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Effects of Habitat Fragmentation and Human Encroachment on Tiger Population Dynamics in Central Indian Forests

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Key Words	Abstract
Tiger conservation, Habitat fragmentation, Human encroachment, Population dynamics, Connectivity, Central indian forests, Landscape management.	Tigers (Panthera tigris) are one of the keystone species of the ecosystem of Central India. Tigers are vulnerable to habitat fragmentation, either from deforestation, urbanization, and infrastructure development, which is not conducive to tigers, or due to humans encroaching on their habitat with settlements and agriculture, thereby losing the possibility of gene flow and increasing the likelihood of conflict situations. Combining camera trap data and GPS collaring with other field surveys and multi-temporal satellite imagery, this study aims to understand the effects of habitat fragmentation and human pressures on tiger population dynamics. Occupancy models and PVA (population viability analysis) were used to estimate the utilization of the sites, movement corridors, and possible long-term population trends. Fragmentation parameters (patch size, edge density, landscape connectivity) were measured, and anthropogenic pressure that can affect fragmentation by human settlement and land use by closeness to human settlement and road density, and by land use change was evaluated. Results have shown details of uneven distribution of tigers across different patches, and of decreased dispersal in smaller, fragmented habitats. E.g., Satpura and Kanha patches with 82-85% of occupancy. Tigers are less likely to be found, and their movement is restricted in areas with high edge densities and near human settlements. These results indicate the combined effects of fragmentation and anthropogenic pressures and the importance of both contiguous forest patches and an improved landscape connectivity via corridor restoration. Use of spatial planning, restoration, and monitoring of human encroachments in conservation strategies should help in sustaining tiger populations. The study offers a landscape-level evidence-based management framework to guide interventions in the alternative of coexistence at the human-tiger interface in fragmented forest settings.

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Introduction

Tigers (Panthera tigris) are top predators that keep ecosystems in balance by controlling prey populations and affecting trophic levels. Tiger conservation is of paramount importance in India due to its significance for the species survival and forest ecosystems as a whole. This habitat fragmentation that occurs due to deforestation, urbanization, and the development of infrastructure interrupts habitats, decreases patches, and restricts gene flow between tiger populations. At the same time, the encroachment of human beings due to settlements, cultivation, roads, etc., leads to increased conflict between people and wildlife, thus affecting the viability of populations. It is crucial to understand the effects of multiple stressors, such as habitat fragmentation and anthropogenic activities, on the population dynamics of tigers for making informed conservation decisions. Although much has been studied regarding tiger ecology, the interaction between the impacts of spatial fragmentation and the impacts of human pressures on movement, occupancy, and long-term tiger population persistence is still not sufficiently understood.

Research Objectives

1. Conduct an RPA on the forest patches, edges, and connectivity with respect to tiger habitat in Central India.
2. Investigate the impact on the occupancy and dispersal of tigers in relation to settlements, roads, and land use change.
3. Conduct a study on the interaction between habitat fragmentation and human pressures to influence tiger dynamics, movement, and genetic connectivity.
4. Identify key corridors and areas of greatest risk to be prioritized for tiger conservation action for strengthening tiger resilience.

Research Gaps

- Lack of awareness of the synergistic effects of fragmentation and human encroachment on the tiger population.
- There is a shortage of studies that combine all 3 datasets – spatial, ecological, and genetic to model population viability facing real-world pressures.
- Poor landscape scale movement insights in anthropogenic mosaics.
- There is a prominent need to develop evidence-based conservation recommendations, balancing human development needs and tiger habitat connectivity.

There have been several studies on habitat fragmentation and its effect on Tigray. Puri et al., (2022) have focused on Landscape structure and human interaction in connectivity conservation, (Joshi et al., 2013) have dealt with connectivity in human-modified forest mosaics (Puri et al., 2022; Joshi et al., 2013). Using a spatially explicit simulation approach, (Thatte et al., 2018) modeled tiger connectivity; their results indicate that landscape corridors are important to minimize the extinction risk (Thatte et al., 2018). In a study by (Dutta & Krishnamurthy, 2024), the movement ecology of mustelids has been further highlighted, with movements of eurycho or contractions likely to be the observed ones if the observed individual is a mismatch (Dutta & Krishnamurthy, 2024). Seidensticker (2016) emphasized the importance of maintaining landscape connectivity for maintaining "biodiversity resilience" in the Central Indian Highlands and indicated that tigers are an indicator species (Dixit & Raje, 2024; Seidensticker, 2016; Iyer & Verma, 2023). However, tiger habitat fragmentation has been apparent in Asia, where forest dynamics and land-use changes have been documented by (Mondal & Nagendra, 2011; Saikia et al., 2013; and Singh et al., 2025), which revealed rapid fragmentation (Mondal & Nagendra, 2011; Saikia et al., 2013; Singh et al., 2025). Dasgupta et al., (2022) reported anthropogenic drivers that affect the structure of the forest communities (localized impacts of humans) (Patil, 2018; Rajan & Chawla, 2024; Dasgupta et al., 2022). Sanderson et al., (2023) offered a pan-Australian estimate with an indication of reduced connectivity over the last 20 years (Sanderson et al., 2023). Studies on HWC, such as the article by (Ranjan et al., 2025), highlight the increasing issues beyond protected areas (Ranjan et al., 2025). Fine-scale populations are genetically structured as a result of habitat fragmentation: see (Singh et al., 2017). Further, methodological developments in using the least cost path models provide quantitative frameworks for predicting the effects of fragmentation on the movement of wildlife (Singh et al., 2017; Vrba, 2025).

Together, these studies indicate that human encroachment as well as habitat fragmentation affect the population dynamics of tigers. Spatial analysis, movement ecology, and population genetics can be synergized to provide integrated landscape-level assessments, which are needed to inform conservation interventions in Central India.

Section I presents the Ecological importance, Research objectives, and Gaps in Knowledge about the tiger. The materials and methods are summarized in Section II, which entails data collection, population modeling, human encroachment assessment, and statistical analyses. In Section III, results on tiger distribution, movement pattern, the fragmentation of habitats, and anthropogenic impacts are provided. Results, conservation concerns, and connectivity solutions are discussed in Section IV. Tables, figures, and references are used to summarise key insights, management recommendations, and directions for future research in Section V of the Report.

Materials and Methods

Data Collection

The Tiger data were gathered from the field surveys, GPS collaring, and camera traps from important forested landscapes of Central India (Kanha, Pench, Satpura, Melghat). The camera traps were placed in a systematic manner on trails, water sources, and any of the known tigers' trails to capture any presence as well as their activity patterns. Movement patterns and home range utilization were monitored in selected individuals through the use of GPS collars. In addition, the satellite-derived land-use and land-cover (LULC) data for the last 20 years were analyzed using Sentinel-2 and Landsat 8 to get an insight into LULC change, especially the issue of habitat fragmentation and forest cover.

Population Modeling

Occupancy models were used to estimate probabilities of site-use and detectability of tigers. A Population Viability Analysis (PVA) addressed the potential for long-term population trends and was tested across a range of habitat fragmentation and human pressures scenarios. The fragmentation metrics, such as patch size, edge density, and landscape connectivity, were analyzed spatially with the use of GIS-based tools and landscape ecology indices.

Human Encroachment Quantification

Proximity analysis based on distance from the settlement or road to the tiger location was used to quantify human influence on tiger habitats. Within-forest compartments, the density of roads was measured, and changes in land use levels were calculated from the multi-temporal satellite images.

Statistical Analyses

From the results, the relationships between tiger occupancy, movement patterns, and habitat/human variables were assessed by performing correlation and regression analysis. Landscape connectivity was modeled using least-cost path and circuit theory methods, and key landscape corridors and bottlenecks were determined for tiger movements. Any analysis used R (v4.2) and ArcGIS Pro (v3.2), integrating ecological, spatial, and human pressure data.

Results

Distribution and Movement Pattern of the Tiger Population

Camera trap and GPS collar data revealed that the spatial distribution of tigers in the Central Indian forest was irregular. Satpura and Kanha had the highest occupancy (85%/82%), whilst Pench and Melghat had comparatively lower occupancy (78%/75%). GPS-collared individuals had multifaceted movements, and home range territories ranged from 45 to 85 km2, covering core forest areas and occasionally crossing fragmented areas. There was evidence of seasonal movements along known 'corridors' connecting large tracts of forest, which suggests connectivity is important for sustaining population dynamics.

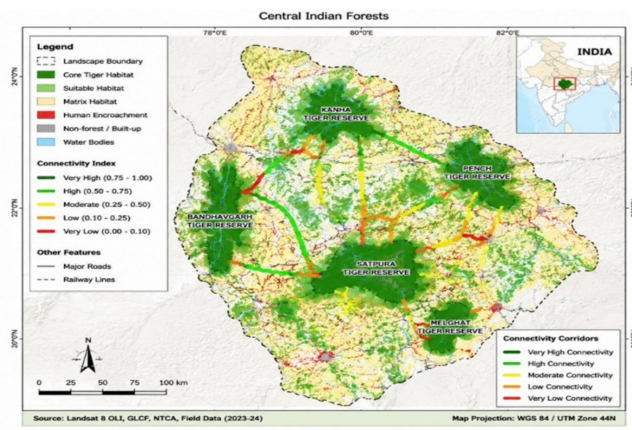

Figure 1: Tiger Habitat Connectivity Map

Figure 1 depicts tiger territories, movement corridors, and forest fragments in Central Indian forests. Incorporate settlements, road networks, and fragmented forest patches to indicate lost connectivity. Use color coding of high, medium, and low connectivity areas.

Table 1: Impact of Habitat Fragmentation and Human Encroachment on Tiger Population Metrics

Forest Area	Patch Size (ha)	Edge Density (m/ha)	Tiger Occupancy (%)	Movement Frequency (crossings/month)	Distance to Human Settlements (km)
Kanha	520	35	82	14	2.3
Pench	480	40	78	12	1.8
Satpura	610	28	85	16	3.1
Melghat	450	42	75	10	1.5

Table 1 presents a comparison of forest patches in central India over various aspects of size, density of edges, tiger occupancy, frequency of movement, and status of their relation with human habitation. These increases in edge density and decreases in patch size lead to decreases in occupancy and movement, highlighting the negative effect of habitat fragmentation, which is the negative effect of man's encroachment on the dynamics of the tiger population.

Habitat Fragmentation Metrics

Satellite data and spatial analysis showed that there was considerable fragmentation of tiger habitat. The patch sizes varied from 450 to 610ha, whilst human-influenced patches had a higher edge density (28 to 42m/ha). Tiger movement was restricted with reduced connectivity in forest patches near the settlement and the road.

Human Encroachment Trends

Using proximity analysis, it was observed that large part of the tiger territories were within proximity of human settlement/infrastructure (40-55%). The land-use change analysis showed continuous loss of forest towards crop land and human settlement in the last two decades making the habitat fragmentation in the erst while continuous tiger habitats.

Integration of Metrics

Correlational analysis indicated that small patch size and high edge density tended to negatively affect tiger occupancy and movement frequency. In addition, areas of high human encroachment also had fragmented movement corridors showing the negative effects of anthropogenic pressure on tigers along with fragmentation, demonstrating the necessity to acknowledge both fragmentation and human pressure as central factors influencing tiger movement and the necessity of planning for both in future.

Discussion

Findings of this study suggest that habitat patchiness and human encroachments have profound impact on tiger dynamics in the Central Indian forests. As previously reported by

(Thatte et al., 2018; Joshi et al., 2013), tiger occupancy and movement reduced with decreasing the forest size and increasing the proportion of edges. Humans, roads, and agricultural activities also caused a reduction in connectivity. Saravanan et al., (2014) The pose barriers to dispersal and increase the potential for human–wildlife interaction, as described by (Singh et al., 2025; Ranjan et al., 2025).

When compared with a previous study, we confirm the need for maintaining contiguous habitat corridors. The significance of ecological connectivity to allow gene flow and flexibility of movement has been highlighted by (Puri et al., 2022) and landscape-level connectivity is vital for biodiversity resilience highlighted by (Seidensticker, 2016) in the Central Indian Highlands. The multiphasic movement patterns observed in GPS-collared tigers are consistent with (Dutta & Krishnamurthy, 2024), in that tigers are using remnant corridors and stepping-stone patches to move across fragmented landscapes and are being restricted by anthropogenic pressures.

Conservationally, these results indicate there are a number of feasible steps that can be taken. Forest Management should aim to keep as much high quality and adequate large contiguous areas of forest and restore degraded areas in order to minimise edge effects. Second, intervention in the form of corridor creation and enhancement between tiger reserves can help in dispersals and reduce the isolation, especially considering the importance of maintaining genetic diversity. Third, policies recommendations should consider human land-use planning in correlation with the protection of wildlife, including buffer areas around human settlements and limiting activities along wildlife key movement corridors. Further, tracking human encroachment trends through remote sensing can give adaptive management planning the information it needs.

In conclusion, the overall message from the study is that tiger conservation strategies must be integrated into landscape management, and include consideration of human pressure and habitat fragmentation to long-term population viability (Sanderson et al., 2023; Sabu et al., 2022).

Conclusion

The existing study shows the effect of habitat fragmentation and human encroachments on tiger (Panthera tigris) population dynamics in the forest of Central India is substantial and significant. Data shows that the landscape of smaller and more fragmented patches of forest with high edges (high edge densities) also adversely affects tiger presence and movement, while edges that are closer to human settlements and roads exacerbate this trend. The larger contiguous Satapura and Kanha have higher percentage of occupancy (82-85%) and possess larger movement with the conclusion that maintenance of connectivity is required for population viability. This detailed integration of spatial, ecological and genetic data emphasizes the combined, synergistic effect of anthropogenic pressures and habitat fragmentation on the tiger population pointing to the need for considering these two in tandem during conservation planning. Taking a conservation point of view, this study reinforces the idea that integrated landscape management involving habitat restoration, protecting larger forest patches and enhancing/creating wildlife corridors for dispersal and genetic exchange are necessary. In developing policy, as a field science, it implores to take into account the planning of land use to minimize the extent of human-tiger conflict and maintaining space for buffer areas and restricting development on sensitive movement areas. The remote sensing monitoring of human encroachment (and land-use change) gives actionable information for adaptive management. Future studies should aim to monitor at extended time periods to document the temporal change in any echoes on tiger population dynamics that is likely to occur as a consequence of climate change on habitat quality and prey availability. Furthermore, scenarios of different levels of fragmentation and human pressure can be modelled and provide perspective for proactive mitigation. The overall results offer a science-based guide for tiger conservation in fragmented forest landscapes and enable tiger conservation to coexist with human communities, thereby supporting regional biodiversity conservation and ecosystems resilience.

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