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Living on the Edge: Assessing spatio-temporal dynamics of Human-Elephant Interactions in Udalguri, Assam

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Abstract

Landscape transformation due to expanding agriculture and infrastructure in Asia has led to extensive habitat loss and fragmentation for Asian elephants (*Elephas maximus*), intensifying human-elephant conflict (HEC) across their range. India, home to nearly 60% of the global Asian elephant population, faces a rising conservation challenge as elephants increasingly venture into human-dominated landscapes, resulting in frequent crop raiding, property damage, and casualties on both sides. This study investigates the spatiotemporal dynamics of HEC in Udalguri district, Assam, a critical elephant landscape bordering Bhutan. Using 13 years (2011–2024) of data obtained from forest departments and validated through ground truthing and community interaction. We quantified seasonal trends in human casualties, property damage, crop raiding, and elephant mortality to identify conflict hotspots. A total of 221 human casualties (144 deaths, 77 injuries) and 96 elephant deaths (14.5% due to electrocution) were recorded, with monsoon and post-monsoon showing the highest conflict intensity. Males were disproportionately affected in human casualties and elephant mortality. Crop raiding was most frequent in the post-monsoon, with paddy being the primary target. Generalized Linear Mixed Model (GLMM) analyses revealed significant effects of season, crop type, and sex on HEC patterns. Conflict hotspots were concentrated near Bornadi Wildlife Sanctuary (BWS) and Khalingduar Reserved Forest (KRF), highlighting the role of forest edges, paddy fields, and tea estates as high-risk zones. Our findings emphasize the need for adaptive, seasonally informed management strategies that integrate habitat restoration, corridor protection, cross-border coordination, and community-based interventions. Reducing anthropogenic threats, improving compensation schemes, and enhancing early warning systems are critical for fostering coexistence. The study offers a robust empirical foundation for designing region-specific mitigation strategies and reinforces the urgency of transboundary, multi-stakeholder approaches to secure the future of Asian elephants in Northeast India.

Keywords: Asian elephants, crop-raiding, habitat fragmentation, HEC, seasonal patterns, tea, transboundary

Introduction

Rapid expansion of human settlements and agriculture in Asia and Africa has led to significant loss of elephant habitats, reduced forage availability, and diminished landscape connectivity, resulting in a marked decline in elephant populations (Thouless *et al.*, 2016; Calabrese *et al.*, 2017). As habitats shrink, elephants are forced into closer contact with human-dominated landscapes, leading to frequent and severe negative interactions over space and resources, including crop raiding and fatal encounters (Leimgruber *et al.*, 2003; Newmark, 2008; McDonald *et al.*, 2009; Western *et al.*, 2009; White & Ward, 2010; Liu *et al.*, 2017). HEC poses a significant challenge in regions where the livelihoods of local communities and the conservation of elephants are closely intertwined, as ongoing landscape transformation further increases the risk of lethal interactions (Naha *et al.*, 2020; Cabral de Mel *et al.*, 2022; de la Torre *et al.*, 2021).

Considering these escalating challenges, the status of Asian elephants (*Elephas maximus*) highlights the urgency of comprehensive conservation efforts. According to the International Union for Conservation of Nature (IUCN, 2024), Asian elephants are classified as "Endangered" on the IUCN Red List, and the species is included in Appendix I of the Convention on International Trade in Endangered Species (CITES). Asian elephants are protected under Schedule I of the Wildlife (Protection) Act, 1972. Their populations are estimated to range between 41,410 and 52,345 individuals across 13 Asian countries, now confined to just 5% of their historical range (Sukumar, 2006). Ever-increasing human population and extensive habitat fragmentation have reduced their available habitat, with only 51% of their range consisting of large, contiguous forested landscapes (Leimgruber *et al.*, 2003). Native to India, Sri Lanka, Thailand, and other Southeast Asian nations, these elephants inhabit diverse forest and grassland ecosystems (Sukumar, 2003).

India harbors the world's largest Asian elephant population, which accounts for nearly 60% of the global total, with estimates of 25,000 to 30,000 individuals spread across approximately 163,000 km^2 of diverse habitats (Pandey *et al.*, 2024b). Asian elephants are long-lived, wide-ranging mega-herbivores whose survival depends on their ability to travel great distances in search of food, water, and social opportunities (Sukumar, 2003). Moreover, a typical family herd, comprising approximately 5 to 20 individuals, occupies a home range spanning 100 to 1,000 km^2 (Fernando & Lande, 2000; Williams *et al.*, 2001; Alfred *et al.*, 2012). Additionally, elephants play a critical ecological role by dispersing seeds and enhancing the survival of large-fruiting trees in protected areas, an engineering effect that underpins the integrity of forest ecosystems (Fritz, 2017; Sekar *et al.*, 2017). Recognizing their ecological and cultural significance, India designated the species as a National Heritage Animal in 2010 (Pandey *et al.*, 2024a).

HEC in India epitomizes the complex interplay between wildlife conservation and development. Fragmentation and disruption of traditional migratory routes for wild Asian elephant populations (Sukumar, 2003; Rangarajan *et al.*, 2010) force elephants out of their natural habitats and into areas dominated by human activity. This trend is especially evident in forested regions such as the Western and Eastern Ghats and in northeastern states like Assam, where intensified human pressure further escalates negative interactions (Choudhury, 2004). Within these human-altered landscapes, elephants frequently forage on crops and encounter roadways, further intensifying negative interactions that threaten their survival and impose considerable socio-economic burdens on local communities. India alone reports approximately 500 human fatalities and 100 elephant deaths annually from such incidents, with an estimated 500,000 families affected by crop damage (Somu & Palanisamy, 2022). In response to these escalating challenges, India has implemented robust measures to safeguard its wild elephant population and mitigate negative interactions. Project Elephant, launched in 1992, protects elephants and their migratory corridors by establishing 33 Elephant Reserves across 14 states, covering approximately 80,777 km^2 (PE-MoEFCC-WII, 2024). These conservation efforts have broadened their focus beyond mitigating habitat degradation and reducing direct mortality to also address issues such as ivory poaching, trafficking, and growing competition for space (Sukumar, 2006). Complementing these initiatives, legal frameworks such as the Wildlife (Protection) Act, 1972 and the Forest (Conservation) Act, 1980 regulate habitat destruction and infrastructure development, fostering integrated strategies that promote coexistence and effective management of negative interactions (Pandey *et al.*, 2024a).

In Northeast India, Asian elephants are found in states including Assam, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Tripura, Mizoram, and Sikkim (Choudhury, 2004). The region is estimated to support approximately 10,139 wild elephants, with Assam alone hosting 5,719 individuals, making it the state with the highest elephant population (MOEFCC, 2017). In response, the Government of India has declared five Elephant Reserves that collectively cover approximately 10,967 km^2 (MOEFCC, 2017). Moreover, maintaining connectivity in fragmented habitats is critical. So far 30 key elephant corridors have been designated to link habitat patches in Northeast India, with Assam holding 12 of these corridors (MOEFCC, 2017; Pandey *et al.*, 2024b). These protected areas and corridors are at the core of the integrated management strategies designed to mitigate negative interactions and ensure the long-term survival of this keystone species, although continued rapid human development is likely to further exacerbate HEC.

In Udalguri district, Assam, the increase in human activities near forest areas has intensified HEC, posing significant challenges for both conservation efforts and local communities. The district includes parts of the Tiger Reserve, which serves as a corridor for elephants. Between 2010 and 2019, the Dhansiri Forest Division (FD) in Udalguri district reported 62 elephant and 155 human fatalities due to HEC (Banerjee, 2022). In 2024, a synchronized elephant population estimation recorded 97 elephants in the Dhansiri FD (Piraisoodan *et al.*, 2024).

This situation underscores the importance of understanding the spatial and temporal patterns of human-elephant interactions to develop effective mitigation strategies and ensure the long-term survival of elephants. This study aims to (a) quantify and characterize seasonal trends in HEC in Udalguri over 13 years, focusing on human fatalities, elephant deaths (both human-induced and natural), and crop-raiding incidents, and (b) map the spatial distribution of negative interaction, identifying hotspots for human casualties, crop raiding, property damage and elephant deaths. By providing a baseline understanding of these dynamics, this study would help to inform future monitoring efforts and offer valuable insights into the current state of human-elephant interactions in the region.

Study Area

Udalguri district, administered under the Bodoland Territorial Council (BTC), is in northeastern Assam, India (Figure 1). The district spans approximately 1,852.16 km^2 and is situated at about 26° 46′ N latitude and 92°08′ E longitude (Khanikar, 2017). Established in 2004 following the bifurcation of Darrang district, Udalguri is bounded by Bhutan and West Kameng district of Arunachal Pradesh to the north, Sonitpur district to the east, Darrang district to the south, and Baksa district to the west. The name Udalguri denotes a place surrounding the Udal tree (*Sterculia villosa*), also known as the elephant rope tree, with "Udal" meaning tree and "Guri" meaning surrounding area.

The landscape of Udalguri is a diverse mosaic of agricultural fields, tea estates, forest tracts, and riverine zones. According to the Tea Board of India, Assam has 845 registered tea estates, with 25 located in Udalguri (Baro, 2021). According to The Indian Express (2015), tea estates serve as natural corridors for elephants. Moreover, key forest areas include the Dhansiri Forest Division and the Khalingduar Reserve Forest, both of which contribute significantly to the region's ecological balance. Bornadi Wildlife Sanctuary (BWLS) and Khalingduar Reserve Forest (KRF) are key parts of the Manas Tiger Reserve (MTR), with the BWLS at the core and the KRF acting as the buffer. The Neoli Proposed Reserve Forest, located in the Nunoi range, connects these two areas (BWLS and KRF), enhancing landscape connectivity. In contrast, Bhairabkunda Reserve Forest (BRF), situated near the Indo-Bhutan border, extends the protected

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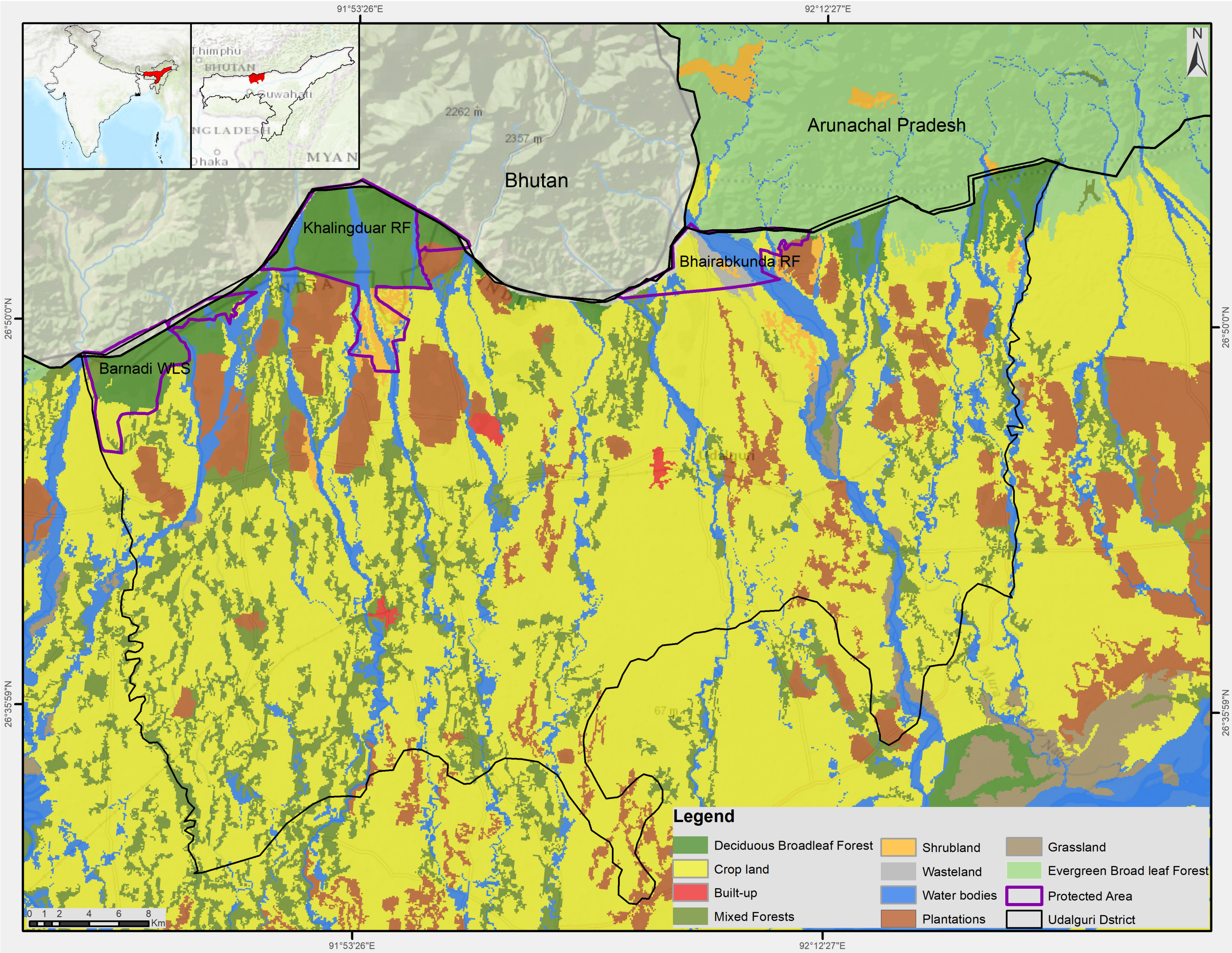

Figure 1. Study area map of Udalguri District, Assam showing the land use, land cover (LULC), and protected area (PA's) boundaries.

landscape beyond the national boundary (Khanikar, 2017; Banerjee & Sharma, 2022). Climatically, the district has a subtropical humid climate characterized by semi-dry, hot summers and cold winters. Agro-climatically, Udalguri falls under the North Bank Plain Zone (Khanikar, 2017). During summer, from May to early September, the region experiences heavy rainfall due to the south-west monsoon, often resulting in flooding. The district receives an average annual rainfall of about 2,000 mm, with temperatures ranging between a maximum of 34.5°C and a minimum of 13.5°C. Relative humidity typically ranges between 82% and 88% (Khanikar, 2017).

According to the 2011 Census, Udalguri district has a population of 831,668, marking an increase of 9.8% since 2001. The district has a literacy rate of 66.6% and a gender ratio of 966 women per 1,000 men, with a population density of 449 inhabitants per square kilometer. Scheduled Castes and Scheduled Tribes account for 4.55% and 32.15% of the population, respectively. The district is multi-ethnic and multi-religious. Bodo constitutes the largest ethnic group, comprising 33.76% of the population. The Adivasi community forms nearly 23.12%, while Bengali Muslims account for about 12%. In urban areas, Assamese and Bengali Hindus are more prevalent, and there is also a scattered presence of the Nepali-speaking Indian Gorkha community, estimated at around 5% of the district's population.

Methodology

HEC data collection

HEC data were collected from the Divisional Forest Office (Dhansiri) and Range Offices (Bornadi, Nunoi, and Mazbat) in Udalguri district, Assam, for a duration between 2011 to 2024. The dataset included incident locations, division names, and dates, along with human casualties (death and injury) by gender, elephant deaths (with date, cause, age class, and gender), and records of crop raiding and property damage with village names and dates. For analysis, the data were categorized seasonally as: Pre-monsoon (March to May), Monsoon (June to August), Post-monsoon (September to November), and Winter (December to February).

Moreover, information obtained from forest department records were cross-verified through ground-truthing at incident locations (for both human and elephant mortality) and discussions with local communities to confirm the accuracy of event details and GPS coordinates.

Data Analysis

Trends of HEC were examined on a yearly and monthly basis for human fatalities, injuries, and crop-forage incidents. Similarly, elephant mortality data were analyzed annually and seasonally, with further breakdowns by age class, gender, and cause of death. Inferential analyses were performed using chi-square tests of independence to evaluate whether the observed differences among categorical variables were statistically significant. In instances where expected cell frequencies were below five, Monte Carlo simulations (10,000 replicates) were employed to obtain robust p-values. When an overall chi-square test yielded a significant result, post hoc pairwise comparisons adjusted using the Bonferroni correction were conducted to identify the specific group differences driving the association. The intensity of HEC, including property damage, crop raiding, and human casualties, was mapped using a kernel density estimator in ArcGIS 10.8.

We assessed habitat preferences using the adehabitatHS package in R (version 4.4.0; R Core Team, 2024). Available habitat, based on data from the National Bank for Agriculture and Rural Development (NABARD, 2016), was comprised of paddy fields, home gardens, and tea estates. Habitat use data were collated from the collected HEC records and compared against availability using Manly's selection index (Wi). We used GLMM via the glmmTMB package in R (version 4.4.0; R Core Team, 2024) to analyze two aspects of human-elephant interactions. A Poisson GLMM was applied to assess the effects of season and sex on human casualties, with year included as a random effect. For elephant crop raid incidents, a negative binomial GLMM was used to model the influence of season and crop type, including year as a random effect.

Result

Human Casualties

Between 2011 and 2024, Udalguri reported 221 human casualties from elephant interactions, including 144 deaths and 77 injuries. Men were more affected (198 cases: 129 deaths, 69 injuries) than women (23 cases: 15 deaths, 8 injuries). However, no trend was observed in elephant attacks on humans during the study period (Figure 2). Monsoon and post-monsoon seasons each recorded 73 incidents, followed by pre-monsoon (41) and winter (34). Of 144 human deaths, only 21 occurred within PA (BWLS and KRF), and 123 occurred outside PA. Similarly, 5 of 77 injuries were inside PA (Figure 3). Elephant attacks were significantly lower in winter ($\beta = -0.75$, $p < 0.001$) and pre-monsoon ($\beta = -0.43$, $p = 0.026$) compared to the monsoon season. Men-related incidents were substantially higher ($\beta = 1.16$, $p < 0.001$) (Supplementary S1). Yearly variation (variance = 0.25±0.5 (SD)) was modest but included in the model (Table 1).

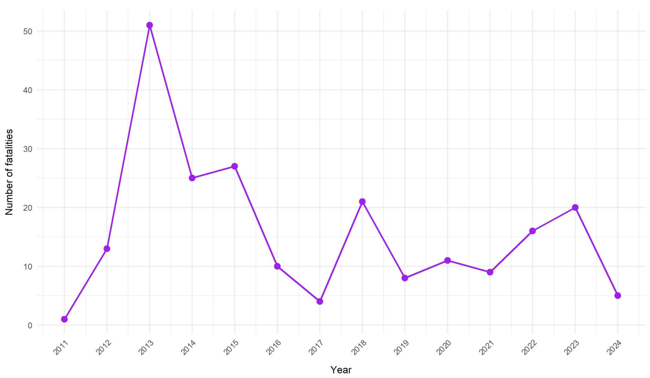

Figure 2: Annual trend of human casualties in Udalguri, Assam (2011–2024).

Crop Raiding: Seasonal Patterns

A total of 1,171 crop-raiding incidents were reported in Udalguri between 2011 and 2024, with paddy being the primary target, accounting for 90.18% of the incidents. Other affected areas included arecanut plantations (4.24%), tea estates (3.28%), and home gardens (2.30%) (Figure 3). Incidents peaked during the post-monsoon season (592), followed by monsoon (318), winter (146), and pre-monsoon (115), with paddy raids dominating across all seasons. (Figure 4). According to NABARD data (2016), paddy (69.48%) was the predominant crop in the study area, followed by home gardens (23.52%) and tea estates (1.50%) as notable land-use types. Scaled selection ratios (Supplementary S2) indicated a strong elephant preference for tea estates ($B_i = 0.59$) and paddy ($B_i = 0.39$), while home gardens ($B_i = 0.02$) were the least selected. Manly's index confirmed the active selection of tea estates and paddy.

Table 1. Parameter estimates (β with standard errors, SE) and statistical significance (z-values and p-values) for the effects of season and sex on human casualties due to elephant attacks, with the year as random effect.

Predictor	Estimate (β)	Std. Error	z-value	p-value
(Intercept)	0.54	0.27	2.02	0.043 *
Season: Post-monsoon	-0.22	0.18	-1.18	0.23
Season: Pre-monsoon	-0.43	0.19	-2.22	0.026 *
Season: Winter	-0.74	0.22	-3.43	0.0006 **
Sex: Male	1.16	0.23	4.94	7.6e-07 **
Random effect (Year)	Variance= 0.25±0.5 (SD)			

*Note: * *Statistically significant at <0.05 level,*
*** Statistically significant at < 0.01 level*

GLMM analysis (with year as a random effect; variance = 2.86±1.69 (SD)) showed that paddy experienced significantly higher raiding incidents ($\beta = 2.63$, $p < 0.001$), while home gardens were raided significantly less ($\beta = -1.42$, $p = 0.045$). Crop raiding was significantly lower during winter compared to the monsoon season ($\beta = -1.90$, $p = 0.013$). A significant increase in paddy raiding was observed in the post-monsoon season ($\beta = 2.05$, $p = 0.011$) (Table 2).

Property damage

A total of 2,984 property damage incidents were reported; the properties affected included houses (2,886), grocery shops (44), community structures (35), and storehouses (6). The damage varied significantly across seasons ($\chi^2 = 30.99$, df = 12, $p < 0.05$), with monsoon and post-monsoon linking to the greatest impact (Supplementary S3). Our spatial analysis revealed that most crop raiding and property damage incidents occurred along forest boundaries, particularly near BWLS and KRF (Figure 3). These areas, dominated by paddy and tea estates, create a high-risk interface between human activities and elephant habitats.

Elephant mortality

A total of 96 elephant deaths were reported, with 21 attributed to anthropogenic, 20 to natural, and 55 to unknown causes. However, the anthropogenic cause of elephant mortality showed significant associations with gender ($\chi^2 = 3.86$, $p = 0.049$), season ($\chi^2 = 18.00$, $p < 0.001$), and age class ($\chi^2 = 8.86$, $p = 0.012$) (Supplementary S4, S5, and S6). Males and sub-adults were more affected, with most deaths occurring in the post-monsoon season. Mostly the deaths occurred close to the protected areas except one juvenile male that died in the southern part of Udalguri district (Figure 5).

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Table 2. Parameter estimates (β with standard errors, SE) and statistical significance (z-values and p-values) for the effects of crop type and season on elephant crop raiding and damage incidents with the year as random effect.

Predictor	Estimate (β)	Std. Error	z value	p-value
(Intercept)	−0.057	0.65	−0.087	0.93
Season: Post-monsoon	−1.264	0.69	−1.830	0.067 .
Season: Pre-monsoon	−1.177	0.662	−1.779	0.075 .
Season: Winter	−1.898	0.764	−2.485	0.013 *
Crop type: Home garden	−1.423	0.711	−2.002	0.045 *
Crop type: Paddy	2.627	0.526	4.993	<0.001 ***
Crop type: Tea plantation	−0.719	0.608	−1.184	0.236
Post-monsoon × Home garden	−0.638	1.42	−0.449	0.653
Pre-monsoon × Home garden	0.001	1.156	0.001	0.999
Winter × Home garden	1.072	1.197	0.896	0.37
Post-monsoon × Paddy	2.053	0.808	2.541	0.011 *
Pre-monsoon × Paddy	−0.413	0.811	−0.509	0.611
Winter × Paddy	1.224	0.891	1.373	0.17
Post-monsoon × Tea plantation	−0.617	1.098	−0.562	0.574
Pre-monsoon × Tea plantation	−0.026	0.972	−0.027	0.979
Winter × Tea plantation	0.252	1.101	0.229	0.819
Random effect (Year)	Variance = 2.86±1.69 (SD)			

*Note: * Statistically significant at <0.05 level,*
**** Statistically significant at <0.001 level*

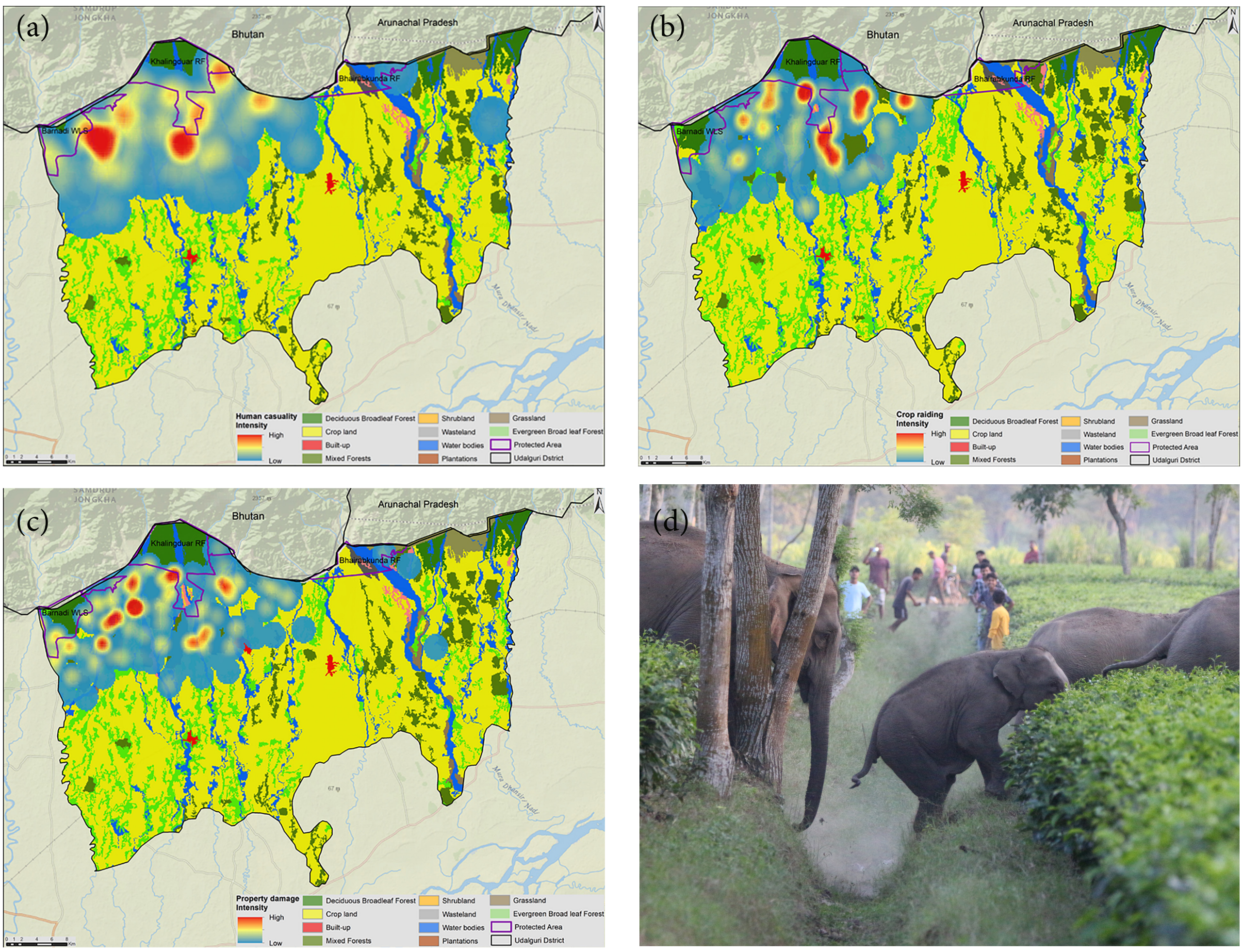

Figure 3: Map showing the hotspot of (a) human casualties, (b) crop raiding, (c) property damage caused by elephants and (d) an incident of human-elephant interaction in Udalguri, Assam (2011-2024).

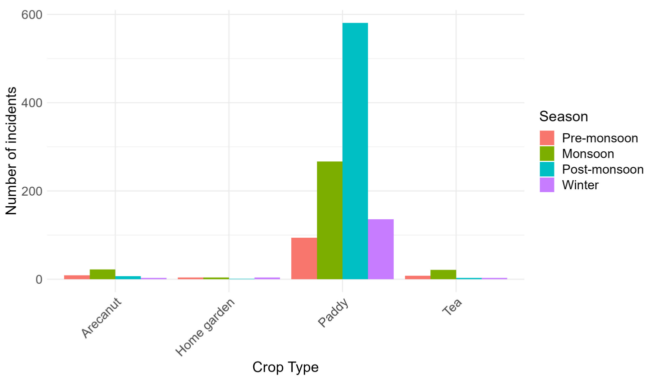

Figure 4: Bar graph depicting the number of elephant crop raiding and damaging incidents by crop type and season.

Discussion

Our study revealed significant annual and seasonal variations in human casualties, pointing to spatiotemporal trends that are crucial for managing HEC. Most incidents occurred outside the forest area, particularly along the boundaries of reserves such as BWLS and KRF, emphasizing the need for mitigation strategies that extend beyond the study area. This pattern aligns with findings from other regions of India, where communities living on the edges of wildlife habitats face heightened conflict (Mohanty & Mishra, 2017; Gubbi, 2012; Nath *et al.*, 2009). In these peripheral zones, including tea estates, often serve as de facto corridors and temporary shelters for elephants that bridge forest patches, croplands, and human settlements (Talukdar *et al.*, 2024; Kashyap, 2015). Although elephants do not forage on tea, their presence in tea estates frequently coincides with crop raiding and village intrusions, intensifying HEC (Vasudev *et al.*, 2020; Wilson *et al.*, 2013; Sukumar, 2003).

Crop raiding and property damage, influenced by seasonal resource availability and elephant movement patterns, are key drivers of HEC. Our findings, consistent with earlier studies, indicate that human casualties peak during the monsoon and post-monsoon, marked by heightened elephant activity and increased crop availability (Dangol *et al.*, 2020; Naha *et al.*, 2020; Rohini *et al.*, 2016; Wilson *et al.*, 2013). In addition to crop raiding, elephants frequently damage properties near forest edges while searching for food (Tripathy *et al.*, 2021 a, b; Gross *et al.*, 2020; Joshi *et al.*, 2020). In Udalguri district, the clustering of human settlements near forests has increased the frequency and severity of such incidents. Men face disproportionately higher casualties due to their involvement in field-based activities near the forest boundary (Sarker *et al.*, 2015). Meanwhile, between 2007 and 2016, elephant activity in Assam led to the destruction of 8,333 houses and damage to 1,400 hectares of cropland (BehanBox, 2023). Notably, in 2015 alone, 108 houses built under the Indira Awaas Yojana were destroyed in villages such as Nonaikhuti,

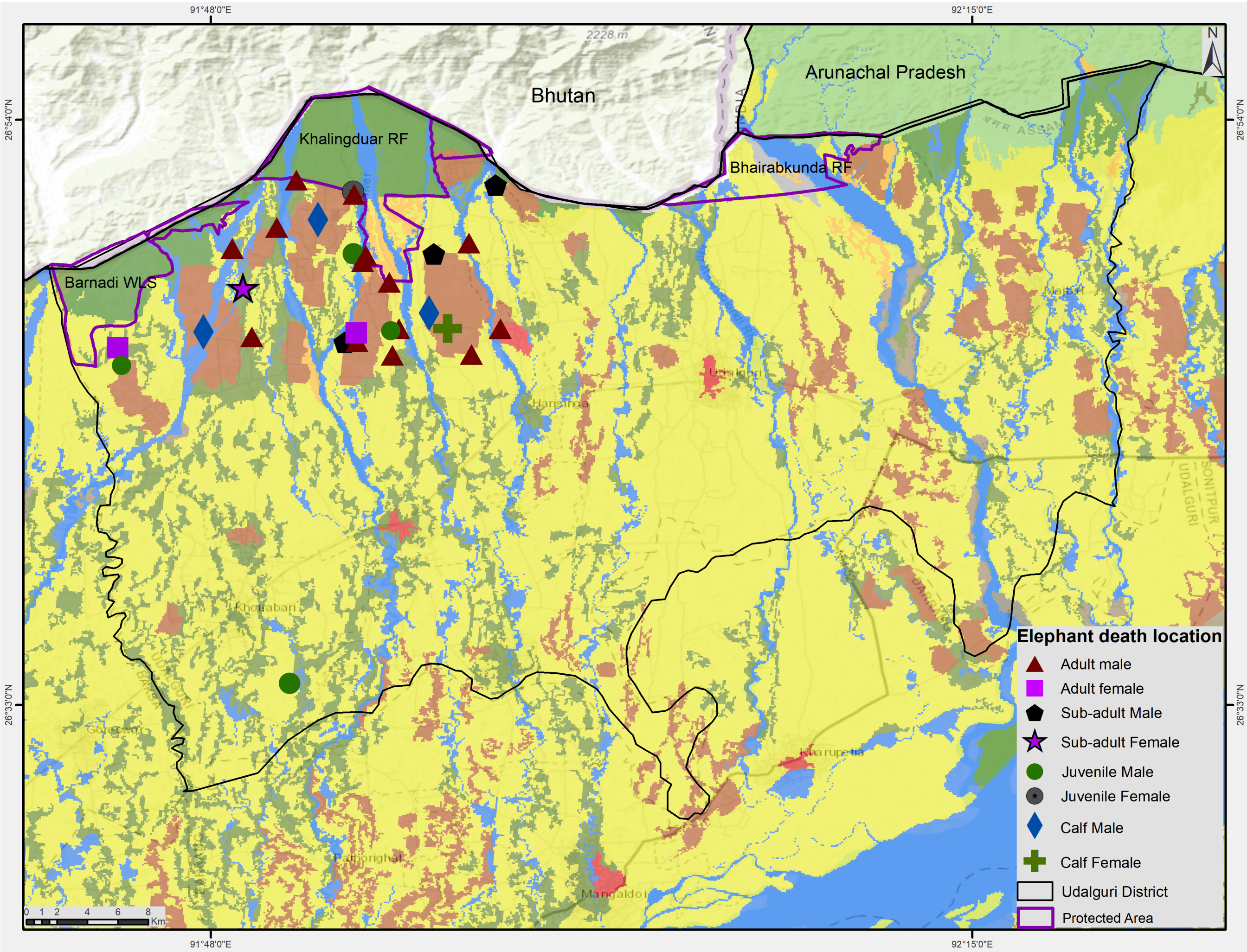

Figure 5: Spatial distribution map of Elephant Mortality in the study site by Age Class and Gender.

Bamunjuli, and Rajagarh (Earth Journalism Network, 2019), highlighting the vulnerability of state-supported housing located in high-risk zones. These temporal and spatial patterns in elephant- driven damages underscore the urgent need for targeted, seasonally adaptive mitigation strategies with an emphasis on safer land use planning in elephant-prone areas.

Elephant deaths, largely attributed to human-induced causes, can impact overall population dynamics. Notably, many reported cases are labeled as unknown but are likely linked to anthropogenic activities. Males, particularly adults and sub-adults, exhibit higher mortality than females due to their solitary and wide-ranging behavior, increasing their exposure to risks (LaDue *et al.*, 2021; Naha *et al.*, 2020; Srinivasaiah *et al.*, 2019; Palei *et al.*, 2014; Fernando *et al.*, 2009). Mortality peaks during the monsoon and post-monsoon seasons, when increased resource availability draws elephants into human-dominated areas, exposing them to threats such as electrocution from power lines and poorly designed fences (Kalam *et al.*, 2018; Haturusinghe & Weerakoon, 2012).

Conservation Implementation

The spatial analysis showed that areas adjacent to forest areas dominated by paddy fields and tea estates, particularly near BWLS and KRF, are hotspots of HEC. Restoring corridors can help link fragmented habitats, reducing the pressure on elephants to venture into human-dominated landscapes. By creating safe passage routes and managing edge effects, it is possible to minimize encounters between elephants and humans, thereby reducing HEC incidents. As Udalguri borders Bhutan and lies within a transboundary elephant movement zone, cross-border coordination in mitigation, law enforcement, and monitoring is crucial to manage HEC effectively. Seasonal variations in HEC further emphasize the need for adaptive management strategies. The monsoon and post-monsoon periods, when HEC peaks, should be targeted for season specific interventions. Implementing early warning systems, increasing patrols, and local community-based monitoring during these high-risk seasons can help mitigate HEC.

Additionally, raising awareness among local communities about non-lethal deterrence methods and improving compensation mechanisms for crop and property losses are essential to foster a cooperative approach to coexistence. Compensation for crops and property damage is a vital component of successful conservation efforts, serving not only to mitigate the immediate financial losses incurred by local communities but also to foster long-term coexistence between people and elephants.

Reducing human-induced threats to elephants is another key consideration. Our observations indicate that elephant mortality is significantly linked to human activities such as electrocution and poisoning. Addressing these issues through the retrofitting of electrical infrastructure and stricter regulation of toxic substances near elephant habitats can help decrease unintended fatalities. Long-term monitoring, combined with local knowledge, is essential for developing practical, site-specific conservation strategies. Effective management of HEC requires coordinated efforts among forest departments, local communities, and conservation organizations.

A multi-pronged, transboundary approach (Tshering *et al.*, 2024) is vital to address governance challenges and sustain elephant populations:

- Institutional arrangements should be established to support transboundary elephant conservation, including political and legal frameworks, conflict mitigation protocols, and enforcement mechanisms.
- Regional cooperation can be strengthened through soft diplomacy and multi-stakeholder platforms to align efforts across administrative boundaries.
- Community engagement is key through cooperative guarding, solar fencing, and education programs that raise awareness about elephant conservation.
- Initiatives integrating capacity-building and law enforcement can help standardize monitoring, reduce illegal activities, and improve data sharing.
- Innovative land-use planning, such as extending eco-sensitive zones across national borders, is needed to preserve contiguous forest habitats and enable long-term conservation beyond political boundaries.

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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

All data are presented in the paper.

AUTHORS' CONTRIBUTION

AN, BH, PN Conceptualized the study, designed the methodology, and supervised data collection. RS, DB, AN collected data. AA, RS, RB, AN, BH help in analysis, interpreted results. RKP, DM, AMG, PN provided critical insights and assisted in manuscript revision and final approval. All authors have read and approved the final manuscript.

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