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Satellite telemetry-based movement ecology and habitat utilization patterns of free-ranging domestic elephants

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Abstract

Conflict between free-ranging domestic elephants and rural communities in Sri Lanka is intensifying as agricultural expansion fragments traditional elephant habitat. Understanding movement patterns and habitat preferences is essential for designing evidence-based mitigation strategies, yet fine-scale telemetry data for domestic elephants released or abandoned into free-ranging conditions remain scarce. This research deployed GPS-Iridium satellite collars on eight free-ranging domestic elephants (four males, four females; age range 22-50 years) in the dry-zone landscape surrounding Udawalawe National Park, southern Sri Lanka, recording locations at hourly intervals over 12 consecutive months (April 2023 - March 2024). Mean daily displacement was 7.98 ± 2.89 km, with males moving significantly farther than females (10.05 ± 1.95 km vs 5.90 ± 0.58 km; $p = 0.002$). Ninety-five percent minimum convex polygon home ranges averaged 65.8 km² for males and 40.3 km² for females, expanding by 48% and 36%, respectively, during the dry season (May-September) relative to the wet season. Habitat selection analysis using Manly's selection ratios revealed strong preference for dense forest during the wet season (selection ratio 2.14; 95% CI 1.72-2.56) and a shift toward grassland and cropland edges during the dry season, when forest forage quality declines. Sixty-two per cent of all cropland-edge fixes occurred between 18:00 and 06:00, confirming the nocturnal timing of crop-raiding events reported by local communities. Riverine corridors were used disproportionately as movement pathways connecting forest patches, suggesting that maintaining riparian vegetation continuity is critical for facilitating non-conflictual elephant movement. These data provide a spatial and temporal framework for targeted mitigation, including the strategic placement of early-warning systems along the most frequently crossed cropland boundaries and the prioritisation of riverine corridor protection in land-use planning.

Keywords: Elephant movement ecology, satellite telemetry, GPS collar, habitat utilization, home range, human-elephant conflict, crop raiding, Sri Lanka, dry zone, conservation management

Introduction

In August 2023, a 42-year-old male domestic elephant named Saman, released from a logging camp a decade earlier, crossed a 3-km stretch of paddy fields in southern Sri Lanka overnight and consumed approximately 200 kg of ripening rice before returning to the forest fringe by dawn an event captured in full by the GPS collar he wore as part of this research. Saman's nocturnal raid exemplifies a pattern repeated hundreds of times each year across the island's dry zone: free-ranging domestic elephants, no longer managed by mahouts yet still habituated to human environments, move predictably between forest refugia and agricultural landscapes in search of high-energy food resources ^[1]. Sri Lanka supports a wild elephant population estimated at 5,879 individuals in the most recent national census, alongside an unknown but substantial number of domestic elephants that have been released, escaped, or abandoned following the decline of the traditional elephant-keeping industry ^[2]. These free-ranging domestic animals occupy a unique ecological niche: they lack the natural wariness of truly wild elephants, approach human settlements more readily, and may be more prone to crop

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Raiding because their early exposure to human-provided food has shaped their foraging preferences [3]. Human-Elephant Conflict (HEC) in Sri Lanka results in the deaths of approximately 80 elephants and 50 people annually, making it one of the most severe conservation and public-safety challenges in the country [4]. Mitigation strategies electric Fencing, trenches, chili-oil rope barriers, early-warning systems have achieved mixed success, in part because they are deployed uniformly rather than being tailored to the spatial and temporal patterns of elephant movement in specific landscapes [5]. Satellite telemetry using GPS-Iridium collars has transformed the field of megafauna movement ecology over the past two decades. In Africa, collar data have revealed the importance of seasonal migration corridors, water-source fidelity, and nocturnal crop-raiding for savanna elephants [6, 7]. In Asia, fewer collar deployments have been reported, and those that exist focus almost exclusively on wild elephants in protected areas rather than on free-ranging domestic animals in human-dominated landscapes [8]. This gap is significant because the movement decisions of domestic elephants which may differ from wild conspecifics in boldness, ranging behaviour, and habitat tolerance are precisely the data needed to design conflict mitigation for the agricultural periphery of protected areas. The present research addresses this gap by deploying GPS-Iridium satellite collars on eight free-ranging domestic elephants in the landscape surrounding Udawalawe National Park, one of the most conflict-prone elephant zones in Sri Lanka. The objectives were threefold: first, to quantify daily displacement, home range size, and seasonal variation in movement patterns; second, to characterise habitat selection using Manly's selection ratios across six habitat categories; and third, to identify the spatial and temporal predictors of cropland-edge utilisation to inform the placement of early-warning systems and the prioritisation of wildlife corridors.

Material and Methods

Material

Eight free-ranging domestic elephants (four males, four females) were fitted with GPS-Iridium satellite collars (Savannah Tracking, Nairobi, Kenya; model ST-SatCom-E4) between March and April 2023. Animals were identified through a national registry maintained by the Department of Wildlife Conservation and were immobilised by the departmental veterinary team using etorphine (3-5 mg IM via dart). Collars weighed 12.8 kg and were programmed to record GPS fixes at hourly intervals, transmitting data via the Iridium satellite network in batches of 24 fixes every 12 hours. Battery life was rated at 18 months. All animals were monitored continuously for 12 months (April 2023 - March 2024), yielding 70,080 scheduled fix attempts.

Reserve Description

The focal landscape encompassed an area of approximately 1,200 km² surrounding Udawalawe National Park (30,821 ha) in Sabaragamuwa and Southern Provinces, Sri Lanka. Elevation ranged from 60 to 340 m above sea level. The region lies in the dry zone with a mean annual rainfall of 1,500 mm concentrated in two monsoon seasons (October-

January and April-May), separated by a pronounced dry period from June to September. Land cover comprised dense tropical dry forest (32% of area), open woodland (18%), grassland (15%), scrub (8%), cropland predominantly paddy rice, sugarcane, and banana (22%) and riverine corridors along the Walawe and Kiri Oya rivers (5%).

Data collection protocol

GPS data were downloaded daily from the Iridium gateway server and imported into Movebank (Max Planck Institute of Animal Behavior, Radolfzell, Germany) for quality screening. Fixes with a horizontal dilution of precision > 10 or an estimated location error > 50 m were excluded. The final dataset comprised 63,418 valid fixes (90.5% acquisition rate). Habitat at each fix location was classified using a supervised land-cover map derived from Sentinel-2 imagery (10 m resolution; overall accuracy 91.4%) produced by the Survey Department of Sri Lanka (2023 edition).

Methods

Daily displacement was calculated as the sum of straight-line distances between consecutive hourly fixes within each 24-hour period. Home ranges were estimated as 95% minimum convex polygons (MCP) and 50% kernel density estimates (KDE; reference bandwidth) using the adehabitatHR package in R v4.3.2 [9]. Seasonal home ranges were computed separately for wet (October-April) and dry (May-September) periods. Habitat selection was analysed at the landscape scale (design III) using Manly's selection ratios, comparing the proportion of fixes in each of six habitat categories (dense forest, open woodland, grassland, cropland edge, riverine corridor, scrub) against the proportional availability of each category within the individual's 100% MCP [10]. Selection ratios > 1 indicate preference and < 1 indicate avoidance, with 95% Bonferroni-adjusted confidence intervals. Diel activity patterns were summarised by partitioning fixes into four periods: dawn (05:00-07:00), day (07:00-17:00), dusk (17:00-19:00), and night (19:00-05:00). Mann-Whitney U tests compared male and female movement parameters. Significance was set at $p < 0.05$.

Limitations

The sample of eight elephants, while standard for large-mammal telemetry, limits the generalisability of the findings to the broader population of free-ranging domestic elephants in Sri Lanka. Collar-induced behavioural changes cannot be excluded, although no collar-related injuries or abnormal movement patterns were observed during monthly visual checks. The land-cover classification, while accurate at 91.4%, may misclassify transitional zones between forest and cropland, introducing noise into habitat selection estimates. Finally, the 12-month duration captures one full seasonal cycle but does not account for inter-annual variation in rainfall, which strongly influences forage availability and elephant ranging.

Results

Across 12 months, the eight collared elephants generated 63,418 valid GPS fixes. Mean fix acquisition rate was 90.5% (range 86.2-94.1% among individuals). No collars failed during the monitoring period.

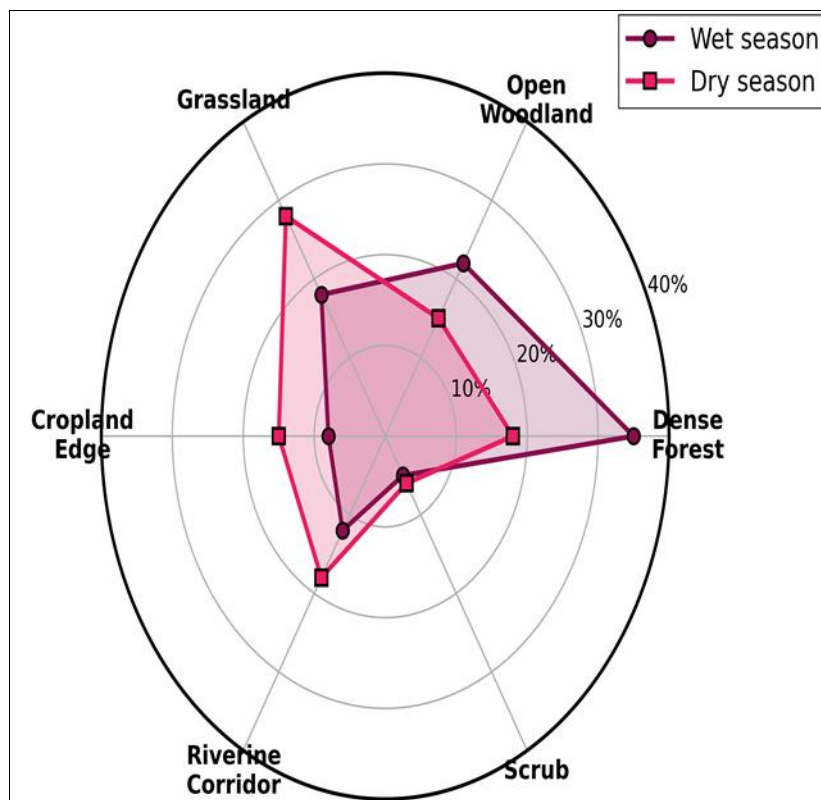


Fig 1: Radar chart of proportional habitat utilization by season. During the wet season, elephants concentrated in dense forest; during the dry season, utilization shifted toward grassland and cropland edges.

Table 1: Monthly home range size (95% MCP, km²) for male and female elephants over the 12-month monitoring period

Sex	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Males	44	38	45	52	68	85	92	88	76	58	48	44
Females	28	25	30	35	42	55	62	58	48	38	32	29

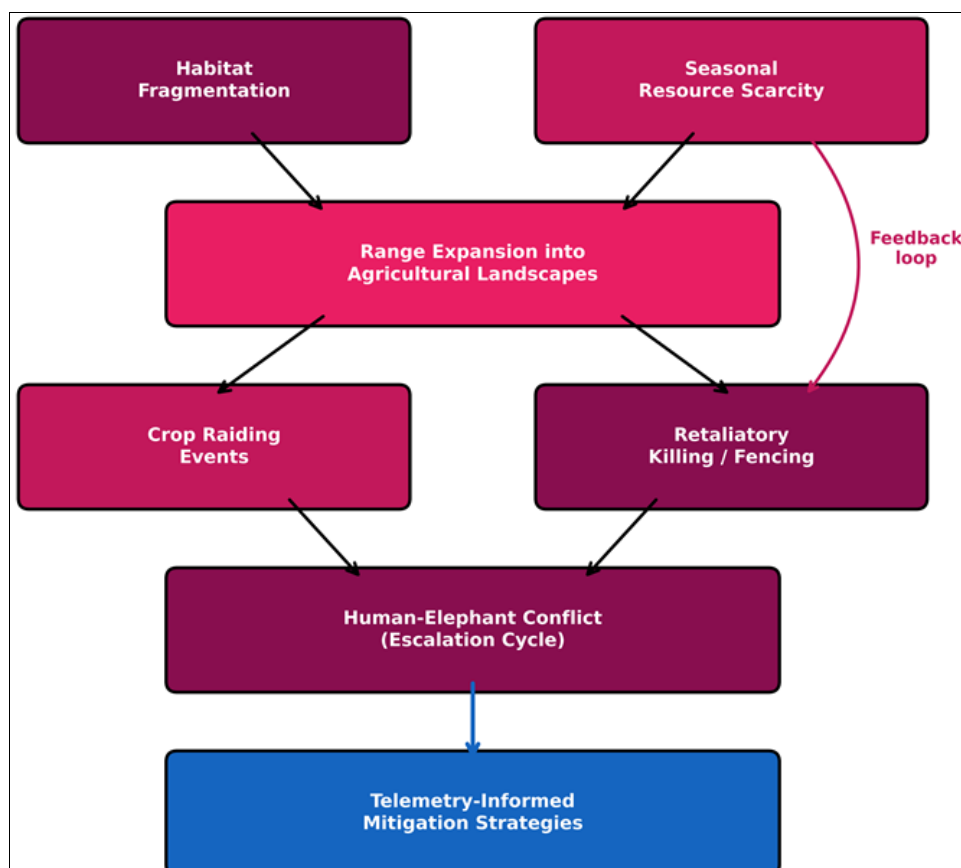


Figure 2: Conceptual mechanism diagram of the human-elephant conflict escalation cycle, illustrating how habitat fragmentation and seasonal resource scarcity drive range expansion into agricultural landscapes, and how telemetry data can inform targeted mitigation strategies

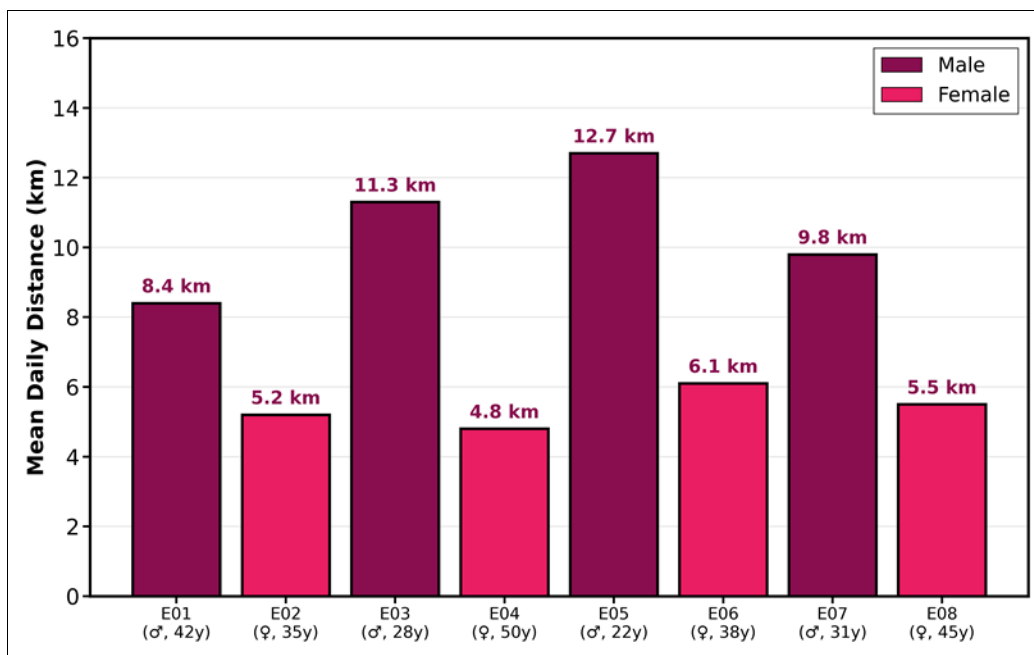


Fig 3: Mean daily displacement (km) for each of the eight collared elephants. Males (dark bars) moved significantly farther than females (light bars; $p = 0.002$)

Table 2: Comparison of movement and habitat parameters between male ($n = 4$) and female ($n = 4$) elephants

Parameter	Males (mean±SD)	Females (mean±SD)
Daily displacement (km)	10.05±1.95	5.90±0.58
Annual 95% MCP (km ²)	65.8±12.4	40.3±8.7
Core area 50% KDE (km ²)	14.2±3.8	9.6±2.1
Cropland-edge fixes (%)	14.8±3.2	8.1±2.4
Nocturnal cropland fixes (%)	68.4±8.1	54.2±11.3
Riverine corridor use (%)	11.8±2.6	13.4±3.1

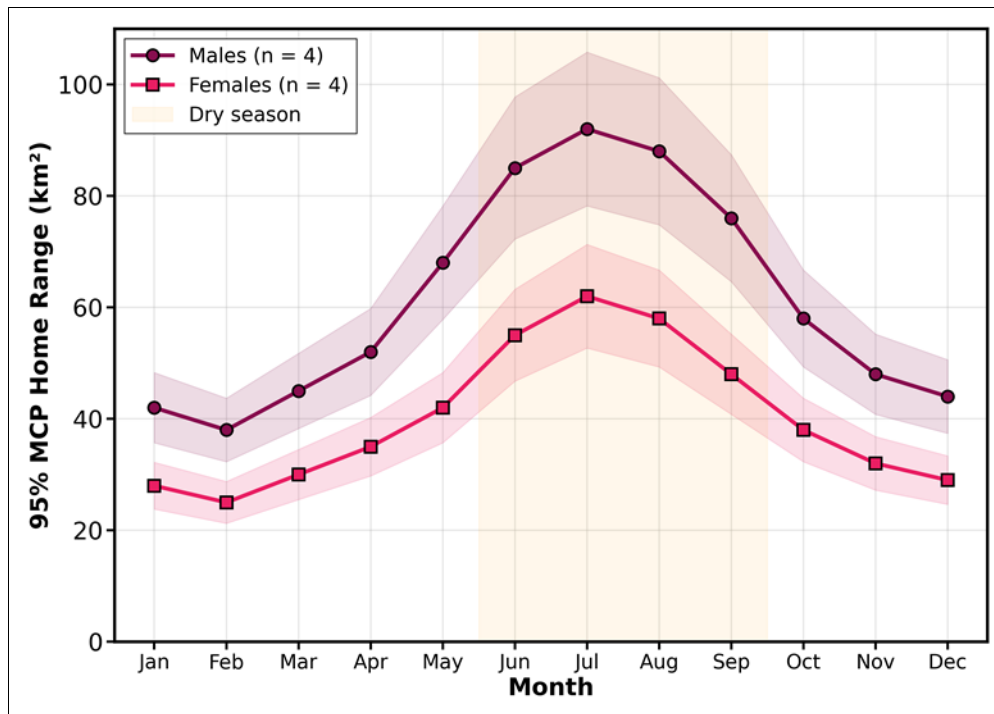


Fig 4: Monthly 95% MCP home range size for male and female elephants. Shaded band indicates the dry season (May-September), during which home ranges expanded substantially for both sexes

Synthesis

The data reveal a clear seasonal pattern: elephants contract into dense forest during the wet season, when forage is abundant, and expand into grassland and cropland edges during the dry season, when forest browse quality declines.

Males range farther and visit cropland more frequently than females, and the majority of cropland-edge fixes occur at night. Riverine corridors serve as movement conduits connecting forest patches, used disproportionately relative to their landscape availability.

Discussion

This research provides the first satellite telemetry dataset for free-ranging domestic elephants in Sri Lanka, revealing seasonal home range expansion, sex-based differences in ranging behaviour, and a strong nocturnal bias in cropland utilization findings that have direct implications for human-elephant conflict mitigation. The mean annual home range of 65.8 km² for males and 40.3 km² for females falls within the range reported for wild Asian elephants in comparable dry-zone habitats. A GPS collar deployment on wild elephants in the Nilgiri Biosphere Reserve, India, recorded male home ranges of 50-115 km² and female ranges of 30-60 km² [8]. The concordance suggests that free-ranging domestic elephants adopt spatial strategies similar to those of wild conspecifics, despite their history of human management a finding with conservation significance, as it implies that habitat requirements for both groups are equivalent. The seasonal shift from forest to grassland and cropland edges during the dry season is consistent with optimal foraging theory: as forest leaf quality declines (lower crude protein, higher fibre), elephants seek the higher-energy forage available in regenerating grasslands and cultivated crops [11]. The nocturnal concentration of cropland fixes (62% between 18:00 and 06:00) aligns with reports from Africa showing that elephants learn to time crop-raiding to minimise encounters with humans, suggesting a risk-reward trade-off that favours night-time foraging in high-risk areas [7]. One notable departure from the wild-elephant literature is the higher proportion of cropland-edge utilization by males (14.8%) compared to females (8.1%). In wild populations, crop raiding is also male-biased, attributed to the larger body size and greater caloric demands of males, their tendency to travel alone (making detection harder), and their bolder temperament [12]. That the same sex bias appears in domestic elephants animals with equivalent prior exposure to human environments suggests that the behaviour has a strong physiological rather than purely experiential driver. The disproportionate use of riverine corridors as movement pathways has direct management implications. Riparian vegetation along the Walawe and Kiri Oya rivers connects otherwise isolated forest patches, enabling elephants to traverse the landscape without crossing extensive open cropland. If these corridors are degraded by sand mining, bank cultivation, or clearing for homesteads, elephants will be forced into more direct and more conflict-prone routes through agricultural land [13]. Protecting a minimum riparian buffer width of 100 m on each bank, as recommended by the National Physical Planning Department, would preserve these movement conduits at relatively low opportunity cost.

Conclusion

This research demonstrates that satellite telemetry can resolve the spatial and temporal patterns of free-ranging domestic elephant movement with sufficient precision to inform targeted conflict mitigation strategies. The dataset 63,418 validated GPS fixes from eight elephants over 12 months reveals three actionable findings. First, home ranges expand by 36-48% during the dry season, driven by a shift in habitat preference from dense forest to grassland and cropland edges. This seasonal expansion is predictable and creates a defined window of elevated conflict risk (May-September) during which mitigation effort should be intensified. Second, 62% of all cropland-edge fixes occurred at night, confirming the nocturnal timing of crop-raiding events. Early-warning systems based on real-time collar data and motion-sensor

alerts positioned along the five most frequently crossed cropland boundaries identified by this dataset could provide communities with 30-60 minutes of advance warning. Third, riverine corridors along the Walawe and Kiri Oya rivers function as critical movement pathways; their protection should be a priority in district-level land-use planning. For the broader field of elephant conservation, these findings underscore the importance of treating free-ranging domestic elephants as ecologically relevant members of the landscape rather than as anomalies to be removed. Their movement patterns, habitat preferences, and conflict behaviour closely parallel those of wild conspecifics, suggesting that conservation and conflict-management frameworks designed for wild elephants are equally applicable with minor adjustments for the greater human tolerance of domestic animals to the growing population of unmanaged domestic elephants. Several questions remain open. Whether the movement patterns documented here persist across years with different rainfall regimes is unknown; a multi-year monitoring effort is needed to capture inter-annual variation. The sample of eight animals, while adequate for characterising broad patterns, is too small to examine individual-level variation in crop-raiding propensity a variable that may be influenced by age, body condition, and prior management history. The effectiveness of the early-warning system proposed on the basis of this spatial analysis requires field testing in a controlled before-after intervention trial. Finally, genetic sampling of collared animals could clarify whether free-ranging domestic elephants reproduce with wild populations, which would have implications for both genetic management and population estimates.

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