

Evaluating Multi-Dimensional Community Interventions on Forest Dependency in the First Addition to Manas National Park, Assam, India

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Abstract

Local communities surrounding protected areas frequently rely on forest biomass for subsistence and income, presenting complex conservation challenges. We evaluated the association between multi-dimensional community interventions implemented by the Wildlife Trust of India and changes in forest resource extraction adjacent to the First Addition to Manas National Park (FAMNP), Assam, India. Applying Ostrom's Social-Ecological Systems framework analytically, we triangulated data over 2019–2021 across two monitoring streams: 1,872 hours of direct observational monitoring along 13 primary forest entry paths and household surveys across 10 fringe villages. Daily resource collectors fell by 59%, while critically forest-dependent households dropped by 80% (from 274 in 2018 to 54 in 2021). Resource extraction contracted asymmetrically: commercial timber declined by 88% and non-timber forest products by 83%, whereas subsistence fuelwood fell by 49%. Interventions combined micro-livelihood support, clean energy provision (LPG), an 11-km community-managed solar fence acting as a selective physical filter, and nine Eco-Development Committees establishing polycentric governance. Subject to confounds including the COVID-19 pandemic, these findings suggest that integrating spatial infrastructure, alternative asset creation, and local co-management can meaningfully decouple fringe community livelihoods from protected forest extraction in vulnerable transboundary landscapes.

1. Introduction

Globally, protected areas (PAs) are recognized as cornerstone instruments for biodiversity conservation, yet their effectiveness is often constrained by the livelihoods of adjacent communities who depend on forest resources for subsistence [1, 2]. In developing countries, an estimated 2.5 billion people rely on biomass sources to meet household energy needs [3]. The relationship between poverty and forest extraction is complex: increasing household assets does not always translate uniformly into reduced forest dependency [4, 5].

The First Addition to Manas National Park (FAMNP), notified in August 2016 as a 350 km² extension adjacent to Manas National Park—a UNESCO World Heritage Site—borders densely populated multi-ethnic communities in Chirang district, Assam, India. The Wildlife Trust of India (WTI) has implemented a portfolio of integrated interventions in this landscape since the early 2000s. Despite growing recognition of multi-dimensional approaches in conservation literature [6, 7], empirical evaluations of their association with reduced forest dependency in Northeast India remain limited.

This study uses two independent monitoring streams—behavioral observation and household surveys—to document changes in forest resource extraction and livelihood dependency in the FAMNP fringe over 2019–2021, examining these changes in relation to WTI's concurrent intervention program. We apply Ostrom's SES framework [8] to structure the evaluation across governance, user, and resource-unit dimensions.

2. Materials and Methods

2.1. Analytical framework. We applied Ostrom's [8] SES framework analytically to specify hypothesized interaction pathways across four subsystems: (i) resource systems (FAMNP forests and biodiversity); (ii) resource units (timber, fuelwood, NTFPs); (iii) governance systems (Forest Department, WTI, Eco-Development Committees [EDCs]); and (iv) resource users (fringe community members). WTI's governance-level interventions were hypothesized to alter user decision-making, manifesting as changes in resource unit extraction detectable through path monitoring. Household surveys captured downstream structural livelihood transitions [7].

2.2. Forest path monitoring. Thirteen forest use paths were identified through community consultations as primary entry points for resource extraction into the FAMNP (Fig. 1). Direct observational surveys were employed [9], wherein trained observers recorded all individuals, their resource loads, and mode of transportation without alerting observed individuals. Data collection spanned 2019–2021 (234 survey days, 1,872 hours), covering monsoon (May–June) and winter (November–December) seasons. Resource types were categorized as timber, fuelwood, or NTFPs; transportation modes as headloads, bicycles, or *thela* (hand-pulled carts; 300–400 kg/trip). Surveys were restricted to daytime (10:00 am–6:00 pm); nocturnal extraction could not be captured. However, the substantial decline in *thela* use—physically impractical at night—provides a monitoring signal less susceptible to temporal displacement bias.

2.3. Household dependency surveys. Household dependency was assessed in 2018 (baseline) and 2021 (endline) across all 10 fringe villages. Households were classified as critically forest-dependent, subsistence-dependent, or non-dependent. This classification is conceptually distinct from path monitoring data—their convergence constitutes methodological triangulation. Village-level endline data were unavailable; only the aggregate of 54 critically dependent households was verified through direct enumeration.

2.4. Study period context. The study period overlapped with the COVID-19 national lockdown (March–June 2020), which may have independently reduced path use. Three lines of evidence suggest a genuine conservation effect beyond the pandemic: (i) decline continued through 2021 after restrictions eased; (ii) structural household dependency shifts are unlikely to reflect temporary mobility constraints; (iii) the 66.5% decline in *thela* use is mechanistically linked to solar fence installation, as carts are impractical at night and the fence blocks boundary crossings.

2.5. Accordance. All observational and survey methods were performed in accordance with the relevant guidelines and regulations, specifically the National Ethical Guidelines for Biomedical and Health Research Involving Human Participants (specifically pertaining to Socio-Behavioural Research).

3. Results

3.1. Forest path use. The combined daily mean number of individuals using the 13 paths declined from 256 in 2019 to 157 in 2020 and 105 in 2021 (59% reduction; Table 1, Fig. 2). Path 4 recorded the highest absolute reduction (57.0 ± 8.4 to 17.2 ± 2.6). Path 6 exhibited a temporary increase in 2020 (2.82 to

13.66 individuals/day), likely reflecting temporary spatial displacement as solar fence construction obstructed major routes; by 2021 it had returned to near-baseline levels (4.50 individuals/day).

Table 1
Average daily number of individuals using each of the 13 forest paths (2019–2021; mean $\pm$ SE).

Forest path	2019 Mean $\pm$ SE	2020 Mean $\pm$ SE	2021 Mean $\pm$ SE
Path 1	9.99 $\pm$ 0.78	5.16 $\pm$ 0.45	4.50 $\pm$ 0.72
Path 2	43.99 $\pm$ 5.74	27.16 $\pm$ 3.02	18.99 $\pm$ 2.96
Path 3	4.99 $\pm$ 0.29	8.99 $\pm$ 1.60	2.83 $\pm$ 0.31
Path 4	56.99 $\pm$ 8.36	18.99 $\pm$ 2.09	17.16 $\pm$ 2.60
Path 5	8.49 $\pm$ 0.74	5.33 $\pm$ 0.48	4.83 $\pm$ 0.51
Path 6	2.82 $\pm$ 0.20	13.66 $\pm$ 0.53	4.50 $\pm$ 0.51
Path 7	29.83 $\pm$ 1.76	17.16 $\pm$ 3.32	15.66 $\pm$ 2.65
Path 8	39.82 $\pm$ 2.54	28.82 $\pm$ 2.09	16.49 $\pm$ 2.67
Path 9	11.32 $\pm$ 1.50	6.67 $\pm$ 0.28	4.50 $\pm$ 0.33
Path 10	4.83 $\pm$ 0.20	4.33 $\pm$ 0.77	3.17 $\pm$ 0.34
Path 11	15.00 $\pm$ 0.84	7.83 $\pm$ 0.41	3.00 $\pm$ 0.40
Path 12	23.16 $\pm$ 2.85	7.67 $\pm$ 0.90	7.83 $\pm$ 1.15
Path 13	4.83 $\pm$ 0.62	5.50 $\pm$ 0.61	1.67 $\pm$ 0.14
Combined total	256.06	157.26	105.10
<i>Note: Combined total is the sum of path-level means. 2020 reduction coincided with COVID-19 national lockdown; the 2021 decline occurred after restrictions eased.</i>			

3.2. Resource extraction. Fuelwood dominated extraction in 2019 (183 ± 3.8 units/day), followed by NTFPs (57.5 ± 1.4 units/day) and timber (8.0 ± 0.4 units/day). By 2021, absolute daily volumes declined across all types: fuelwood to 93.5 ± 1.6 units/day (– 49%), NTFPs to 9.5 ± 0.5 units/day (– 83%), and timber to 1.0 ± 0.1 units/day (– 88%) (Fig. 3). Proportional composition also shifted: NTFPs declined from 23.1% to 9.1% of total extraction volume, while timber fell from 3.2% to 0.9%, and fuelwood’s share rose from 73.6% to 89.9%, indicating commercially oriented extraction contracted faster than subsistence fuelwood collection.

3.3. Transportation mode. *Thela* use declined 66.5% by 2021, representing a disproportionate reduction in large-volume commercial extraction (Fig. 4). Overall assisted transport declined 41%. The solar fence physically obstructed *thela*-sized loads at boundary crossing points, providing a mechanistic explanation independent of the pandemic.

3.4. Household dependency. Baseline surveys (2018) identified 274 critically forest-dependent households (17% of 1,611 surveyed). Aggregate endline enumeration (2021) identified 54 critically dependent households (80% reduction; Fig. 5). Village-level endline data were unavailable; limitations of self-reported classifications are discussed in Section 4.7.

3.5. Interventions. Direct interventions provided livelihood support to 121 households and LPG connections to 60 households (181 total; 66% of the critically dependent baseline). Indirect interventions—EDC formation, solar fence management, and promotion of unused land cultivation—benefitted approximately 1,290 households across all 10 villages.

4. Discussion

Evaluating community conservation interventions requires disentangling multi-scalar interactions between human livelihood strategies, spatial landscape barriers, and institutional governance structures. Over the 2019–2021 evaluation period, monitoring in the FAMNP fringe revealed substantial, concurrent reductions in direct forest resource extraction and self-reported household dependency. These observed changes coincided with the execution of WTI's integrated community conservation framework. Applying Ostrom's (2009) SES framework analytically, these outcomes reflect mutually reinforcing feedbacks across four interconnected subsystems: governance systems, resource users, resource units, and the broader resource system.

4.1. Social-ecological systems synthesis and livelihood decoupling

The conceptual backbone of integrated conservation-development projects (ICDPs) rests on the premise that poverty alleviation and alternative asset creation can decouple rural livelihoods from forest degradation [2, 10]. In the FAMNP fringe, baseline conditions across 10 villages reflected severe resource dependency, with 274 out of 1,611 surveyed households (17%) categorized as critically forest-dependent. Under the SES framework, the Resource System (FAMNP's 350 km² protected forest core) was subjected to chronic extraction of Resource Units (timber, fuelwood, NTFPs) by Resource Users (fringe community members in Chirang District) operating under weak formal enforcement.

The multi-component intervention altered this feedback loop across multiple entry points. EDC institutionalization re-established rule legitimacy and community co-management platforms. Direct asset transfers (livelihood support and clean energy) reduced the economic necessity of forest entry. By 2021, critically dependent households declined 80% to 54, while mean daily human entry across 13 paths dropped 59% (256.1 to 105.1 individuals/day), indicating meaningful socio-ecological decoupling in a landscape with historical socio-political volatility [11].

4.2. Micro-economic resource selection: asymmetric contraction rates

A critical finding of this study is the asymmetric reduction across resource types: commercial timber extraction contracted by 88% (8.0 to 1.0 units/day) and NTFP gathering by 83% (57.5 to 9.5 units/day), whereas subsistence fuelwood collection declined by a more moderate 49% (183.0 to 93.5 units/day). This differential contraction provides empirical evidence regarding how household asset portfolios dictate resource harvesting decisions [12, 4].

In rural buffer zones throughout South Asia, commercial timber and bulk NTFP collection frequently function as high-effort, asset-generating strategies for capital-constrained households attempting to overcome liquid income deficits [13, 14]. By providing targeted micro-livelihood support—such as piggery, poultry, goat rearing, and horticulture—to 121 households, the project directly offset the financial drivers of commercial extraction. These alternative income streams enabled vulnerable households to “step up” (enhance asset accumulation) or “step out” (transition into non-forest livelihoods) from commercial forest exploitation [15, 16].

Conversely, fuelwood’s persistence (89.9% of remaining 2021 extraction) aligns with global energy transition paradigms. Households engage in “energy stacking,” using LPG alongside biomass [17, 3]. Complete fuelwood abandonment was limited by recurring refill costs and entrenched cooking habits [12]; elimination requires sustained subsidies and clean-energy infrastructure [18].

4.3. Spatial friction: solar fencing as a dual-function landscape mechanism

While physical barriers in conservation are traditionally designed to manage human-wildlife conflict (HWC), our findings suggest that the 11-km community-managed solar fence exerted a significant secondary influence on human resource extraction mechanics. The solar fence introduced selective physical friction across the landscape boundary, disproportionately suppressing bulk transport modes while leaving minor pedestrian traffic less constrained. Specifically, hand-pulled carts (*thela*) declined by 66.5% across seasons. *Thela* transport represents commercial-scale biomass extraction (300–400 kg per trip). Because hand-pulled carts require wide, clear ground access, the physical obstruction created by the solar fence perimeter effectively blocked cart passage at primary forest entry points. Conversely, bicycles and headloads exhibited smaller, gradual declines, as pedestrian harvesters could navigate narrow fence access gates or natural terrain bypasses, explaining why low-volume collection persisted at higher rates than cart transport.

The solar fence also generated a positive feedback for local agricultural economics. Prior to installation, crop-raiding by wildlife forced fringe farmers to abandon land adjacent to the park boundary. By reducing crop damage, the fence enabled safe recultivation of fallow fields, expanding agricultural yields without inducing forest clearing [11, 10]. Physical landscape infrastructure, when combined with community co-management, can therefore function as both an HWC mitigation tool and a non-coercive filter against large-scale extraction.

4.4. Spatial displacement, leakage signals, and path-level dynamics

A major methodological challenge in evaluating protected area interventions is distinguishing true extraction reductions from spatial or temporal displacement [5]. Our observational path data captured a clear signal of temporary spatial displacement along Path 6. In 2019, Path 6 recorded minimal usage (2.82 ± 0.20 individuals/day). In 2020, daily usage surged to 13.66 ± 0.53 individuals/day—a ~ 389% localized increase—before dropping to 4.50 ± 0.51 individuals/day in 2021. This temporary spike strongly suggests spatial displacement: as initial solar fence construction obstructed major extraction routes (such as Path 4, which dropped from 57.0 to 19.0 individuals/day), harvesters temporarily redirected activity toward Path 6. By 2021, as EDC governance consolidated and alternative livelihoods matured, extraction along Path 6 relaxed toward baseline levels, while aggregate path activity across all 13 routes reached a three-year low.

Regarding temporal displacement, because *thela* carts are physically unmanageable on unlit, rough forest terrain at night, the 66.5% reduction in cart volume provides a robust monitoring signal largely immune to nocturnal shift bias. Coupled with the 80% reduction in verified critically dependent households (274 to 54), the empirical weight of evidence indicates that the observed reductions represent a genuine contraction in landscape-level extraction pressure rather than a simple spatial reallocation.

4.5. Polycentric governance, institutional trust, and community co-management

Top-down, exclusionary protected area enforcement in socio-economically vulnerable landscapes often breeds hostility, retaliatory extraction, and enforcement failure [1, 2]. In the Bodoland Territorial Region, historical socio-political instability further strained community-state relationships [11]. Re-establishing effective governance required building polycentric institutional structures that fostered local self-governance [8, 7]. In comparable South Asian landscapes, approximately 40% of forest-adjacent households are at or near the poverty line, making institutional trust a prerequisite for sustained compliance with PA rules [19].

The nine EDCs provided a formal institutional bridge between the Assam Forest Department, WTI, and local village leadership. An estimated 1,290 fringe households benefitted indirectly from EDC-managed activities, including solar fence maintenance and recultivated land access. This explains why critically dependent households declined by 220 (274 to 54), exceeding the 181 direct beneficiaries. EDC formation created peer-monitoring networks, enhanced institutional legitimacy, and established shared norms around PA boundary rules [6, 18], driving community-wide reductions in forest dependency [1, 20].

4.6. Ecological implications for habitat recovery and megafaunal conservation

Suppressing chronic biomass harvesting and human foot traffic has direct benefits for forest structural recovery and wildlife conservation in FAMNP. Suppressing commercial timber logging preserves structural canopy complexity, while reducing human presence lowers encounter rates between resource gatherers and megafauna—including Asian elephants (*Elephas maximus*), Indian rhinoceros (*Rhinoceros unicornis*), and Bengal tigers (*Panthera tigris*) [11]. Reduced edge disturbance enhances functional habitat for wide-ranging species and supports the ecological integrity of transboundary conservation corridors across the Eastern Himalayas [21, 22].

4.7. Study limitations, methodological confounds, and future research directions

While this evaluation presents triangulated empirical evidence, several methodological limitations must be acknowledged. First, the study design lacked an unsampled control fringe area, making it impossible to fully isolate program effects from regional economic trends or external shocks using counterfactual logic. Second, the study period overlapped with the national COVID-19 lockdown (March–June 2020), which restricted general rural labor mobility. However, three lines of evidence support a genuine conservation signal beyond lockdown effects: (i) forest path use continued to decline through 2021 after national mobility restrictions were lifted; (ii) structural livelihood transitions reflect multi-year household asset shifts rather than temporary mobility constraints; and (iii) the 66.5% decline in

Future evaluations should adopt quasi-experimental designs (e.g., Before-After-Control-Impact frameworks), integrate infrared camera traps along entry paths to capture nocturnal human movement, and implement longitudinal household panel tracking to assess long-term livelihood sustainability.

5. Conclusion

Monitoring in the FAMNP fringe documented a 59% decline in daily resource collectors and 80% reduction in critically forest-dependent households (274 to 54) over 2019–2021, coinciding with WTI's integrated conservation program. Triangulated evidence from behavioral observation and household surveys, combined with the intervention-specific signal from *thela* decline, suggests these changes reflect a genuine conservation association. The SES framework analysis revealed mutually reinforcing interactions across governance, user, and resource-unit subsystems: EDC formation increased institutional legitimacy, LPG provision and livelihood support altered household extraction economics, and the solar fence disproportionately curtailed high-volume commercial flows. Effective PA governance in economically marginal fringe landscapes requires sustained investment in community well-being alongside ecological protection. Future priorities include expanding solar fence coverage, formalizing NTFP harvesting protocols, and embedding monitoring within designs supporting stronger causal inference.

Declarations

Competing interests:

The authors declare no competing interests.

Clinical trial number

not applicable.

Ethics and Consent to Participate

This study was approved by the Institutional Ethics Committee of Wildlife Trust of India. Permission was obtained from the appropriate authority at FAMNP forests and biodiversity for conducting the field survey. Informed consent was obtained from all individual participants included in the study.

Consent to Publish:

Not applicable, as this manuscript does not contain any human identifiable images or personal data.

Plant Reproducibility, Guidelines, Permissions, and Sources

We respectfully clarify that this study did not involve the experimental collection, cultivation, or taxonomic sampling of plant material by the researchers. As detailed in the Methods section, the research utilized direct observational surveys of community members transporting biomass (categorized broadly as timber, fuelwood, or NTFPs) and household dependency surveys. Because no physical plant specimens or seeds were collected, sourced, or deposited by the research team, requirements for voucher specimens, herbarium IDs, and plant collection permits are not applicable to this study.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used Claude (Anthropic) in order to assist with language editing, and manuscript formatting. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Author Contribution

Conceptualization: K.D., H.C., R.B.; Methodology: K.D., H.C.; Data collection: K.D., S.D., P.B., N.I., H.C.; Formal analysis: K.D., H.C.; Writing – original draft: H.C., K.D.; Writing – review and editing: K.D., H.C., R.B.; Supervision: R.B. All authors read and approved the final manuscript.

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Data Availability

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

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Figures

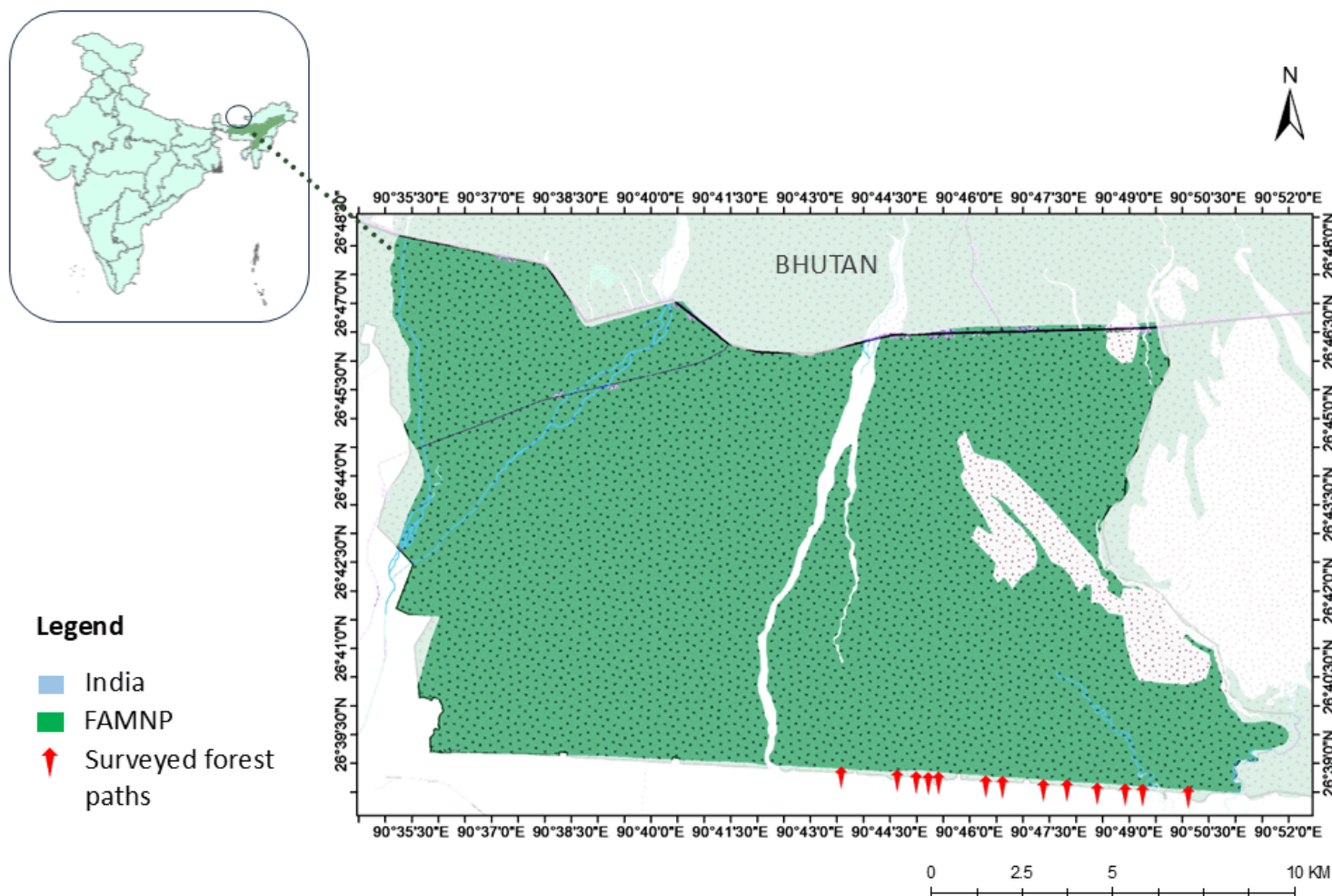


Figure 1

Map of the study area showing the First Addition to Manas National Park (FAMNP), Chirang District, Assam, India, with 13 monitored forest use paths along the southern boundary

Figure 2. Daily mean number of individuals recorded on each forest path (2019-2021)

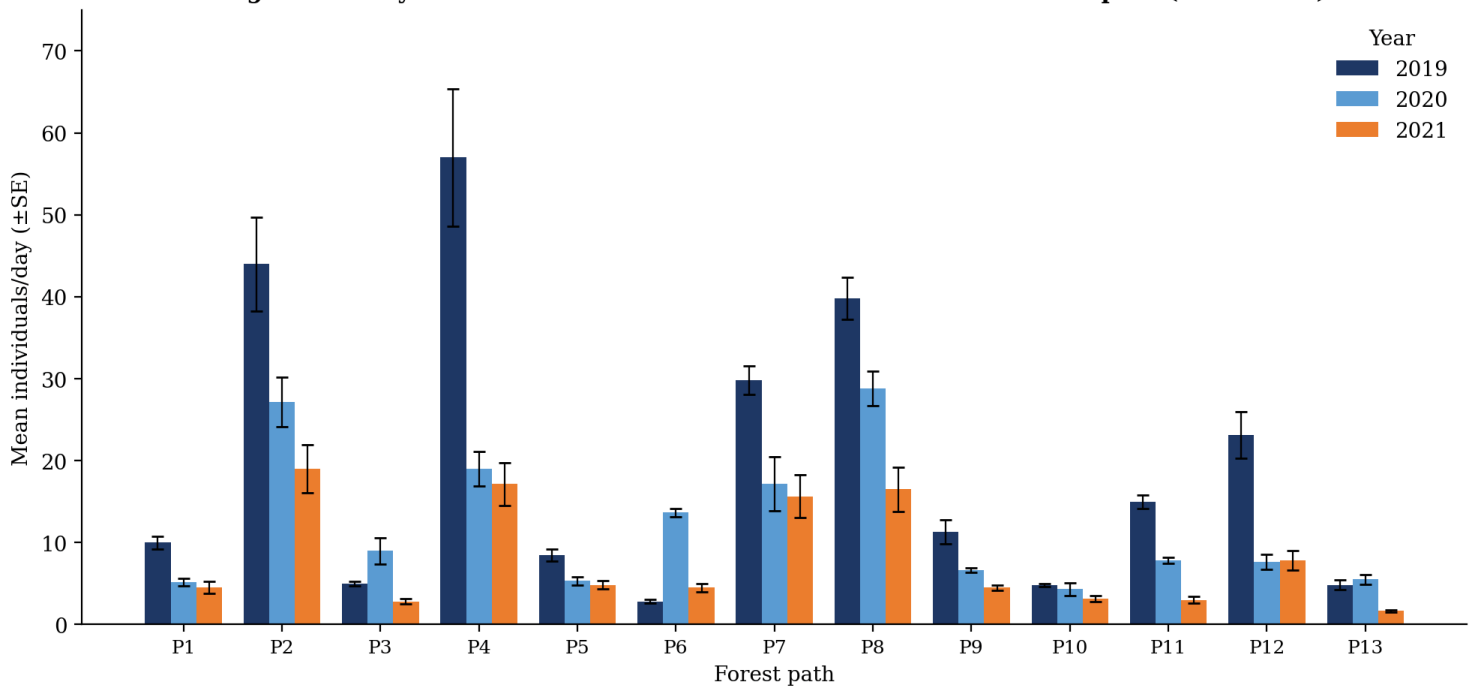


Figure 2

Daily mean number of individuals recorded using each of the 13 forest paths during 2019, 2020, and 2021 (bars = mean $\pm$ SE)

Figure 3. Daily extraction volumes by resource type and proportional composition (2019-2021)

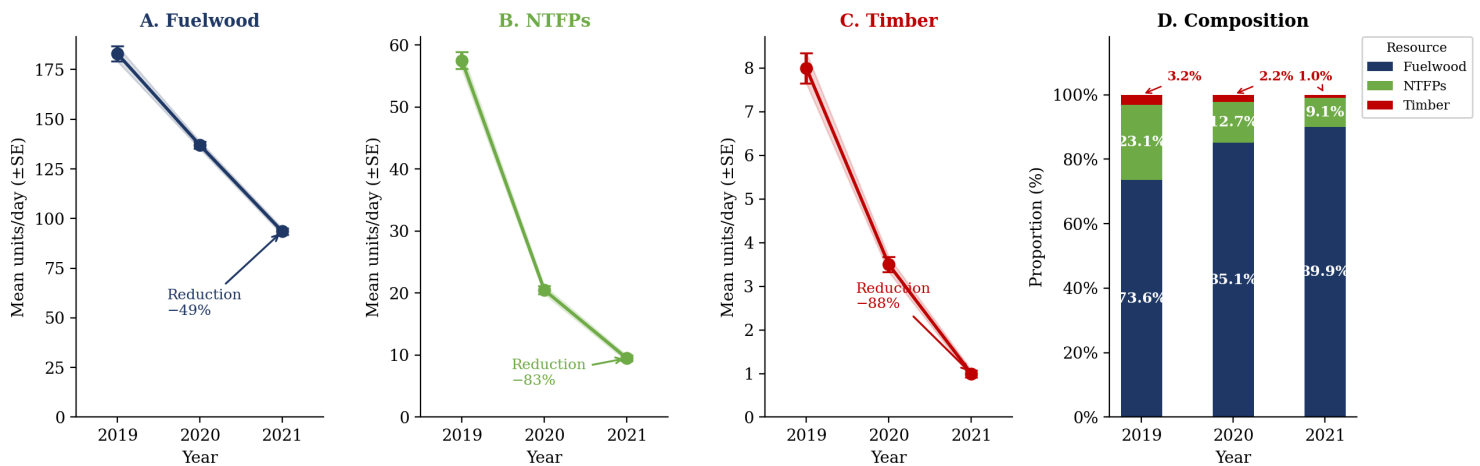


Figure 3

Resource extraction trends (2019–2021): Panels A–C show annual trends in mean daily extraction volumes ($\pm$ SE) for fuelwood, NTFPs, and timber; panel D shows proportional composition of total extraction by resource type with percentage labels

Figure 4. Trends in transportation mode for forest resource extraction (2019-2021)

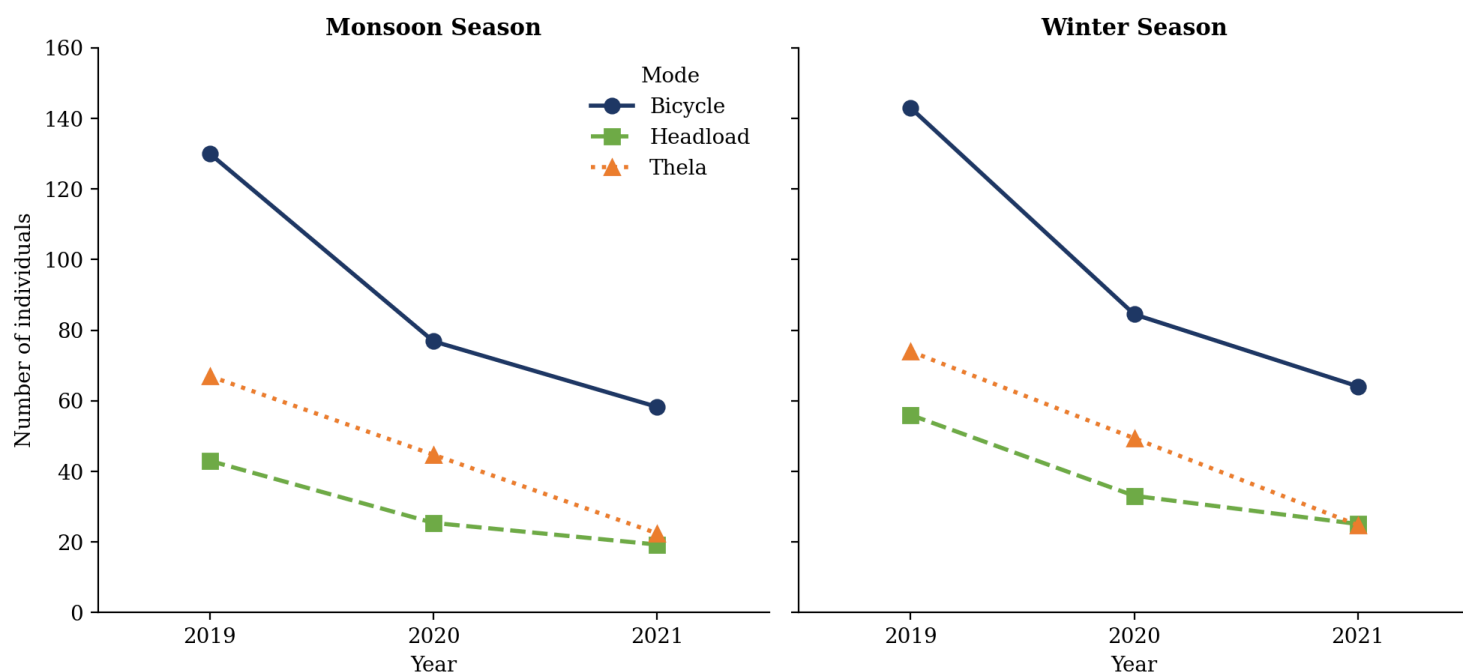


Figure 4

Trends in transportation mode (bicycle, headload, and *thela*) used for forest resource extraction by season (monsoon and winter) during 2019–2021.

Figure 5. Critically Forest-Dependent Households Before and After WTI Interventions (Baseline 2018 vs. Endline 2021)

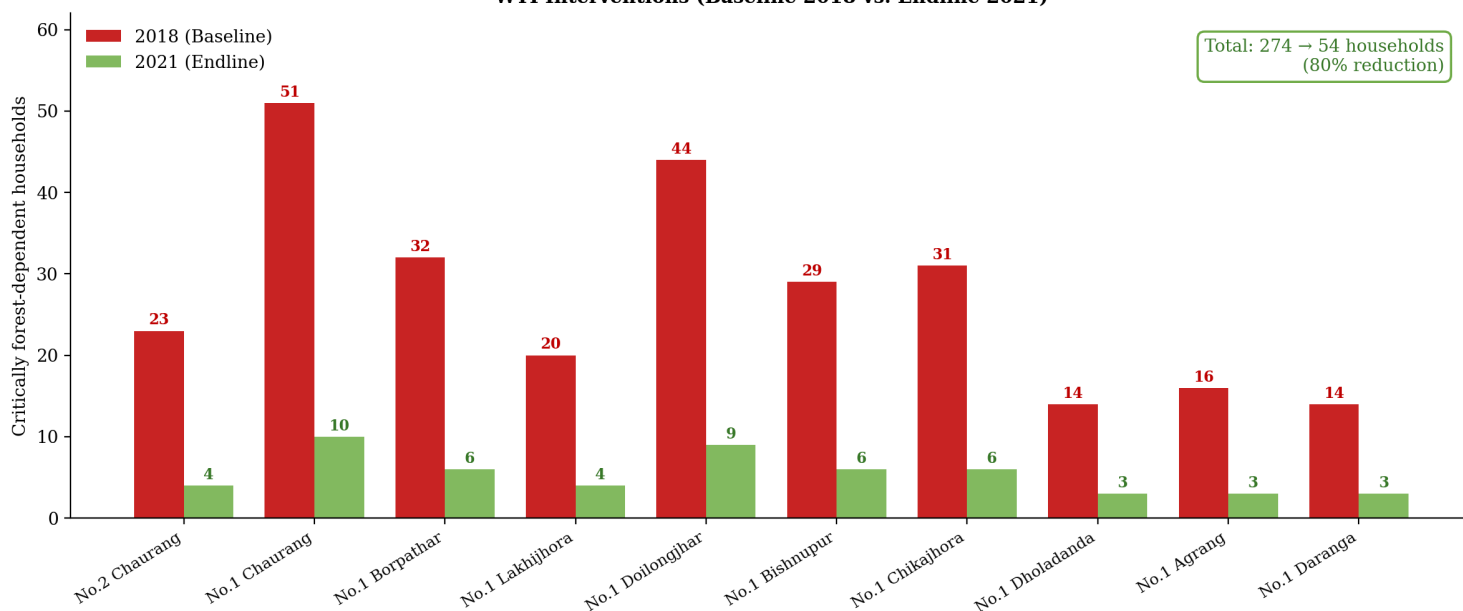


Figure 5

Aggregate critically forest-dependent households at baseline (2018) and endline (2021). Total declined from 274 to 54 (80% reduction)