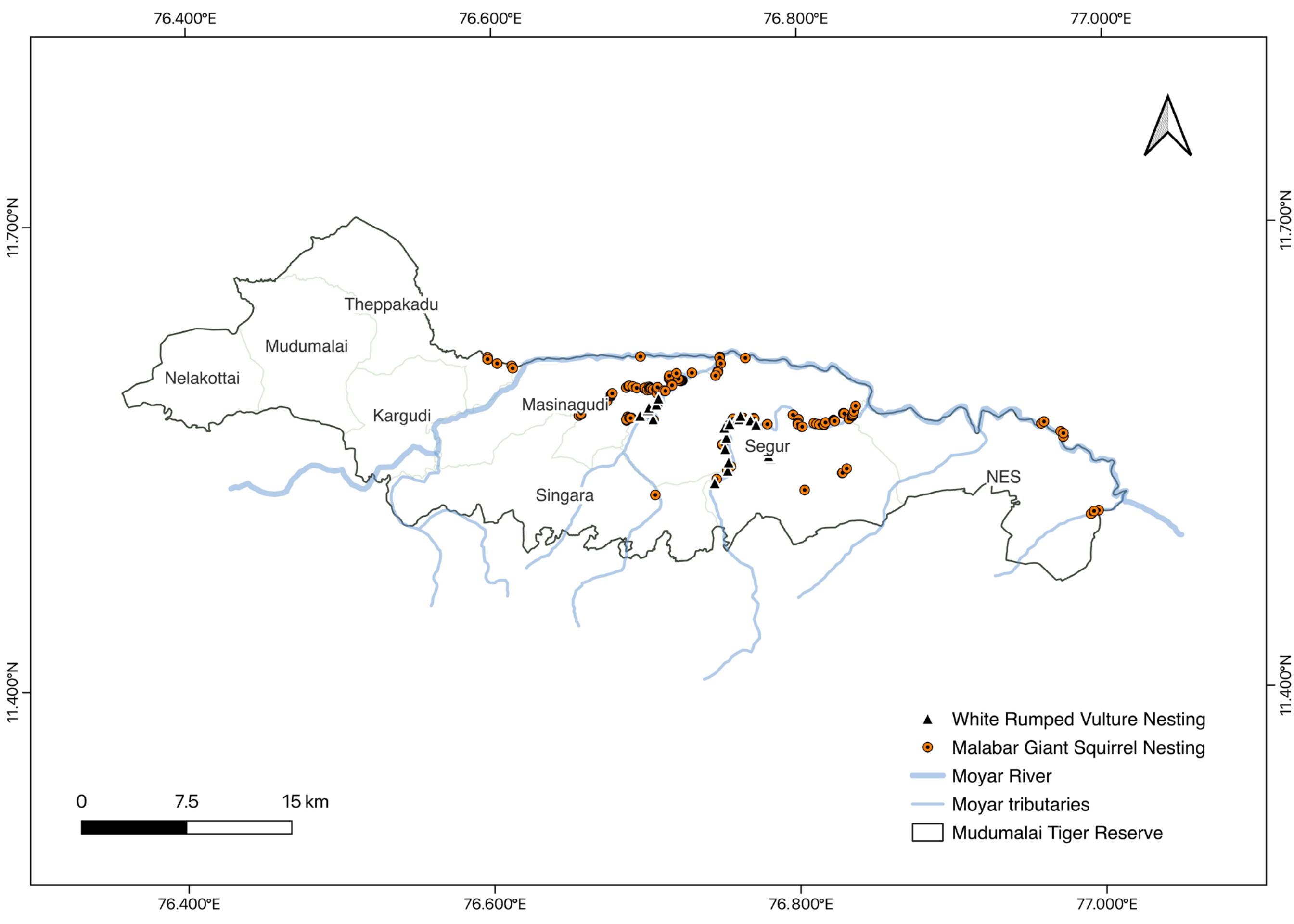


Figure 4: The distribution of White-rumped vultures and giant squirrel nesting sites in the Moyar River valley.

Acknowledgment

We thank the Mudumalai Tiger Conservation Foundation, Udhagamandalam (Proc.No.151/2023 (MTCF) for funding the project. We thank the Tamil Nadu Forest Department, including the PCCF (HoFF), PCCF and Chief Wildlife Warden, Field Director, Deputy Directors for their guidance and the FROs, Field staff, and Anti-poaching watchers of Mudumalai Tiger Reserve, for their support during field sampling. We also thank Dr. Nehru Prabakaran and Mr. Karthy S from the Wildlife Institute of India for their assistance with data analysis and manuscript review. We express our gratitude to Dr. Arokianathan Samson, Centre Manager, BNHS- VCBC, and Dr. Manigandan Selvaraj, SRF, CWS, for guidance with the data collection. We thank our field assistants (Thiru. Saranmoorthi J, Thiru. A. Rishi Kesavan, Thiru. Hemanth Kumar S), field biologist Dr. S. Vimal, and other staff for their help with data collection.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

DATA AVAILABILITY

The data used in the study are available upon request from the corresponding author

AUTHOR CONTRIBUTIONS

T.V.: Data analysis; Writing - Conceptualization; original manuscript; review & editing; Investigation.
I.S.: Data Collection & analysis; Writing - review & editing.
N.M.S.: Data Collection & analysis; Writing - review & editing.
S.T.T.: Writing - review & editing.
S.R.S.: Supervision; Writing - review & editing.
A.P.: Funding; Supervision
S.S.: Funding; Supervision

ORIGINALITY STATEMENT

The submitted research work is original, and we confirm that the manuscript is neither published nor under consideration for publication elsewhere in whole or in part. No generative AI was used for the manuscript.

References

Anoop, N. R., Babu, S., Bharathidasan, S. & Nagarajan, R. (2018). Status of raptors in the Moyar River Valley, Western Ghats, India. *Journal of Threatened Taxa*, 10(10), 12317–12327. https://doi.org/10.11609/jott.3054.10.10.12317-12327

Arandhara, S., Sathishkumar, S., Gupta, S. & Baskaran, N. (2021). Influence of invasive *Prosopis juliflora* on the distribution and ecology of native blackbuck in protected areas of Tamil Nadu, India. *European Journal of Wildlife Research*, 67(3), 48. https://doi.org/10.1007/s10344-021-01485-3

Arockianathan, S. (2020). *Nesting behavior of Indian giant squirrel (Ratufa indica Erxleben, 1777) in Mudumalai Tiger Reserve*, Western Ghats, southern India. In: Mulungu, L. S. (ed.). Rodents, IntechOpen. https://doi.org/10.5772/intechopen.92337.

Arzoo, E., Bhatia, R., Singh, M. C., Singh, L. & Gowthami, G. V. (2022). Conservation of old trees – a review. *Journal of Ornamental Horticulture*, 25(1-2), 97–104. https://doi.org/10.5958/2249-880X.2022.00015.9

Avery, T. E. & Burkhart, H. E. (2015). Forest measurements. Waveland Press.

Babst, F., Bouriaud, O., Alexander, R., Trouet, V. & Frank, D. (2014). Toward consistent measurements of carbon accumulation: A multi-site assessment of biomass and basal area increment across Europe. *Dendrochronologia*, 32(2), 153-161. https://doi.org/10.1016/j.dendro.2014.01.002

Bar-Ness, Y. D., Conservation of Indian heritage trees. *Journal of Ornamental Horticulture*, 2013, 25(1-2), 97–104.

Baskaran, N. & Boominathan, D. (2010). Roadkill of animals by highway traffic in the tropical forests of Mudumalai Tiger Reserve, southern India. *Journal of Threatened Taxa*, 2(3), 753–759. https://doi.org/10.11609/JoTT.o2101.753-9

Baskaran, N., Venkatesan, S., Mani, J., Srivastava, S. K. & Desai, A. A. (2011). Some aspects of the ecology of the Indian Giant Squirrel *Ratufa indica* (Erxleben, 1777) in the tropical forests of Mudumalai Wildlife Sanctuary, southern India and their conservation implications. *Journal of Threatened Taxa*, 3(7), 1899-1908. https://doi.org/10.11609/JoTT.o2593.1899-908

Cairns, M. A., Brown, S., Helmer, E. H. & Baumgardner, G. A. (1997). Root biomass allocation in the world's upland forests. *Oecologia*, 111(1), 1–11. https://doi.org/10.1007/s004420050201

Champion, H. G. & Seth, S. K. (1986). *A Revised Survey of the Forest Types of India, Govt*. India Publication.

Chauhan, S. K., Singh, S., Sharma, S., Sharma, R. & Saralch, H. S. (2019). Tree biomass and carbon sequestration in four short-rotation tree plantations. *Range Management and Agroforestry*, 40(1), 77–82. https://publications.rmsi.in/index.php/rma/article/view/200

Chave, J., Andalo, C., Brown, S., Cairns, M. A., Chambers, J. Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N. *et al.* (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, 145(1), 87–99. https://doi.org/10.1007/s00442-005-0100-x

Chave, J., Coomes, D., Jansen, S., Lewis, S. L., Swenson, N. G. & Zanne, A. E. (2009). Towards a worldwide wood economics spectrum. *Ecology*. Letters, 12(4), 351–366. https://doi.org/10.1007/s00442-005-0100-x

Daniels, R. R. J. (1993). The Nilgiri Biosphere Reserve and its role in conserving India's biodiversity. *Current Science*, 64(10), 706-708. https://www.jstor.org/stable/24122226

Gibbons, P. & Lindenmayer, D. (2002). *Tree Hollows and Wildlife Conservation in Australia*, CSIRO Publishing. https://doi.org/10.1071/9780643090033

Hauck, M., Csapek, G. & Dulamsuren, C. (2023). The significance of large old trees and tree cavities for forest carbon estimates. *Forest Ecology and Management*, 546, 121319. https://doi.org/10.1016/j.foreco.2023.121319

Hein, S. & Dhôte, J. F. (2006). Effect of species composition, stand density, and site index on the basal area increment of oak trees (*Quercus* sp.) in mixed stands with beech (*Fagus sylvatica* L.) in northern France. *Annals of Forest Science*, 63(5), 457–467. https://doi.org/10.1051/forest:2006026

IPCC [Intergovernmental Panel on Climate Change] (2005). *Carbon Dioxide Capture and Storage.* Prepared by working group III of the Intergovernmental Panel on Climate Change.

Kauppi, P. E., Birdsey, R. A., Pan, Y., Ihalainen, A., Nöjd, P. & Lehtonen, A. (2015). Effects of land management on large trees and carbon stocks. *Biogeosciences*, 12, 855–862. https://doi.org/10.5194/bg-12-855-2015

Kujur, E., Jhariya, M. K., Yadav, D. K. & Banerjee, A. (2021). Biomass, carbon storage, and CO_2 mitigation potential of two riparian sites of northern Chhattisgarh, India. *Environmental Earth Sciences*, 80(21), 723. https://doi.org/10.1007/s12665-021-10019-8

Lindenmayer, D. B. & Laurance, W. F. (2017). The ecology, distribution, conservation, and management of large old trees. *Biological Reviews*, 92(3), 1434–1458. https://doi.org/10.1111/brv.12290

Lindenmayer, D. B. (2017). Conserving large old trees as small natural features. *Biological Conservation*, 211, 51–59. https://doi.org/10.1016/j.biocon.2016.11.012

Lindenmayer, D. B., Laurance, W. F. & Franklin, J. F. (2012). Global Decline in Large Old Trees. *Science*, 338(6112), 1305–1306. https://doi.org/10.1126/science.1231070

Maheshnaik, B. L. & Baranidharan, K. V., Impact of invasive alien species-*Prosopis juliflora* on floral diversity of Sathyamangalam Tiger Reserve, Tamil Nadu, India. *Biodiversity International Journal*, 2018, 2(6), 579–585. https://doi.org/10.15406/bij.2018.02.00115

Manning, A. D., Fischer, J. & Lindenmayer, D. B. (2006). Scattered trees are keystone structures – Implications for conservation. *Bio* *logical Conservation*, 132(3), 311–321. https://doi.org/10.1016/j.biocon.2006.04.023

Nagaraja, B. C., Sunil, C. & Somashekar, R. K. (2014). *Protection of Riparian Habitats to Conserve Keystone Species with Reference to Terminalia arjuna – A case study from South India*. In: Grillo, O. (ed.), Biodiversity- The Dynamic Balance of the Planet, IntechOpen. https://doi.org/10.5772/58355

Nagarajan, M. K. & Bhaskar, A. (2023) Plant species diversity in the riparian forests of the Moyar River in southern India. *Journal of Threatened Taxa*, 15(4), 22955–22967. https://doi.org/10.11609/jott.4722.15.4.22955-22967

NTCA [National Tiger Conservation Authority] (2025). *Mudumalai Tiger Reserve: Brief Note*. Retrieved August 6, 2025, from https://ntca.gov.in/assets/uploads/briefnote/mudumalai.pdf

PE-MoEFCC-WII (2024). *Management Effective Evaluation of Elephant Reserves in India*: Pilot Study and Revision of Criteria & Indicators, Project Elephant Division, Ministry of Environment, Forest and Climate Change, Government of India, and Wildlife Institute of India.

Pushpakaran, B. & Gopalan, R. (2014). Distribution of rare and noteworthy Zingibers in Mudumalai Tiger Reserve. *Research Journal of Agricultural and Forestry Sciences*, 2(1), 1–6.

Qureshi Q., Jhala Y. V., Yadav S. P. & Mallick A. (Eds.). (2023), *Status of Tigers in India – 2022: Photo-captured Tigers, Summary Report,* National Tiger Conservation Authority and Wildlife Institute of India, Dehradun, 2023, TR. No./2023/03.

R Core Team (2024). R: *A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.r-project.org

Rajput, N., Baranidharan, K., Vijayabhama, M. & Sawant, A. (2019). Ecological impact of *Prosopis juliflora* on the habitat conditions of blackbuck in Sathyamangalam Tiger Reserve, Tamil Nadu, India. *Methods*, 7(3), 610-615.

Ramakrishnan, B., Kannan, G., Samson, A., Ramkumar, K. & Ramasubramanian, S. (2014). Nesting of White-rumped vulture (Gyps bengalensis) in the Segur Plateau of the Nilgiri North Forest Division, Tamil Nadu, India. *Indian Forester*, 140(10), 1014–1018.

Samson, A. & Ramakrishnan, B. (2020). The critically endangered White-rumped vulture Gyps bengalensis in Segur Plateau, Western Ghats, India: Population, breeding ecology, and threats. *Journal of Threatened Taxa*, 12(13), 16752–16763. https://doi.org/10.11609/jott.3034.12.13.16752-16763

Samson, A., Princy, J. L., Beulahbah, J., Regupathikannan, J., Edward, P. S. & Mionudheen, N. (2024). Raptors in Mudumalai Tiger Reserve, Tamil Nadu, India. Nepalese *Journal of Zoology*, 8(1), 63–70. https://doi.org/10.3126/njz.v8i1.67111

Sathya, M. & Jayakumar, S. (2017). Post-fire regeneration status of tree species in a tropical dry deciduous forest of Southern India. *Journal of Tropical Forest Science*, 29, 305–317. https://www.jstor.org/stable/44272908

Sivakumar, K., Rawat, G. S., Badola, R., Adhikari, B. S. & Kamalakannan, B. (2018). *Study on the ecological and socio-economic impact of invasive species, Prosopis juliflora and Lantana camara, and their removal from forest, common, and fallow land of Tamil Nadu*. Technical Report, Wildlife Institute of India, Dehradun, India.

Srinivas, K. & Sundarapandian, S. (2019). Biomass and carbon stocks of trees in the tropical dry forest of East Godavari region, Andhra Pradesh, India. *Geology, Ecology, and Landscapes*, 3(2), 114–122. https://doi.org/10.1080/24749508.2018.1522837

Sunil, C., Somashekar, R. K. & Nagaraja, B. C. (2019). Influence of *Terminalia arjuna* on the riparian landscapes of the River Cauvery of South India. *Landscape Research*, 44(8), 982–996. https://doi.org/10.1080/01426397.2018.1560400.

Sunil, C., Somashekar, R. K. & Nagaraja, B. C. (2010). Riparian vegetation assessment of Cauvery River basin of South India. *Environmental Monitoring and Assessment*, 170, 545–553. https://doi.org/10.1007/s10661-009-1256-3

The Intergovernmental Panel on Climate Change (IPCC) (2003). *Good practice for land use, land use change and forestry*. Intergovernmental Panel on Climate Change Reports.

Thirumurugan, V., Prabakaran, N., Nair, V. S. & Ramesh, C. (2021). Ecological importance of two large heritage trees in Moyar River valley, southern India. *Journal of Threatened Taxa*, 13(1), 17587–17591. https://doi.org/10.11609/jott.6095.13.1.17587-17591

Thompson, I. D., Ortiz, D. A., Jastrebski, C. & Corbett, D. (2006). A comparison of prism plots and modified point-distance sampling to calculate tree stem density and basal area. N*orthern Journal of Applied Forestry*, 23(3), 218–221. ttps://doi.org/10.1093/njaf/23.3.218

Venkitachalam, R. & Senthilnathan, S. (2018). White-rumped vulture: New features and nest tree characteristics of Gyps bengalensis (Aves: Accipitriformes: Accipitridae) in Moyar Valley of Tamil Nadu, India. *Zoo's Print*, 33(8), 19–25.

WFO (2025). *Terminalia arjuna* (Roxb. ex DC.) Wight & Arn. Published on the Internet; http://www.worldfloraonline.org/taxon/wfo-0000407013 (Accessed on 11 August 2025)

Zanne, A. E., Lopez-Gonzalez, G., Coomes, D. A., Ilic, J., Jansen, S., Lewis, S. L., Miller, R. B., Swenson, N. G., Wiemann, M. C. & Chave, J. (2009). Global wood density database. *Dryad*. http://datadryad.org/handle/10255/dryad.235

ISSN (Online): 3048-7803

JWLS

Volume 2, Issue 4 (December 2025)

TYPE Short Communication

Rapid reconnaissance counts and distribution of the Endangered Hog Deer (*Axis porcinus*) in Corbett Tiger Reserve, India

Saket Badola[1] & Shahbaz Ali[1]

[1] Corbett Tiger Reserve, Ramnagar

DIAMOND OPEN ACCESS Crossref Check for updates

EDITED BY
Shomita Mukherjee
Salim Ali Centre for Ornithology and Natural History, Tamil Nadu.

*CORRESPONDENCE
Shahbaz Ali
ali701480@gmail.com

RECEIVED 21 August 2025
ACCEPTED 23 October 2025
ONLINE EARLY 24 November 2025
PUBLISHED 22 December 2025

CITATION
Badola, S. & Ali, S. (2025). Rapid reconnaissance counts and distribution of the Endangered Hog Deer (*Axis porcinus*) in Corbett Tiger Reserve, India. *Journal of Wildlife Science,* 2(4), 141-146. https://doi.org/10.63033/JWLS.VBZY1026

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Abstract

The hog deer (*Axis porcinus*), an Endangered grassland specialist of South and Southeast Asia, occurs at low densities across much of its range due to habitat loss and fragmentation. In Corbett Tiger Reserve, populations are mainly restricted to isolated alluvial grasslands, with major declines following the submergence of prime habitat by the Kalagarh Dam in 1974. To document distribution and provide rapid count indices, a three-day reconnaissance survey (22-24 May 2025) was undertaken in all 12 forest ranges, covering 141 beats during peak activity hours (06:00-10:00 am). Direct sighting counts were made daily, with the highest tally used as an index of relative abundance. Hog deer were recorded in only four ranges, indicating a restricted distribution. A total of 189 individuals were recorded, with observations expressed as relative abundance indices (CTR 0.15 ind/km^2; Dhikala 2.31 ind/km^2). Dhikala accounted for 175 individuals, concentrated in the Dhikala Chaur and Jalashay beats, underscoring the role of high-quality alluvial grasslands and perennial water. As a rapid count without detection correction, findings represent indices rather than true population estimates. Results highlight the need for grassland management, invasive species control, and habitat connectivity to ensure long-term conservation of hog deer in CTR.

Keywords: Grassland, habitat fragmentation, population distribution, relative abundance, ungulate

Introduction

The hog deer (*Axis porcinus*) is a species belonging to the genus Axis, endemic to the tall, moist grasslands of South and Southeast Asia. Its robust build and characteristic behavior of dashing through dense vegetation with its head held low are thought to have inspired its common name (Schaller, 1967; Prater, 1980; Biswas & Mathur, 2000; Gupta *et al.*, 2018). Within the Terai Arc Landscape of India, the species is regarded as an obligate grassland specialist, with a strong affinity for habitats dominated by blady grass (*Imperata cylindrica*), which offers both forage and concealment (Biswas, 2004; Arshad *et al.*, 2012). In Thailand and Indo-China, the species is associated with alluvial floodplain grasslands, which similarly support its ecological requirements (Maxwell *et al.*, 2007; Arshad *et al.*, 2012; Hill *et al.*, 2019).

The hog deer is currently classified as Endangered as per the IUCN Red List and is protected under Schedule I of the Indian Wildlife (Protection) Act, 1972, due to continuing declines in population and habitat quality (Timmins *et al.*, 2015; Gupta *et al.*, 2018). Two subspecies are recognized: *A. p. porcinus*, occurring in India, Nepal, Bangladesh, and Myanmar, and *A. p. annamiticus*, historically distributed across Vietnam, Laos, Cambodia, Thailand, and parts of southern China (Biswas & Mathur, 2000; Angom *et al.*, 2020).

The moist floodplain grasslands, typically located along river corridors, are often dominated by *Imperata cylindrica*, *Saccharum spontaneum*, and other early-successional grasses. These habitats are crucial for hog deer, especially during fawning and foraging periods, offering an optimal balance of visibility and cover (Dhungel & O'Gara, 1991; Arshad *et al.*, 2012). However, habitat degradation is a major conservation challenge. Key threats include agricultural expansion, unsustainable livestock grazing, grass harvesting, and altered hydrological regimes due to infrastructure development (Biswas, 2004; Odden *et al.*, 2005).

Moreover, suppression of fire and the decline of traditional habitat management have allowed woody vegetation to colonize open grasslands, rendering them unsuitable for *A. porcinus* (Hussain *et al.*, 2025). Although conservation areas have introduced burning and cutting regimes to maintain grassland structure, mistimed interventions may inadvertently reduce protective cover and increase the risk of predation (Biswas, 2004).

The Indian subspecies faces elevated conservation concern due to genetic isolation, habitat fragmentation, and limited connectivity across populations (Gupta *et al.*, 2018; Angom *et al.*, 2020). These conditions raise concerns over reduced gene flow, inbreeding, and long-term viability. Despite its ecological importance and legal protection, the hog deer remains underrepresented in wildlife research and monitoring programs in India. While substantial research has been conducted in regions like Assam and Kaziranga, there remains a significant data gap in the western Terai, including Uttarakhand (Hussain *et al.*, 2025).

In Corbett Tiger Reserve (CTR), the hog deer occurs in low densities and is mainly confined to isolated grassland patches within the Dhikala, Phulai, Khinanauli, Paterpani, and Dhela ranges. A major population decline was observed following the submergence of large grassland areas due to the construction of the Kalagarh Dam on the Ramganga River in 1974, which led to habitat loss, fragmentation, and isolation of populations. These changes impeded natural movement and regeneration, rendering the species increasingly vulnerable to local extinction. The current localized existence of hog deer in CTR continues to face pressure from both ecological and anthropogenic factors. Accurate assessment of its population status is therefore essential, as it informs demographic understanding and helps identify priority areas for conservation management (O'Brien, 2011).

In this context, a field-based census of hog deer was conducted in CTR, covering key habitats historically known for the species. This assessment offers updated insights into the distribution, population status, and demographic structure of *A. porcinus* within the reserve. Given the limited and shrinking habitat within CTR, such targeted evaluations are crucial for prioritizing conservation zones and ensuring the continued persistence of this endangered grassland specialist. The present study represents an initial reconnaissance, intended to provide a baseline count and distribution update for hog deer in CTR.

Material & Methods

Study Area

CTR is situated in the foothills of the western Himalayas, encompassing parts of Nainital and Pauri Garhwal districts in Uttarakhand, India. Geographically, it lies between 29°25′–29°40′ N latitude and 78°5′–79°50′ E longitude. Established in 1936 as Hailey's National Park, it holds the distinction of being India's first national park. It was later renamed Ramganga National Park in 1954 and finally Corbett National Park in 1957, honoring Jim Corbett for his pivotal role in wildlife conservation (Rastogi *et al.*, 2010).

Initially covering 323.75 km^2, the park's area was increased to 520.82 km^2 in 1966. The present-day CTR spans 1,288.32 km^2, comprising the core area, Sonanadi Wildlife Sanctuary (301.18 km^2), and an additional buffer zone (466.32 km^2). In 1973–74, it was brought under India's Project Tiger, recognizing it as a critical habitat with one of the highest tiger densities in the country (Jhala *et al.*, 2008).

The reserve comprises 12 forest ranges, namely Bijrani, Dhela, Dhikala, Jhirna, Kalagarh, Adnala, Mandal, Maidawan, Pakhrau, Palain, Sarpduli, and Sonanadi. The census focused on prominent grassland habitats where hog deer are known to occur. These areas predominantly consist of alluvial grasslands, often influenced by the Ramganga River and its tributaries. (Figure 1)

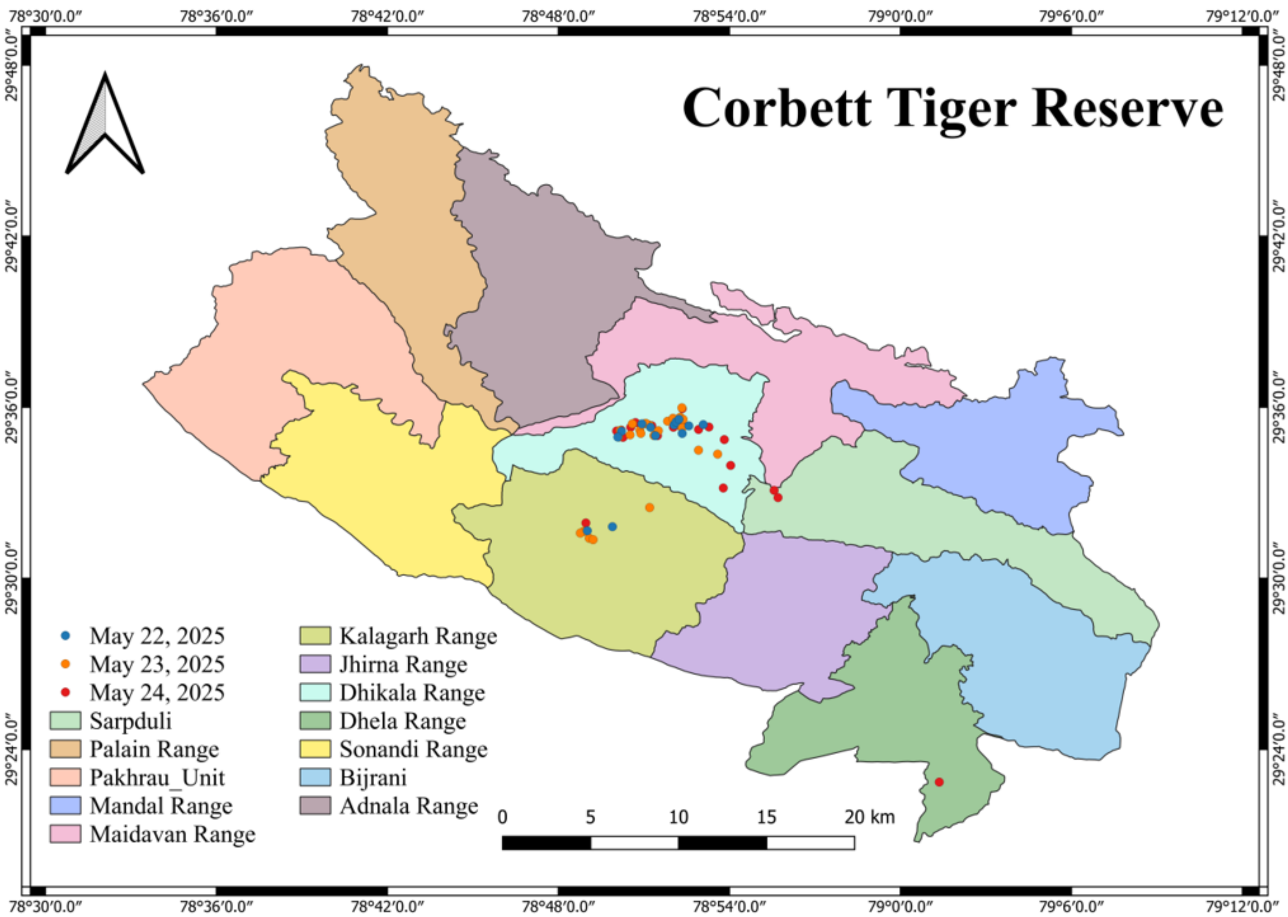


Figure 1: Spatial distribution of hog deer direct sightings across Corbett Tiger Reserve recorded during the three-day census.

 https://doi.org/10.63033/JWLS.VBZY1026

Data collection
A training program was conducted collaboratively with The Corbett Foundation (TCF) and WWF-India on April 17th, 2025, at Kalagarh training centre, CTR. Five to six officials from each of the 12 ranges attended the training for hog deer identification. Later, the information was circulated to all the beats and staff through trained attendees.

We conducted direct sighting counts instead of formal distance sampling (Buckland *et al.*, 2001; Thomas *et al.*, 2010). The reconnaissance survey of hog deer in CTR was carried out over a three-day period from 22nd to 24th May 2025 in all 12 ranges of the reserve, including 141 beats. The census was conducted during the early morning hours between 06:00 AM and 10:00 AM, when animal activity and visibility are optimal. The census was carried out through direct observation methods, involving systematic field surveys along pre-established routes within identified grassland habitats. The survey team consisted of forest guards, research staff, and volunteers (The Corbett Foundation & WWF-India) of 4-6 observers and covered approximately 12 km each day (Table 1). The total distance covered across all ranges during the three-day survey was 4042.8 km. Data from all three days were treated as replicates. For reporting purposes, the maximum daily count was used as an index of relative abundance. Relative encounter rate was calculated as individuals observed per km² of available grassland (Miller *et al.*, 2019). We emphasize that these counts are not corrected for detection probability and should therefore be interpreted as indices rather than true densities. The extent of grassland habitat within CTR was derived from the Tiger Conservation Plan (2016–2025), which outlines the reserve's vegetation types and management zones.

Data Analysis
To evaluate whether hog deer presence varied significantly across ranges, contingency tables were created from daily detection records. The data were analyzed using Fisher's Exact test of independence in SPSS version 26.0. Both asymptotic and exact significance values are reported, and results were interpreted at a significance level of $p < 0.05$.

Results

During the three-day census in CTR, the presence of hog deer was confirmed only in a few forest ranges, indicating a spatially restricted distribution pattern. Hog deer sightings were consistently recorded in the Dhikala and Kalagarh ranges on all three days of the survey, highlighting these areas as core habitats for the species within the reserve.

Additional observations were made in the Sarpduli range on the 23rd and 24th , and a single sighting was reported from the Dhela range on 24th May. No individuals were encountered in other surveyed ranges, including Bijrani, Jhirna, or any of the ranges falling under the Kalagarh Tiger Reserve Division, namely Adnala, Mandal, Maidavan, Palain, Pakhrao, and Sonanadi (Table 1).

Across the three-day census, the recorded number of hog deer ranged between 169 and 189 individuals with a mean of 182.33 ± 6.64 (SE) and a coefficient of variation of 6.3%, depending on daily environmental factors such as visibility, weather conditions, and animal movement patterns. The corresponding 95% confidence interval was 169 to 195 individuals, reflecting the uncertainty inherent in raw count-based indices. These fluctuations underscore the importance of multi-day surveys for achieving a more accurate population estimate.

On the final day of the census, 24th May 2025, a total of 189 hog deer individuals were sighted across all forest ranges of CTR. This represents the maximum count and was reported as an index of relative abundance. This included 153 adults and 36 fawns, representing the highest adult count recorded during the three-day survey. In contrast, the highest number of fawns (46) was observed on the second day of the census. Among all surveyed locations, the Dhikala Range remained the key habitat, holding 175 individuals (141 adults and 34 fawns), which accounted for over 92% of the total sightings on the final day (Table 2). The total relative abundance for CTR (area = 1288.31 km²) was estimated at 0.15 ind/km² and in the Dhikala range itself, a grassland with an area of 75.64 km², the relative abundance was estimated at 2.31 ind/km². Please note that these figures should not be confused with actual density estimates.

A breakdown of observations within Dhikala revealed that Dhikala Chaur (79 individuals) and Jalashay beat (area that remains submerged during monsoon; 77 individuals) were the two primary hotspots for Hog Deer, followed by smaller numbers in Phoolai West (14) and Phoolai East (5). This concentration is likely due to the availability of suitable

Table 1: The value under Total hog deer observations (3-days) was already corrected earlier as per reviewer comments; kindly retain the corrected version.

Range	No. of Beats	Distance covered in all 3 days (km)	Team Size	Total hog deer observations (3-days)	Encounter rate (ind/km)
Bijrani	16	484.8	5	0	0
Dhikala	8	295.2	6	334	1.131
Sarpduli	15	463.5	5	19	0.041
Dhela	12	385.2	5	1	0.003
Jhirna	9	315.9	4	0	0
Kalagarh	12	327.6	5	16	0.048
Adnala	14	348.6	6	0	0
Mandal	9	259.2	4	0	0
Maidavan	11	310.2	5	0	0
Palain	14	331.8	4	0	0
Pakhrao	11	277.2	6	0	0
Sonanadi	10	243.6	5	0	0

 https://doi.org/10.63033/JWLS.VBZY1026

grassland habitats, perennial water sources, and lower levels of human disturbance within this range. The Sarpduli Range recorded 11 individuals (10 adults and 1 fawn), indicating a small but stable sub-population. On the other hand, Kalagarh and Dhela reported only 2 and 1 individuals, respectively. (Table 2).

A Fisher's Exact Test indicated a significant association between survey range and hog deer presence (two-sided exact p = 0.001), confirming that detections were not uniformly distributed across the reserve. Instead, sightings were strongly clustered in a few key ranges, particularly Dhikala, which supported the majority of individuals, and parts of Kalagarh, where small sub-populations were observed.

Discussion

When compared with other protected areas across South Asia, hog deer numbers in CTR appear low. Reported hog deer densities vary considerably across South and Southeast Asia, largely reflecting differences in habitat quality, management, and survey methods. In Chitwan National Park, Nepal, Dhungel & O'Gara (1991) estimated densities of 15.5–19.1 individuals/km^2 in savanna grasslands using distance sampling, while much higher densities of 77.3 individuals/km^2 were reported from the floodplain grasslands of Bardia National Park, Nepal (Odden *et al.*, 2005). Similarly, Karanth & Nichols (2000) recorded 38.6 individuals/km^2 in the floodplain grasslands of Kaziranga National Park, India. In contrast, lower densities have been reported from other sites such as Keibul Lamjao National Park, India (2.51 individuals/km^2; Angom, 2020), and Taunsa Barrage Wildlife Sanctuary, Pakistan (11.8 individuals/km^2; Arshad *et al.*, 2012). Within India, Goswami & Ganesh (2014) estimated a density of 4.59 individuals/km^2 in Manas National Park, whereas Sinha *et al.* (2019) reported a higher density of 18.22 individuals/km^2 from the same site. In Sukhlaphanta Wildlife Reserve, Nepal, Lovari *et al.* (2015) recorded densities of 4.1 and 11.6 individuals/km^2 in 2010 and 2011, respectively. In comparison, the present study yielded much lower relative abundance indices, 0.15 individuals/km^2 across the reserve and 2.31 individuals/km^2 within the Dhikala Range.

However, it is important to note that nearly all of these estimates were generated using distance sampling or other model-based methods that explicitly account for detection probability. In contrast, our study relied on rapid reconnaissance counts without correction for detectability, and should therefore be interpreted only as indices of relative abundance. Direct comparisons between these values and formal density estimates from other sites are not appropriate, but the contrast does emphasize that hog deer in CTR are far more localized and occur at a possibly lower abundance than in other South Asian strongholds.

Hog deer occurrence was largely confined to the Dhikala Range, with a few records from Sarpduli (23–24 May) and a single sighting from Dhela on the final day. No individuals were detected in other surveyed ranges. This restricted distribution underscores the species' dependence on alluvial grasslands and wetlands concentrated in the Dhikala–Sarpduli landscape.

Table 2: Daily counts of hog deer recorded during reconnaissance survey (22–24 May 2025) in Corbett Tiger Reserve

Date	Range	Beat	Survey Effort (km)	Adult	Fawn	Total No.
22/05/2025	Kalagarh	Paterpani North	8.5	6	2	8
	Dhikala	Phoolai East	10.9	3	0	3
		Jalashay	11.5	65	23	88
		Dhikala Chaur	13.2	60	10	70
TOTAL				**134**	**35**	**169**
23/05/2025	Kalagarh	Paterpani North	9.7	3	3	6
		Boxad	9.3	1	1	2
	Dhikala	Phoolai West	11.1	6	1	7
		Jalashay	11.4	61	20	81
		Dhikala Chaur	13.3	67	18	85
	Sarpduli	Khinanauli	10.4	5	3	8
TOTAL				**143**	**46**	**189**
24/05/2025	Kalagarh	Paterpani North	8.9	1	1	2
	Dhikala	Phoolai West	13.7	11	3	14
		Phoolai East	12.4	5	0	5
		Jalashay	13.1	61	16	77
		Dhikala Chaur	12.3	64	15	79
	Sarpduli	Khinanauli	9.4	9	0	9
		Bhumakiya	11.1	1	1	2
	Dhela	Dhela Hill	10.7	1	0	1
TOTAL				**153**	**36**	**189**

Note: Counts represent raw sightings during the three-day survey. Encounter rates (individuals/km^2 of available grassland) are presented in the text as indices only, not as absolute density estimates, since detection probability was not estimated.

The absence from other areas likely reflects local extirpation or very low densities due to habitat loss and fragmentation. These results highlight the need for grassland restoration, invasive species control, and continued monitoring to support the species' persistence in CTR (Figure 1; Table 1).The absence of records from several other ranges underscores the highly localized distribution of hog deer within CTR, reflecting the fragmented and limited extent of suitable grassland habitats. These results reaffirm the Dhikala Range as the primary stronghold for the species, highlighting the importance of preserving its alluvial grasslands that provide essential resources for foraging, breeding, and fawn rearing. The observed presence of fawns indicates ongoing recruitment and a potentially stable breeding population in this core area. In contrast, the scarcity of sightings elsewhere points to the need for habitat restoration, improved survey coverage, and reduction of anthropogenic disturbances to facilitate recolonization and ensure the long-term persistence of hog deer across the reserve.

Due to resource constraints, habitat covariates could not be formally analyzed. However, >90% of sightings in alluvial grasslands with perennial water availability strongly indicate habitat preference. Future studies should incorporate GIS-based layers and occupancy models to test for habitat associations statistically.

Conclusion

The persistence of hog deer in CTR now depends largely on the quality of a few grassland refuges. Habitat loss from the Kalagarh Dam, woody succession, and invasive plant spread continue to limit their range. Focused management through controlled burning, timely cutting, removal of invasive species, and restoration of connectivity between grassland patches will be essential to stabilize and expand the population.

Future monitoring must adopt more rigorous methods, such as distance sampling, to provide reliable population estimates and track trends. By combining improved monitoring with habitat restoration, CTR can continue to serve as an important stronghold for this endangered grassland specialist in the western Himalaya.

Acknowledgment

We express our sincere gratitude to Mr. Ranjan Kumar Mishra, IFS, PCCF (WL) & CWLW, Uttarakhand, for providing guidance and direction for this survey, and to Dr. Vivek Pandey, IFS, APCCF (Wildlife), for his valuable support and encouragement. We also extend our thanks to the forest staff whose dedicated efforts in the field made it possible to obtain the results presented in this study.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

DATA AVAILABILITY

The data used in the study are available upon request from the corresponding author

AUTHOR CONTRIBUTIONS

Saket Badola: Original concept, drafting the manuscript, supervision, reviewed the manuscript.

Shahbaz Ali: Drafting the manuscript, analysis of material, reviewed the manuscript.

References

Angom, S., Tuboi, C., Ghazi, M. G. U., Badola, R. & Hussain, S. A. (2020). Demographic and genetic structure of a severely fragmented population of the endangered hog deer (*Axis porcinus*) in the Indo-Burma biodiversity hotspot. *PLoS one*, 15(2), e0210382. https://doi.org/10.1371/journal.pone.0210382

Arshad, M., Ullah, I., Chaudhry, M. J. I. & Khan, N. U. H. (2012). Estimating hog deer *Axis porcinus* population in the riverine forest of Taunsa Barrage Wildlife Sanctuary, Punjab, Pakistan. *Records: Zoological Survey of Pakistan*, 21, 25-28.

Biswas, T. (2004). Hog deer (*Axis porcinus*). ENVIS Bulletin (Wildlife Institute of India, Dehradun) 7, 6178.

Biswas, T. & Mathur, V. B. (2000). A review of the present conservation scenario of hog deer (*Axis porcinus*) in its native range. *Indian Forester*, 126(10), 1068-1084. https://doi.org/10.36808/if/2000/v126i10/3297

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L. & Thomas, L. (2001). *Introduction to distance sampling: estimating abundance of biological populations*. Oxford University Press. https://doi.org/10.1093/oso/9780198506492.001.0001

Dhungel, S. K. & O'Gara, B. W. (1991). Ecology of the hog deer in Royal Chitwan National Park, Nepal. *Wildlife monographs*, 119, 3-40. https://www.jstor.org/stable/3830632

Goswami, R. & Ganesh, T. (2014). Carnivore and herbivore densities in the immediate aftermath of ethno-political conflict: the case of Manas National Park, India. *Tropical Conservation Science* 7(3), 475– 487. https://doi.org/10.1177/194008291400700308

Gupta, S. K., Kumar, A., Angom, S., Singh, B., Ghazi, M. G. U., Tuboi, C. & Hussain, S. A. (2018). Genetic analysis of endangered hog deer (*Axis porcinus*) reveals two distinct lineages from the Indian subcontinent. *Scientific reports*, 8(1), 16308. https://doi.org/10.1038/s41598-018-34482-9

Hill, E., Linacre, A., Toop, S., Murphy, N. & Strugnell, J. (2019). Widespread hybridization in the introduced hog deer population of Victoria, Australia, and its implications for conservation. *Ecology and Evolution*, 9(18), 10828-10842. https://doi.org/10.1002/ece3.5603

Hussain, S. A., Tuboi, C., Ghazi, M. G., Basak, S., Gupta, S. K. & Badola, R. (2025). Hog Deer *Axis porcinus* (E. A. W. von Zimmermann, 1780). In: Melletti, M. & Focardi, S. (eds.), *Deer of the World: Ecology, Conservation and Management*, Cham: Springer Nature , Switzerland. pp.275-287. https://doi.org/10.1007/978-3-031-17756-9_17

Jhala, Y. V., Gopal, R. & Qureshi, Q. (2008). Status of tigers, co-predators and prey in India. National Tiger Conservation Authority, Government of India, New Delhi, and Wildlife Institute of India, Dehradun

Karanth, K. U. & Nichols, J. D. (2000). Ecological status and conservation of tigers in India (Final Technical Report). Bangalore, India: Centre for Wildlife Studies, p.124

Lovari, S., Pokherel, C. P., Jnawali, S. R., Fusani L. & Ferretti, F. (2015). Coexistence of the tiger and the common leopard in a prey-rich area: the role of prey partitioning. *Journal of Zoology* 295, 122-131. https://doi.org/10.1111/jzo.12192

Maxwell, A., Nareth, C., Kong, D., Timmins, R. & Duckworth, J. W. (2007). Hog deer (*Axis porcinus*) confirmed in the wild in eastern Cambodia. *Natural History Bulletin of the Siam Society*, 54, 227-237.

Miller, D. L., Rexstad, E., Thomas, L., Marshall, L. & Laake, J. L. (2019). Distance sampling in R. *Journal of Statistical Software*, 89, 1-28. https://doi.org/10.18637/jss.v089.i01

O'Brien, T. G. (2011). Abundance, Density and Relative Abundance: A Conceptual Framework. In: O'Connell, A. F., Nichols, J. D. & Karanth, K. U. (eds.), *Camera traps in animal ecology: methods and analyses*, Springer, Tokyo, Japan. pp.71-96. https://doi.org/10.1007/978-4-431-99495-4_6

Odden, M., Wegge, P. & Storaas, T. (2005). Hog deer *Axis porcinus* need threatened tallgrass floodplains: a study of habitat selection in lowland Nepal. *Animal Conservation*, Cambridge University Press. 8(1), pp.99-104. https://doi.org/10.1017/S1367943004001854

Prater, S. H. (1980). The book of Indian animals. Bombay Natural History Society, Mumbai.

Rastogi, A., Badola, R., Hussain, S. A. & Hickey, G. M. (2010). Assessing the utility of stakeholder analysis to Protected Areas management: The case of Corbett National

Park, India. *Biological Conservation*, 143(12), 2956-2964. https://doi.org/10.1016/j.biocon.2010.04.039

Schaller, G. B. (1967). The Deer and the Tiger. The University of Chicago press, Chicago, 370pp.

Sinha, A., Lahkar, B. P., & Hussain, S. A. (2019). Current population status of the endangered Hog Deer *Axis porcinus* (Mammalia: Cetartiodactyla: Cervidae) in the Terai grasslands: a study following political unrest in Manas National Park, India Â. *Journal of Threatened Taxa*, 11(13), 14655-14662. https://doi.org/10.11609/jott.5037.11.13.14655-14662

Thomas, L., Buckland, S. T., Rexstad, E. A., Laake, J. L., Strindberg, S., Hedley, S. L., Bishop, J. R. B., Marques, T. A. & Burnham, K. P. (2010). Distance software: design and analysis of distance sampling surveys for estimating population size. *Journal of Applied Ecology*, 47(1), 5–14. https://doi.org/10.1111/j.1365-2664.2009.01737.x

Timmins, R., Duckworth, J. W., Kumar, N. S., Islam, M. A., Baral, H. S., Long, B. & Maxwell, A. (2015). *Axis porcinus*. In The IUCN Red List of Threatened Species 2015: e.T41784A22157664. https://doi.org/10.2305/IUCN.UK.2015-4.RLTS.T41784A22157664.en (Accessed on 08 August 2025)

ISSN (Online): 3048-7803
JWLS
Volume 2, Issue 4 (December 2025)

TYPE Natural History Note

First Evidence of Allonursing in Gaur (*Bos gaurus gaurus*): Social Flexibility in a Translocated Population

Arun Kumar Gorati[1], Ritesh Vishwakarma[1], Bhaskar Bhandari[1], Bilal Habib[1] & Parag Nigam[1*]

[1]Wildlife Institute of India, Dehradun, India, 248001

DIAMOND OPEN ACCESS Crossref Check for updates

EDITED BY
Sambandam Sathyakumar
Wildlife Institute of India, Dehradun.

*CORRESPONDENCE
Parag Nigam
nigamp@wii.gov.in

RECEIVED 02 July 2025
ACCEPTED 04 September 2025
ONLINE EARLY 25 September 2025
PUBLISHED 22 December 2025

CITATION
Gorati, A. K., Vishwakarma, R., Bhandari, B., Habib, B. & Nigam, P. (2025). First Evidence of Allonursing in Gaur (*Bos gaurus gaurus*): Social Flexibility in a Translocated Population. *Journal of Wildlife Science,* 2(4), 147-150.
https://doi.org/10.63033/JWLS.NQFE5213

FUNDING
Madhya Pradesh Forest Department

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Abstract

Allonursing is the nursing of non-filial offspring by lactating females. It is a rare form of alloparental care and remains virtually undocumented in wild bovids. Here, we report the first photographic and video evidence of allonursing in gaur (*Bos gaurus gaurus*), Asia's largest extant bovine, from Bandhavgarh Tiger Reserve, Madhya Pradesh, India. The behaviour was observed during soft release monitoring as part of an ongoing project on population management strategies for gaur through supplementation. A lactating female was observed nursing a non-filial male calf from a different natal herd within the soft release enclosure. This behaviour provides new insights into the social flexibility of gaur and has implications for understanding behavioural flexibility in conservation-driven translocation efforts.

Keywords: Allonursing, alloparental care, bovine, gaur, mega herbivore, supplementation.

Introduction

Maternal care in ungulates is generally uniparental and short-term, especially for wild species of Bovidae (Stead *et al.,* 2019). Allonursing is a rare form of alloparental care in which a lactating female nurses a non-filial offspring. Alloparental care has been observed and documented across numerous taxa, including birds, rodents, primates, canids, carnivores, and megaherbivores (Mota-Rojas *et al.,* 2021; Stead *et al.,* 2019; Bădescu *et al.,* 2016; Malyjurková *et al.,* 2014; Lewis *et al.,* 1997). While alloparental care is common in cooperative breeders, it is unprecedented among wild Bovidae, where maternal care is extremely uniparental (Orihuela *et al.,* 2021). Though allosuckling has been described in water buffaloes, there has been no documentation of allonursing in wild bovids, particularly gaur, until now (Orihuela *et al.,* 2024).

Gaur (*Bos gaurus*), the largest extant wild bovid, is a gregarious herbivore found across South and Southeast Asia (Duckworth *et al.,* 2008). In India, the distribution of species spans over three regions: Northeast, South-western, and Central Indian landscapes (Ashokkumar *et al.,* 2011). The species inhabits diverse habitats ranging from evergreen to thorn forests and from lowlands to elevations of up to 2800m above mean sea level (Sankar *et al.,* 2013; Ashokkumar *et al.,* 2010; Krishnan, 1972). Gaur lives in a matrilineal society with fluid group composition where male lives solitary or form bachelor groups and mixed herds (Qureshi *et al.,* 2025; Duckworth *et al.,* 2016; Ashokkumar *et al.,* 2011).

After becoming locally extinct in Bandhavgarh Tiger Reserve, Madhya Pradesh, in 1998, 50 individuals of gaur were reintroduced to the landscape in 2011-12 (Sankar *et al.,* 2013, Nigam *et al.,* 2022). The reintroduction was carried out to restore a viable gaur population and ecosystem functions. Also, gaur is a valuable prey species for large carnivores such as tigers (Sankar *et al.,* 2013). Over time, the translocated population showed a growth rate of 5.7% every three years (Nigam *et al.,* 2022). However, a genetic bottleneck became evident, necessitating the supplementation of individuals from a new genetic pool to improve genetic variability and ensure long-term species survivability (Nigam *et al.,* 2022). Consequently, 23 animals from different herds were translocated from Satpura Tiger Reserve, Madhya Pradesh, in February 2025. The animals were soft-released into an enclosure with ample space and time for acclimatization and social bonding. During monitoring, a unique case of allonursing was observed.

Native herd profile

A total of five herds were chosen for the capture and translocation of gaur from Satpura Tiger Reserve to Bandhavgarh Tiger Reserve, which included 18 females and 5 males (Table 1). Care was taken while selecting the individuals for capture, and efforts were made to avoid disrupting social bonds or introducing biases that could compromise the group integrity. An adult female gaur (ID: BF-7) and male calf (ID: BM-4), which were noticed staying together during the capture operation and identified as biological mother-calf, were captured together and translocated. After soft releasing the animal in the enclosure at Bandhavgarh Tiger Reserve, BF-7 was confirmed as a non-biological mother over a series of observations.

Table 1: Details of translocated gaur from Satpura Tiger Reserve to Bandhavgarh Tiger Reserve (Nigam *et al.,* 2025).

Sr. No.	Capture Date	Area/ Herd ID	Animal ID	Sex	Estimated Age (in years)	Age Class	Colour Coded Bands /VHF* Collar	Soft Release in Enclosure
1	20-02-2025 (Morning Hours)	Sridana/ Herd 1	BF-1	Female	5-6	Adult	VHF	21-02-2025
2			BF-2	Female	6	Adult	Red Band (with D47 LORA device)	
3			BF-3	Female	8-9	Adult	Brown-Blue Band (VHF)	
4			BM-1	Male	5-6	Adult	Orange Band	
5			BM-2	Male	2.5-3	Sub-Adult	VHF	
6	20-02-2025 (Evening Hours)	Sridana/ Herd 2	BF-4	Female	4-5	Adult	Yellow Band	21-02-2025
7			BF-5	Female	3-4	Adult	Sky Blue-Yellow Band (VHF)	
8			BF-6	Female	4-5	Adult	Green Band	
9	21-02-2025	Churna/ Herd 3	BF-7	Female	3-4	Adult	Red-Green Band	22-02-2025
10			BM-3	Male	2.5-3	Sub-Adult	Brown-White Band (with LORA device)	
11			BM-4	Male	1.5-2.5	Calf	NOT ANY	
12			BF-8	Female	1.5-2	Sub-Adult	NOT-ANY	
13	22-02-2025 (Morning Hours)	Marram/ Herd 4	BF-9	Female	3-4	Adult	White Band	23-02-2025
14			BF-10	Female	4-5	Adult	Brown Band (with LORA device)	
15			BF-11	Female	4-5	Adult	Pink Band	
16			BF-12	Female	5-6	Adult	VHF	
17			BF-13	Female	4-5	Adult	Red-Blue Band	
18			BF-14	Female	4-5	Adult	VHF	
19	22-02-2025 (Evening Hours)	Churna/ Herd 5	BF-15	Female	2.5-3	Sub-Adult	Yellow-Red Band	23-02-2025
20			BF-16	Female	3-4	Adult	VHF	
21			BF-17	Female	2.5-3	Sub-Adult	White-Blue Band	
22	23-02-2025	Churna/ Herd 5	BM-5	Male	5-6	Adult	VHF	24-02-2025
23			BF-18	Female	4-5	Adult	Blue-Green Band	

VHF* - Very High Frequency

Observation of Allonursing

On 8th March 2025, we observed a newly translocated male calf (ID: BM–4) at Bandhavgarh Tiger Reserve inside the soft-release enclosure, approaching and attempting to suckle from an adult female gaur (ID: BF–6). Both individuals were brought in from different wild herds, with BM–4 being brought on 21 February and BF–6 on 20 February 2025. There was no evidence of kinship between BM–4 and BF–6. Moreover, BF–6 neither avoided BM–4 nor displayed aggressive behavior. Instead, the female gaur (ID: BF-6) stood relaxed and allowed the calf (ID: BM-4) to suckle and groomed the calf (Figure 1).

Allonuring behavior was observed opportunistically for the next 23 days, until 30th March 2025, before the animal's release into the wild. As the animals were not purposefully followed, no systematic study design was employed. During this period, BM–4 continually sought to suckle from BF–6, and BF–6 allowed the calf to suckle. The seemingly effortless and tolerating behavior by the female, along with grooming while suckling,

 https://doi.org/10.63033/JWLS.NQFE5213

suggested that an affiliative relationship formed between the female gaur and calf (Figure 1). Throughout the observation, neither individual appeared to show signs of rejection, defensive behaviors, or manifest distress.

The animals were identifiable with the full combination of ear tags, neck bands, and horn sleeve markers (Figure 2&3). As all translocated individuals came from various native herds, and the female BF–6 and the male calf BM–4 did not share any established biological relationship, this case was unequivocally confirmed as allonursing in gaur, a rarely observed phenomenon in social animals and a specific form of alloparental care (Mota-Rojas *et al.,* 2021; Engelhardt *et al.,* 2014).

Figure 1: A lactating female gaur nurses a non-filial calf

Figure 2: Camera trap picture of the female gaur with the non-filial calf

Figure 3: Calf with the non-biological female gaur after being released from the enclosure into the open forest

Discussion

The case of BM–4 and BF–6 is the first documented case of allonursing in free-ranging gaur. It highlights the social flexibility to develop some form of social bond between the species in a novel ecological and social context introduced through conservation translocation. The frequent presence of and prodromal opportunities of affiliation suggest some form of intent (Engelhardt *et al.,* 2014; Mota-Rojas *et al.,* 2021), unlike those cases of milk theft or mismothering.

Alloparental care has been observed and documented across numerous taxa (Guo *et al.*, 2022; Mota-Rojas *et al.,* 2021; Stead *et al.,* 2019; Bădescu *et al.,* 2016; Malyjurková *et al.,* 2014; Lewis *et al.,* 1997). Earlier studies have recorded alloparental care in some domestic and semi-wild species such as water buffalo (Orihuela *et al.,* 2024) and reindeer (Engelhardt *et al.,* 2014). In wild bovid species, the allonursing is virtually unrecorded. Several hypotheses have been proposed to explain why alloparental care occurs, some of which include misdirected maternal behavior, milk evacuation process, gaining maternity skills, kin selection, and reciprocal altruism (Engelhardt *et al.,* 2016; Maniscalco *et al.,* 2007). For calves, such behavior may be beneficial by providing immunological advantages and nutritional compensation (Orihuela *et al.,* 2024; Mota-Rojas *et al.,* 2021; Engelhardt *et al.,* 2014; Brandlová *et al.,* 2013).

As shown in domestic water buffalo (*Bubalus bubalis*), cooperative nursing has been observed in a high-density resource-limited context (Orihuela *et al.,* 2024). We hypothesize that the socially dynamic and controlled space of the soft-release enclosure was the essential ecological cue that facilitated allonursing in this case. These semi-natural environments could promote other affiliative responses as species-specific adaptive responses to environmental stressors and social situations associated with their translocation.

In our study, the occurrence of allonursing in translocated gaur may be linked to: a) Mistaken direct maternal behavior, because of hormonal state (Maniscalco *et al.,* 2007; Engelhardt *et al.,* 2014), b) Formation and renegotiation of social bonds in a new social environment (Mota-Rojas *et al.,* 2021; Orihuela *et al.,* 2021), c) Potentially reciprocal altruism or other mechanisms of inclusive fitness, especially in systems where kin discrimination is weak (Hamilton, 1964; Engelhardt *et al.,* 2016), or d) Social cohesion by virtue of stress, facilitated by proximity in an enclosure (Malyjurková *et al.,* 2014).

Most importantly, the soft release of the male calf in the enclosure probably added to its survival. Maternal dependency of the calf could have made it vulnerable due to starvation and predation, especially by tigers. Therefore, demonstrating allonursing in this context is not only an indication of behavioral plasticity, but also a situational altruistic response. This incident also underlines the ecological significance of transitional enclosures. Such enclosures could promote species-appropriate social behaviors that induce fitness in new environmental conditions associated with conservation.

In the context of this finding, translocation-related stress, social restructuring, and affiliative bonding may have contributed to the emergence of allonursing behavior. The defined area of enclosure may have facilitated social restructuring that supported alloparental care. Remarkably, such behavior could specify adaptive social flexibility in gaur, particularly in response to novel environmental or social conditions.

https://doi.org/10.63033/JWLS.NQFE5213

Conservation implications

Understanding the alloparental behaviour in translocated animals has a significant role in refining conservation strategies. In species with complex social systems, behavioural plasticity, such as allonursing, could enhance calf survival in unfamiliar environments, especially when natal social bonds are disrupted. Further, given current observations on gaur and other similar findings on buffaloes, contexts that facilitate a series of affiliative interactions may help alleviate the stress of social instability. The documentation of allonursing in gaur highlights the significance of post-release monitoring to understand the complexity of behavioral traits. This report can help better inform translocation efforts and facilitate social integration of translocated individuals in a novel environment.

Acknowledgment

We appreciate the hard work put forth by the staff at the Bandhavgarh Tiger Reserve. We thank the Madhya Pradesh Forest Department for their positive attitude towards wildlife conservation.

ETHICAL STATEMENT

The work does not involve any animal handling or invasive sampling. Observations are carried out from the predesignated watchtowers and camera traps to minimize disturbance to wildlife.

CONFLICT OF INTEREST

Bilal Habib & Parag Nigam hold editorial positions at the Journal of Wildlife Science. However, they did not participate in the peer review process of this article except as authors. The authors declare no other conflict of interest.

DATA AVAILABILITY

The videography will be provided upon request from the corresponding author

AUTHOR CONTRIBUTIONS

GAK contributed in data collection; GAK, BB prepared the first draft; RV edited and refined the manuscript; PN, BH provided inputs on the draft.

References

Ashokkumar, M., Nagarajan, R. & Desai, A. A. (2010). Gaur: Wild Cattle in Peril. *Science Reporter*, (November 2010), 33-35.

Ashokkumar, M., Swaminathan, S., Nagarajan, R. & Desai, A. A. (2011). Distribution, ecology and conservation of the Gaur (*Bos Gaurus*, H. Smith, 1824). *Animal diversity, natural history and conservation*, 1, 77-94.

Bădescu, I., Watts, D. P., Katzenberg, M. A. & Sellen, D. W. (2016). Alloparenting is associated with reduced maternal lactation effort and faster weaning in wild chimpanzees. *Royal Society open science*, 3(11), 160577. https://doi.org/10.1098/rsos.160577

Brandlova´ K, Bartosˇ L, Haberova´ T (2013) Camel Calves as Opportunistic Milk Thefts? The First Description of Allosuckling in Domestic Bactrian Camel (*Camelus bactrianus*). *PLoS ONE* 8(1): e53052. doi:10.1371/journal.pone.0053052

Duckworth, J. W., Sankar, K., Williams, A. C., Samba Kumar, N. & Timmins, R. J. (2016). *Bos gaurus. The IUCN Red List of Threatened Species* 2016: e. T2891A46363646. https://dx.doi.org/10.2305/IUCN.UK.2016-2.RLTS.T2891A46363646.en.

Duckworth, J. W., Steinmetz, R., Timmins, R. J., Pattanavibool, A., Than Zaw, Do Tuoc & Hedges, S. 2008. *Bos gaurus. The IUCN Red List of Threatened Species* 2008: e.T2891A9491805. http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T2891A9491805.en.

Engelhardt, S. C., Weladji, R. B., Holand, Ø., de Rioja, C. M., Ehmann, R. K. & Nieminen, M. (2014). Allosuckling in reindeer (*Rangifer tarandus*): Milk-theft, mismothering or kin selection?. *Behavioural Processes*, 107, 133–141. https://doi.org/10.1016/j.beproc.2014.08.013

Guo, Y., Grueter, C. C. & Lu, J. (2022). Allomaternal care and 'adoption' in an edge-of-range population of Taihangshan macaques in Northern China. *Current Zoology*, 69(2), 215-218. https://doi.org/10.1093/cz/zoac027

Hamilton, W. D. (1964). The genetical evolution of social behaviour. I & II. *Journal of Theoretical Biology*, 7(1), 1–52. https://doi.org/10.1016/0022-5193(64)90038-4

Krishnan, M. (1972). An ecological survey of the larger mammals of peninsular India. *The Journal of the Bombay Natural History Society*, 69, 26–54.

Lewis, S. E. & Pusey, A. E. (1997). Factors influencing the occurrence of communal care in plural breeding mammals. *Cooperative breeding in mammals*, 335-363. https://doi.org/10.1017/CBO9780511574634.013

Malyjurková, L., Hejzlarová, M., Vymyslická, P. J. & Brandlová, K. (2014). Social Preferences of Translocated Giraffes (*Giraffa camelopardalis giraffa*) in Senegal: Evidence for Friendship among Females?. *Maternal Behaviour in Giraffes*, 47(1), 92.

Maniscalco, J. M., Harris, K. R., Atkinson, S. & Parker, P. (2007). Alloparenting in Steller sea lions (*Eumetopias jubatus*): correlations with misdirected care and other observations. *Journal of Ethology*, 25, 125-131. https://doi.org/10.1007/s10164-006-0001-4

Mota-Rojas, D., Marcet-Rius, M., Freitas-de-Melo, A., Muns, R., Mora-Medina, P., Domínguez-Oliva, A. & Orihuela, A. (2021). Allonursing in Wild and Farm Animals: Biological and Physiological Foundations and Explanatory Hypotheses. *Animals*, 11(11), 3092. https://doi.org/10.3390/ani11113092

Nigam, P., Gorati, A. K., Vishwakarma, R., Bhandari, B., Habib, B., Mondol, S., Sen, S., Krishnamoorthy. L., Sahay, A., Nanda, R. & Tiwari, V. R. (2025). *Supplementation of Gaur in Bandhavgarh Tiger Reserve, Madhya Pradesh–Technical Report.* Wildlife Institute of India, Dehradun, India. (Tr. No./2025/10, Dated: 16/06/2025), p.60.

Nigam, P., Mondol, S., Habib, B., Vishwakarma, R., Nandwanshi, V.B., Bhati, R. & Annigeri, B. S. (2022). Monitoring Reintroduced Gaur (*Bos gaurus*) in Bandhavgarh Tiger Reserve, Madhya Pradesh, Phase II, Extension (2018-22) – Final Report, Wildlife Institute of India, Dehradun, India. (Tr. No.2022/23, p.119)

Orihuela, A., Bienboire-Frosini, C., Chay-Canul, A., Álvarez-Macías, A., Marcet-Rius, M., Domínguez-Oliva, A., Mora-Medina, P., Olmos-Hernández, A. & Napolitano, F. et al. (2024). Allonursing in water buffalo: Cooperative maternal behavior in domestic Bovidae. *Journal of Animal Behaviour and Biometeorology*, 12(3), 2024023. https://doi.org/10.31893/jabb.2024023

Orihuela, A., Pérez-Torres, L. I. & Ungerfeld, R. (2021). Evidence of cooperative calves' care and providers' characteristics in zebu cattle (*Bos indicus*) raised under extensive conditions. *Tropical Animal Health and Production*, 53, 1-6. https://doi.org/10.1007/s11250-020-02451-y

Qureshi, Q., Kolipakam, V., Jhala, V. Y., Kumar, U., Habib, B., Mathur, C, V., Mallick, A., Yadav, P. S., Bharadwaj, S. G. & Tiwari, R. V. (2025). *Status of Ungulates in Tiger Habitats of India*. National Tiger Conservation Authority, New Delhi, and Wildlife Institute of India, Dehradun.

Sankar, K., Pabla, H. S., Patil, C. K., Nigam, P., Qureshi, Q., Navaneethan, B., & Mondal, K. (2013). Home Range, Habitat Use and Food Habits of Re-Introduced Gaur (*Bos Gaurus Gaurus*) in Bandhavgarh Tiger Reserve, Central India. *Tropical Conservation Science*, 6(1), 50-69. https://doi.org/10.1177/194008291300600108

Stead, S., Mucha, S. & Bădescu, I. (2019). Alloparental Care. In: Vonk, J. & Shackelford, T. (eds.), Encyclopedia of Animal Cognition and Behavior. Cham, Switzerland. *Springer*, pp.1–7. https://doi.org/10.1007/978-3-319-47829-6_1400-1

JWLS

JOURNAL OF WILDLIFE SCIENCE

Interdisciplinary Journal of Wildlife Research, Conservation and Management

Contact Information:

Journal of Wildlife Science
Wildlife Institute of India,
PO Box # 18, Chandrabani,
Dehradun – 248001 INDIA
Email: info@jwls.in

https://jwls.in