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Effects of concurrent conservation initiatives on forest-adjacent communities in the Chitwan Valley, Nepal☆

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ABSTRACT

Forest-adjacent communities in Nepal depend on livestock fodder and firewood for their livelihoods. This study examines how overlapping conservation efforts—namely, Community Forestry (CF) and silvicultural practices promoted under Scientific Forest Management (SFM)—have shaped household access to these resources. Using spatial mapping, forest committee surveys, and household data from over 1200 respondents in 2014 and 1400 in 2017, including a longitudinal analysis of over 600 matched households, we assess changes in travel distance to collect fodder and firewood across time and social groups. Our models reveal a shift in key predictors: under CF alone, household factors such as caste and land size were most associated with travel distance. Following the spread of SFM-inspired practices, forest management activities became stronger predictors. While these interventions appeared to improve fodder access, firewood collection distance increased significantly among marginalized groups, including Dalit, Terai Janajati, and female-headed households. This divergence highlights how concurrent conservation initiatives can produce unequal livelihood outcomes. Our findings underscore the need for integrated forest governance that addresses these social equity trade-offs, and they point toward a critical need for future research using mixed-methods and quasi-experimental designs to untangle the causal pathways of these complex policy interactions.

1. Introduction

Nepal's community forestry (CF) program is a widely recognized model of participatory conservation with remarkable achievements for forest-dependent communities (Ghimire and Lamichhane, 2020). By granting local communities use rights over national forests and promoting pro-poor livelihood-building policies, CF provides communities with critical access to forest resources and livelihood opportunities (Acharya, 2002; Thoms, 2008; Nirmal et al., 2009). However, the CF program is not without flaws. Recent studies also highlight the shortcomings of CF of failing to balance conservation with livelihood improvement (Kanel and Dahal, 2008), the widening of wealth disparities that led to a loss of participants, and the rise of dysfunctional user groups that favor powerful individuals over disadvantaged ones (Varughese and Ostrom, 2001; Ojha et al., 2023; Laudari et al., 2024). This established context of inherent and distributional inequality within CF can be further complicated because of the introduction of concurrent and often conflicting forest management programs.

This issue of inherent and distributional inequality can be further complicated by the introduction of new conservation programs originally intended to accompany and improve CF performance, which creates overlapping conservation efforts, a phenomenon identified as concurrent conservation initiatives (An et al., 2022). Existing studies highlight how these initiatives can interact in ways that alter household behavior, either through spillovers from misaligned efforts or creating synergies, also referred to as motivational crowding-in or -out effect (Agrawal and Gupta, 2005; Agrawal et al., 2015; Oniki et al., 2023). For forest management, these complex interactions between incentives and conservation programs can alter how forest users access forest resources. Participants in favorable socioeconomic positions may "stack" economic benefits from multiple programs, whereas disadvantaged participants may spend more effort to maintain their existing resource access (An et al., 2022). This theoretical lens is crucial for understanding how multiple, simultaneous forest conservation efforts can create unintended social outcomes.

In Nepal, this concurrent conservation initiatives phenomenon is exemplified by the Scientific Forest Management (SFM) program, introduced by the Nepali government to promote silvicultural practices

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for increasing Nepal's domestic timber production (Joshi et al., 2018; Adhikari et al., 2024). While the formal adoption of SFM by individual CFs was inconsistent, its promotion as a national strategy has influenced the practices of forest management across the landscape. Therefore, this study examines the widespread influence of the "SFM-inspired" silviculture, rather than comparing SFM and non-SFM sites. The concurrent implementation of CF and SFM programs complicates forest governance in Nepal by introducing conflicting rules and reintroducing top-down structures that undermine CF's decentralized approach (Bastakoti and Davidsen, 2014). In particular, SFM represents a significant shift from CF's broad focus on local stewardship and equitable access to subsistence resources to a more intensive forest management model emphasizing timber yield (Poudyal et al., 2020). The coexistence of these conflicting approaches can complicate households' decisions regarding forest resource access and potentially derail the original goal of CF for decentralized, community-based forest management.

The interaction of these forest management programs directly impacts how households access the subsistence resources essential for local livelihoods. In Nepal, CFs primarily provide firewood for subsistence needs, such as cooking and heating, and livestock fodder for raising cattle. This CF service aligns with recent findings from Liberia, where non-timber products like firewood contributed more to household income than timber, reinforcing the importance of such resources to livelihoods across the Global South (Amadu and Miller, 2024). Within a Social-Ecological Systems (SES) framework, where people and nature are intrinsically linked, CF participants in Nepal must navigate through the conflicting governance of CF and SFM policies to secure access to essential forest resources (McGinnis and Ostrom, 2014; Clark and Harley, 2019). This study measured such efforts by the distance traveled by a household to collect a type of essential forest resources, which is a key indicator of well-being and is known to vary based on participants' socioeconomic status and their interactions with CF governance (Pattanayak et al., 2004; Gautam and Andersen, 2016). Therefore, layering a production-focused silviculture model onto a subsistence-focused CF system creates a significant risk that the distributional inequalities among CF participants can be inherited or even expanded. This layering of conservation efforts also highlights how forest policy decisions can either mitigate or exacerbate socioeconomic disparities, as seen in recent research from Sudan, which shows that income from tree-based resources can impact inequality levels among forest users (Adam et al., 2024).

However, while the risk of concurrent initiatives exacerbating existing inequality is clear, limited empirical research has explored how these interaction effects can impact households differently based on their socioeconomic standing. To address this gap, this study employs a Social-Ecological Systems (SES) framework and longitudinal data to examine how household efforts to access forest resources in the Chitwan Valley, Nepal, were shaped by interacting forest governance strategies between 2014 and 2017. By focusing on travel distance to collect fodder and firewood, this research seeks to answer the following questions:

1. What socioeconomic, institutional, and environmental factors determined household efforts to access forest resources before the widespread implementation of SFM-inspired silviculture?
2. How did the concurrent implementation of CF and SFM-inspired practices change these efforts, and did these impacts differ across socioeconomically advantaged and disadvantaged households?

2. Methods

2.1. Study area and governance context

Our research project focuses on the western Chitwan Valley in Nepal's subtropical Terai region (hereafter referred to as Terai, a marshy lowland area) along the foothills of the Himalayas. This region is both ethnically diverse and experiencing rapid population growth (Sharma, 1990; Lehmkuhl, 1994). In this area, the northern region is primarily agricultural and densely settled, while the southern region is dominated by Chitwan National Park (CNP). Established in 1973 and later designated a UNESCO World Heritage Site, CNP remains Nepal's flagship protected area, covering 93,200 ha of riparian forest and grassland that provide critical habitat for over 50 mammal species, including endangered ones (Lehmkuhl, 1994). Deforestation and settlement in the northern valley began in the 1950s and 1960s, following a successful malaria eradication program that made the Terai—a region historically more habitable for the malaria-resistant Tharu people—accessible to migrants from Nepal's hill regions (Terrenato et al., 1988; McLean, 1999).

Population growth and migration have shaped complex human-environment interactions around CNP, including rising demand for forest resources like firewood and livestock fodder, changes in livelihood strategies due to migration to foreign countries for better income, and a pressing need for sustainable forest management to balance livelihood promotion and conservation (Stræde and Helles, 2000). As subsistence farming and traditional energy use remain standard, household practices such as collecting firewood and gathering fodder reflect critical aspects of local livelihood strategies. This is particularly true for the indigenous Tharu communities of the region, whose socioeconomic status is closely linked to agriculture (Sharma et al., 2021). Western Chitwan has also become a focal point for conservation efforts to protect the primary forests in and around CNP, with many households participating in conservation initiatives but having limited understanding of their roles in sustainable forest management.

This challenging context set the stage for Nepal's innovative approach to forest governance. Since its inception, Nepal's Community Forestry (CF) program has demonstrated remarkable resilience—emerging during the final years of Nepal's centralized Panchayat political regime (1960–1990) (Paudel et al., 2022) and surviving the civil conflict driven by the Maoist insurgency in the 2000s to become successful model of participatory governance of the public commons (Nirmal et al., 2009; Baynes et al., 2015). The long-standing approach was formally established nationwide by the 1993 Forest Act, which enabled local communities to take an active role in forest management (Acharya, 2002). A few years later, the Buffer Zone Management Regulation of 1996 introduced Buffer Zone Community Forests (BZCFs) surrounding Chitwan National Park (CNP), creating a co-management model to balance conservation with subsistence needs, though the equitable distribution of conservation incentives within this zone has been a subject of ongoing study (Spiteri and Nepal, 2008). This landscape was further complicated in 2014 when the government formally introduced the SFM program across the Terai, including Chitwan, to boost timber production through silvicultural interventions.

The concurrent presence of these overlapping policies creates a complex reality on the ground in Chitwan. Generally, CF members are typically permitted to collect understory biomass and fallen branches for use as livestock fodder and firewood, while large-scale timber harvesting remains restricted (Ojha et al., 2009). However, the nationwide promotion of SFM has influenced practices even in places that have not formally adopted SFM (Poudyal et al., 2020). For instance, during a field visit in August 2024, we observed several BZCFs, which were not formal SFM sites, engaged in SFM-inspired practices such as forest thinning, removal of invasive species, and clearing of understory vegetation. This convergence of forest management practices has blurred the line between decentralized and centralized forest governance models, leading to confusion among forest-adjacent communities and contributing to ambiguity in local rule enforcement and variation in resource access.

2.2. Household and community forest data collection

We used two rounds of social surveys collected in 2014 and 2017. The years correspond to key periods in Nepal's forest policy landscape. The 2014 survey reflects conditions just before the official promotion of

SFM-inspired silvicultural practices across the Terai. The 2017 follow-up survey allows us to capture potential responses to evolving silvicultural practices and policy interactions over a three-year interval. These years also mark a stable window in community forestry administration in the Chitwan Valley, allowing for meaningful cross-temporal comparison.

Data collection focused on three domains: (1) household socio-demographic characteristics and livelihood strategies, (2) spatially explicit patterns of forest resource use, including travel distance to collect fodder and firewood, and (3) institutional and ecological management practices within local Community Forests (CFs). We collected both self-reported and geocoded data on household behavior and perceptions, supplemented with forest-level administrative data.

Households were selected through a three-stage stratified random sampling process. First, administrative wards in CF catchment areas were sampled proportionate to population size, based on the 2011 census in Chitwan District. These wards were then divided into sub-wards, each comprising approximately 400 households. From these sub-wards, we selected a random subset for complete household enumeration, which generated the household sampling frame. Within each selected sub-ward, households were then randomly sampled for an interview. In total, 1235 households were surveyed in 2014 and 1489 in 2017. Fig. 1 illustrates the locations of surveyed households across both rounds, showing spatial distribution within the buffer zone and community forest boundaries.

The sampling design supports a 95 % confidence level with an estimated margin of error ranging from ±3 % to ±5 %, depending on subgroup size. In the case of non-response, enumerators returned up to three times or substituted the next household on the randomized list. The final household response rate exceeded 98 % in both survey rounds. We cleaned all data through a multi-step process including validation of household coordinates, consistency checks, outlier removal, and exclusion of incomplete records. All spatial and social data were cross-referenced to community forest boundaries using ArcGIS Pro. Ethical approval for analyzing the survey data was granted by the Institutional Review Board at Auburn University (Exempt Protocol #23–665 EX 2401).

2.3. Social-demographic data

The household survey included modules on demographics, land ownership, income, forest dependency, livestock, caste and ethnicity, and perceptions of environmental risks such as invasive species and wildlife conflict. The survey design was informed by prior studies in the Chitwan Valley (Shova and Hubacek, 2011; Yabiku et al., 2022) and

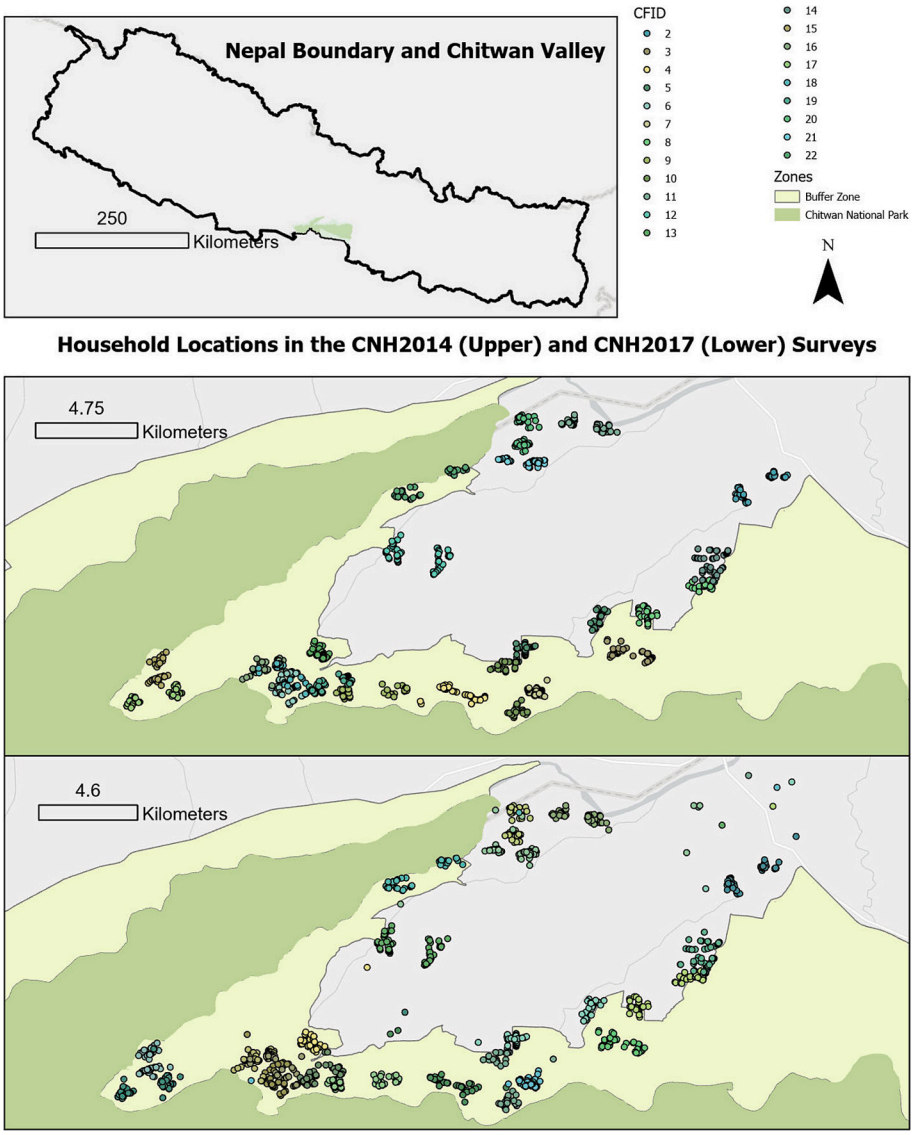

Fig. 1. Study Area in Nepal and Household Locations in the CNH 2014 and CNH 2017 Surveys.

mapped directly onto the study's objectives by integrating human, spatial, and institutional perspectives on forest resource use.

Spatial data were collected using a tablet-assisted mapping application. A knowledgeable adult in each household was asked to mark firewood and fodder collection sites directly on satellite imagery. This technique minimized social desirability bias and improved spatial accuracy compared to self-reported distance. Of the households surveyed in both years, 616 consistently reported firewood collection, and 656 reported collecting fodder. These subsets form the basis of the panel analysis. Due to variations in collection behaviors across years, sample sizes vary across models. Households outside CF catchment (eligibility sites) areas were excluded from the final analysis. In cases where responses to key explanatory variables were missing, we applied a combination of variable recoding and listwise deletion. Responses such as "don't know" or skipped answers were recoded into appropriate categories when analytically justifiable. For variables with critical missingness or non-interpretable values, observations were excluded using listwise deletion. All data cleaning and variable recoding steps were implemented in R.

2.4. Community forest interview data

We measured how and where CFs implemented their silvicultural practices. A representative for each of the 21 CF management committees was interviewed in 2014 and 2017. Survey questions focused on management techniques, handling of invasive plants, and challenges. The interview data served as the foundation for analyzing CF-level spatial data to examine whether CF-level SFM-inspired activities overlapped with the CF-managed forest boundaries.

2.5. Spatial data

To assess travel destinations of households in the forests, a knowledgeable household member—typically the household head—was asked to use an interactive tablet app on an Android device. The app displayed touch-enabled satellite imagery of the Chitwan region, enabling participants to mark locations where household members had collected natural resources, such as livestock fodder and firewood. Previous studies have shown that this tablet-assisted approach effectively captures spatial data in similar contexts (Yabiku et al., 2017; Yabiku et al., 2022). To avoid influencing participants' willingness to disclose collection sites, especially for activities that might be restricted, the app did not display administrative boundaries of community forests (CF) or Chitwan National Park (CNP). To further reduce social desirability bias, we avoided directly asking about potentially prohibited activities. This tablet-based method provides greater spatial accuracy than traditional survey methods, which rely solely on self-reported distance.

For the 21 community forest (CF) committee representatives mentioned above, each CF representative used the tablet to mark areas of disturbance associated with silvicultural activities, such as forest fires, new plantations, and forest clearing. Representatives also identified areas within their CF affected by invasive species, creating a detailed spatial record of ecological and silvicultural conditions. Additionally, we created spatial relationship variables based on the overlap of data provided by CF representatives to determine if the CF area intersected with new SFM-inspired silvicultural activities. Specifically, we tested for overlap between forest clearing activities and the removal of three invasive plant species, such as *Mikania micrantha* (Mikania), *Lantana camara* (Lantana), and *Chromolaena odorata* (Chromolaena), and created binary indicators at the CF level for these intersecting activities.

3. Data analysis

3.1. Dependent variables: travel distance to forest resources

We derived six dependent variables, including household travel distance to fodder and firewood collection sites in 2014 and 2017. To determine the travel distance, we first recorded household homes' GPS coordinates and calculated the Euclidean distance between each household home and the centroid of the designated firewood or fodder collection sites for both 2014 and 2017. In our survey, each household only provided one shapefile of natural resources collection sites, allowing us to create multiple one-on-one relationships between household homes and natural resources collection sites. There was no indication of multi-site natural resource collection. Given that the Chitwan Valley is a flat lowland region, the Euclidean distance can represent the travel efforts by households to collect forest resources. We then applied a logarithmic transformation to all travel distances, enabling us to interpret percentage changes in these dependent variables in response to marginal changes in our explanatory variables.

3.2. Covariates and theoretical justification

We hypothesize that a household's travel distance to collect firewood and fodder will vary according to the following factors derived from our observations and a previous study (An et al., 2024): 1) economic conditions, 2) use and management of forest resources, 3) perception of the environment, and 4) concurrent influences of Community Forestry (CF) and SFM-inspired silvicultural practices (Table 1).

Specifically, we hypothesize that household economic conditions—such as income from remittances, owning a small business, having a wage job, having savings, living in a single-family house, and landholding size—will be negatively associated with travel distance, as these factors may reduce a household's reliance on distant resources. Natural resource management strategies are also expected to have a negative association with travel distance. Variables such as primarily using firewood for cooking, male involvement in firewood collection, and purchasing firewood from the market reducing the need to travel long distance for resources. We also hypothesize that negative environmental perceptions will be positively associated with travel distance. Longer travel distance may contribute to negative perceptions regarding barriers to resource extraction, such as the presence of invasive plant species and the risk of wildlife attacks. Finally, we anticipate that the concurrent implementation of CF and SFM-inspired silvicultural practices will have mixed associations with travel distance, depending on the specific activities involved. For example, practices such as using controlled forest fires and the clearing of invasive plants, including Mikania, Lantana, and Chromolaena, are expected to increase travel distance by limiting accessible resources. In contrast, the establishment of new plantations within CF areas may reduce travel distance by bringing resources closer to households.

In our study area, the ethnic groups are diverse and are influenced by Nepal's caste system. We classified these groups into five major categories, following the caste classifications used in previous studies in this region (Axinn and Yabiku, 2001): 1) High-caste Hindu or Brahmin, representing the highest caste and most socially advantaged group; 2) Hill Janajati or Hill Tibetoburmese, who are domestic migrants from Nepal's hill regions to Chitwan; 3) Dalit, or low-caste Hindu, considered the most socioeconomically disadvantaged; 4) Newar, traditionally associated with commerce and business; and 5) Terai Janajati, indigenous groups native to the Terai region, including the Tharu community (Guneratne, 2007).

3.3. Statistical models: regression and random forest variable importance

We used multivariate regressions to understand the factors affecting households' travel distances to livestock fodder and firewood collection sites. We compared the factors predicting a household's travel distance to natural resources collection before and after the concurrent implementation of two conservation initiatives within the same landscape.

Furthermore, because more than 600 households participated in surveys in both years and self-reported natural resources collection sites,

Table 1
Variables and data sources used in the analysis.

Variable	Data Source	Details
Dependent Variables		
Household travel distance to firewood collection (meters)	Tablet data from household survey	Euclidean distance from household to firewood collection sites
Household travel distance to fodder collection (meters)	Tablet data from household survey	Euclidean distance from household to fodder collection sites
Change in firewood collection distance (2014–2017)	Tablet data from household survey	Change in firewood travel distance between survey waves
Change in fodder collection distance (2014–2017)	Tablet data from household survey	Change in fodder travel distance between survey waves
Livelihood Strategies		
Primary income source: foreign remittance	Household survey	Binary: 1 if income mainly from household member abroad
Primary income source: small business	Household survey	Binary: 1 if income mainly from small business
Primary income source: wage employment	Household survey	Binary: 1 if income mainly from wage job
Household has savings in financial institution	Household survey	Binary: 1 if household has savings in a financial institution
Socioeconomic Status		
Lives in a single-family house	Household survey	Binary: 1 if living in a single-family house
Land size (kitta)	Household survey	Size of household land (1 kitta ≈ 338.63 m^2)
Primarily using firewood for cooking	Household survey	Binary: 1 if firewood is the main cooking fuel
Men involved in firewood collection	Household survey	Binary: 1 if male household members collect firewood
Purchasing firewood from market	Household survey	Binary: 1 if household buys firewood
Perceived Ecological Stressors		
Invasive plant species having an impact	Household survey	Binary: 1 if respondent perceives impact of invasive plants
Wildlife attack is a problem	Household survey	Binary: 1 if household reports threat from wildlife
Management Interventions under SFM-Inspired Silvicultural Practices		
Forest fires observed in CF	Tablet data (CF manager survey)	Binary: 1 if CF official reports fire within CF boundary
New plantations reported in CF	Tablet data (CF manager survey)	Binary: 1 if plantations indicated by CF managers
Mikania removal reported	Tablet data (CF manager survey)	Binary: 1 if CF engaged in Mikania removal
Lantana removal reported	Tablet data (CF manager survey)	Binary: 1 if CF engaged in Lantana removal
Chromolaena removal reported	Tablet data (CF manager survey)	Binary: 1 if CF engaged in Chromolaena removal
Controls		
Caste group	Household survey	Main caste and ethnic groups in Chitwan (Brahmin, Hill Janajati, Dalit, Newar, and Terai Janajati) as coded dummy variables, with Brahmin as the reference group.
Household income >50,000 NPR*	Household survey	Binary: 1 if income >50,000 rupees (~$450); 0 otherwise
Female-headed household	Household survey	Binary: 1 if household head is female

* Note: Binary variable coded as 1 if the household's self-reported annual income exceeds 50,000 Nepalese Rupees (~USD 450 in 2017), and 0 otherwise. This threshold roughly corresponds to the national poverty line in Nepal and aligns with prior household income classification used in regional studies.

we used the longitudinal data to analyze the differences of travel distances to firewood and fodder collection sites. We regressed these net changes of travel distance against the independent variables. We also regressed the initial travel distance in 2014 for these households as a comparison. For comparison purposes, we used the non-logarithmic travel distances as the baseline scenario to compare with the net changes of travel distances, both in meters.

To complement our multivariate regression models, we also employed a random forest classification approach to calculate variable importance for the independent variables of interest. While multivariate regression assumes linear relationships between independent and dependent variables, which can limit its effectiveness when data relationships are complex or nonlinear, random forests offer a more flexible alternative. Random Forest Variable Importance (RFVI), an ensemble machine learning method, captures complex, nonlinear interactions between variables without requiring explicit specification of these relationships. This approach ranks predictors based on their contribution to reducing prediction error, providing an intuitive measure of each variable's overall influence on the model (Strobl et al., 2008). By including RFVI alongside traditional regression analysis, we gain insights into contributions of variables that may not be apparent through linear modeling alone.

4. Results

4.1. Descriptive patterns of travel distance and resource use

According to Table 2, in 2014, households that reported collecting natural resources traveled an average of 497.34 m to collect fodder and 899.28 m to collect firewood. By 2017, these travel distances had shifted

Table 2
Descriptive statistics for survey datasets (2014–2017).

Variable	2014	2017	Test Result
Firewood distance (m)	899.3 (1354.97)	430.0 (881.00)	$t = 8.231$, $p < 0.001$
Fodder distance (m)	497.3 (701.30)	2064.7 (4004.81)	$t = -10.79$, $p < 0.001$
Land size (kitta)	10.36 (12.73)	9.72 (11.21)	$t = 1.33$, $p = 0.185$
Foreign income main source	36.00 %	37.60 %	$\chi^2 = 0.64$, $p = 0.42$
Small business main source	24.70 %	28.80 %	$\chi^2 = 5.04$, $p = 0.025$
Wage job main source	28.70 %	37.70 %	$\chi^2 = 16.93$, $p < 0.001$
Has savings	49.50 %	81.40 %	$\chi^2$271.33, $p < 0.001$
Single-family home	95.00 %	89.60 %	$\chi^2 = 24.15$, $p < 0.001$
Primarily uses firewood for cooking	73.80 %	56.90 %	$\chi^2 = 76.69$, $p < 0.001$
Men involved in firewood collection	34.30 %	42.10 %	$\chi^2 = 15.60$, $p < 0.001$
Buys firewood	42.60 %	24.00 %	$\chi^2 = 94.43$, $p < 0.001$
Perceives invasive plant impacts	27.40 %	34.90 %	$\chi^2 = 15.83$, $p < 0.001$
Wildlife is a problem	42.80 %	40.70 %	$\chi^2 = 44.45$, $p < 0.001$
Forest fires in CF	34.60 %	14.20 %	$\chi^2 = 135.62$, $p < 0.001$
New plantations in CF	13.30 %	4.30 %	$\chi^2 = 59.95$, $p < 0.001$
Cleaning Mikania in CF	31.50 %	14.70 %	$\chi^2 = 94.57$, $p < 0.001$
Cleaning Lantana in CF	34.80 %	18.30 %	$\chi^2 = 83.33$, $p < 0.001$
Cleaning Choromolaena in CF	30.50 %	18.00 %	$\chi^2 = 50.95$, $p < 0.001$
Caste: Hill Janajati	16.30 %	15.80 %	$\chi^2 = 0.07$, $p = 0.79$
Caste: Dalit	13.20 %	12.70 %	$\chi^2 = 0.09$, $p = 0.77$
Caste: Newar	3.80 %	3.70 %	$\chi^2 = 0$, $p = 1$
Caste: Terai Janajati	17.00 %	16.80 %	$\chi^2 = 0.01$, $p = 0.92$
HH income >50,000 NPR	71.00 %	95.50 %	$\chi^2 = 264.86$, $p < 0.001$
Female HH head	66.60 %	76.90 %	$\chi^2 = 31.35$, $p < 0.001$

substantially. The average distance for fodder collection increased to 2064.7 m, representing a more than fourfold increase. In contrast, the average distance for firewood collection dropped to 429.97 m, reflecting a 50 % reduction. While this aggregate trend may suggest improved access to forest resources, the underlying drivers are complex with substantial variation across households, as the regression analyses will show.

4.2. Regression models of fodder collection distance

We first presented our findings on the factors influencing household travel distance to fodder collection sites in 2014 and 2017. These two years highlight different sets of factors shaping household travel distance to fodder collection, as detailed in Table 3.

According to the 2014 CNH survey (Table 3), several household economic conditions and resource management decisions were associated with logarithmic distance (hereafter, travel distance) to fodder collection. Within the economic conditions category, reliance on income from business, wage jobs, or employment abroad did not significantly ($p < 0.05$) affect travel distance to fodder collection, nor did having savings in a financial institution or living in a single-family home. However, larger landholdings were associated with slightly shorter travel distances, as land size showed a significant ($p < 0.05$), though small, negative relationship with travel distance to fodder collection. Households primarily using firewood for cooking exhibited significantly ($p < 0.05$) longer fodder collection distance, while households with male members responsible for firewood collection or purchasing firewood from a market showed no significant ($p < 0.05$) association with fodder collection distance. In terms of environmental perceptions, viewing invasive plants as negatively impacting livelihoods was significantly ($p < 0.05$) associated with longer travel distance to collect fodder. However, the perception of wildlife as a problem was not linked to changes in travel distance.

Our model results also indicate that the interaction effects between community forestry (CF) and SFM-inspired silvicultural practices influenced fodder collection distance. Specifically, membership in a community forest with a history of forest fires and involvement in jungle-clearing activities in Lantana-infested areas was associated with significantly ($p < 0.05$) longer fodder collection distance. Among the control variables, belonging to the Dalit caste, which is the most socioeconomically disadvantaged caste, was significantly associated with longer fodder collection distance ($p < 0.05$). In comparison, households with an income above 50,000 Nepali rupees exhibited significantly ($p < 0.05$) shorter travel distance.

Comparing the 2014 and 2017 CNH survey results reveals several notable shifts in predictors of fodder collection distance (Table 3). In 2017, predictors related to household livelihoods, perceptions of invasive species, and control variables no longer had a significant influence ($p < 0.05$) on fodder collection distance. Within household economic factors, households with male members responsible for collecting firewood or those purchasing firewood from the market were negatively associated with fodder travel distance. Meanwhile, membership in a community forest with a history of forest fires remained a significant predictor ($p < 0.05$), contributing to longer travel distance to collect fodder.

Table 3
Determinants of household travel distance for fodder collection in 2014 ($n = 809$) and 2017 ($n = 783$).

Variables	2014 Survey		2017 Survey	
	Estimate (SE)	*p*-value	Estimate (SE)	p-value
Livelihood Strategies				
Foreign income main source	0.06 (0.10)	0.56	−0.15 (0.98)	0.12
Small business main source	−0.12 (0.12)	0.30	0.03 (0.11)	0.74
Wage job main source	0.01 (0.11)	0.92	0.11 (0.10)	0.26
Has savings	−0.01 (0.10)	0.92	0.17 (0.12)	0.15
Socioeconomic Status				
Single-family home	−0.43 (0.26)	0.10	0.06 (0.20)	0.78
Land size (kitta)	−0.01 (0.04)	0.03*	−0.01 (0.01)	0.88
Primarily uses firewood for cooking	0.45 (0.13)	<0.01*	−0.01 (0.10)	0.97
Men involved in firewood collection	−0.13 (0.11)	0.24	−0.21 (0.10)	0.03*
Buys firewood	0.19 (0.10)	0.06	−0.22 (0.11)	0.05*
Perceived Ecological Stressors				
Perceives invasive plant impacts	0.27 (0.11)	0.02*	0.18 (0.10)	0.06
Wildlife is a problem	0.10 (0.06)	0.09	0.07 (0.06)	0.21
Management Interventions under SFM-Inspired Silvicultural Practices				
Forest fires in CF	0.63 (0.12)	<0.01*	1.16 (0.17)	<0.01*
New plantations in CF	−0.64 (0.17)	<0.01*	0.29 (0.25)	0.23
Cleaning Mikania in CF	0.04 (0.14)	0.79	−0.46 (0.29)	0.12
Cleaning Lantana in CF	−0.09 (0.13)	0.50	0.32 (0.19)	0.09
Cleaning Choromolaena in CF	0.03 (0.15)	0.84	0.32 (0.37)	0.38
Controls				
Caste: Hill Janajati^	−0.10 (0.15)	0.50	−0.01 (0.14)	0.96
Caste: Dalit^	0.19 (0.17)	0.25	0.07 (0.15)	0.65
Caste: Newar^	−0.14 (0.29)	0.64	−0.10 (0.28)	0.72
Caste: Terai Janajati^	0.31 (0.15)	0.03*	0.10 (0.14)	0.48
HH income >50,000 NPR	−0.22 (0.11)	0.05*	−0.49 (0.25)	0.06
Female HH head^^	−0.05 (0.11)	0.66	−0.01 (0.11)	0.97
Intercept	5.10 (0.32)	<0.01*	6.63 (0.35)	<0.01*

* 95 % confidence interval excludes zero.
^ Reference group for dummy variable is "Caste: Brahmin (high Hindu)."
^^ Reference group for dummy variable is "gender of household head: male."

4.3. Regression models of firewood collection distance

We presented an additional model predicting the logarithmic distance (hereafter, travel distance) to firewood collection using data from the 2014 and 2017 rounds of the CNH survey, comparing predictors across these two years.

According to the model based on the 2014 CNH survey, travel distance to firewood collection was negatively associated with land area among household characteristics but not related to other economic condition variables. In the resource management and environmental perception categories, travel distance to firewood collection distance was positively associated with using firewood for cooking, purchasing firewood from the market, and viewing wildlife attacks on humans as a problem. Conversely, having male household members involved in firewood collection was associated with shorter travel distances to firewood collection.

For community forestry (CF) and SFM-inspired silvicultural practices predictors, travel distance to firewood collection increased for households that were members of CFs with a history of using controlled forest fires or participated in jungle-clearing activities in areas affected by Lantana. Additionally, the model indicates that membership in the Hill Janajati (consisting primarily of domestic migrants), Dalit (disadvantaged caste), and Terai Janajati (Chitwan indigenous group) castes was linked to longer travel distances firewood collection. Being in the Newar caste (mainly merchants engaged in small businesses) was not associated with changes in firewood collection distances.

In comparison, the 2017 CNH survey model shows that travel distance to firewood was associated with fewer predictors. Among household characteristics, only male members involved in firewood collection

remained a significant factor, associated with shorter distance. However, perceived ecological stressors became more associated. Viewing invasive plants as problematic and perceiving wildlife attacks as an issue were both linked to increased travel distance. Within the forest management category, only the clearing of Mikania-infested areas was associated with a significant reduction in travel distance ($p < 0.05$). Most importantly, factors of social disadvantages remained strong predictors of increased travel distance to collect firewood. Households belonging to the Dalit (disadvantaged caste) or Terai Janajati (indigenous group) castes, as well as those headed by a female, were significantly ($p < 0.05$) associated with longer travel distance for firewood.

4.4. Regression models of net changes of travel distance

For 656 households that participated in the surveys in 2014 and 2017 (Table 5), in the baseline scenario, households dependent on firewood for cooking or being members of CFs that used controlled forest fires had longer fodder collection distances. Larger land sizes correlated with small and negative fodder collection distances. However, the net changes in fodder collection distance indicated a different pattern. Households with savings or experiencing invasive species impacts reported significantly ($p < 0.05$) positive changes of fodder collection distance. Households that relied on remittance (working in a foreign country) as the source of income significantly ($p < 0.05$) reduced the travel distance to collect fodder. Silvicultural practices, such as clearing invasive species like Mikania, Lantana, Chromolaena, have shown varying impacts. Clearing Lantana led to increased travel distance, whereas other species' clearance shortened travel distance. Using controlled forest fires in community forests was associated with significant ($p < 0.05$) increases in travel distance for fodder collection.

Table 6 presents findings on the temporal changes in firewood collection distances for 616 households, highlighting both baseline distance in 2014 and changes observed between 2014 and 2017. In 2014, households in CFs with a history of forest fires or Lantana-clearing

Table 4
Determinants of household travel distance for firewood collection in 2014 ($n = 778$) and 2017 ($n = 868$).

Variables	2014 Survey		2017 Survey	
	Estimate (SE)	*p*-value	Estimate (SE)	p-value
Livelihood Strategies				
Foreign income main source	0.15 (0.13)	0.27	−0.13 (0.12)	0.28
Small business main source	−0.05 (0.15)	0.73	−0.14 (0.13)	0.29
Wage job main source	−0.04 (0.14)	0.98	−0.21 (0.12)	0.71
Has savings	−0.14 (0.13)	0.27	0.19 (0.14)	0.20
Socioeconomic Status				
Single-family home	0.07 (0.30)	0.82	0.11 (0.23)	0.65
Land size (kitta)	−0.01 (0.01)	0.01*	0.01 (0.01)	0.78
Primarily uses firewood for cooking	0.34 (0.17)	0.05*	0.19 (0.13)	0.14
Men volved in firewood collection	−0.30 (0.13)	0.02*	−0.40 (0.12)	<0.01*
Purchasing firewood from market	0.28 (0.14)	0.04*	0.21 (0.16)	0.18
Perceived Ecological Stressors				
Perceives invasive plant impacts	−0.24 (0.14)	0.09	0.34 (0.12)	<0.01*
Wildlife is a problem	0.30 (0.08)	<0.01*	0.44 (0.72)	<0.01*
Management Interventions under SFM-Inspired Silvicultural Practices				
Forest fires in CF	0.36 (0.15)	0.02*	0.02 (0.22)	0.94
New plantations in CF	−0.23 (0.21)	0.28	−0.31 (0.31)	0.32
Cleaning Mikania in CF	−0.25 (0.17)	0.15	−0.90 (0.36)	0.01*
Cleaning Lantana in CF	0.51 (0.16)	0.02*	0.38 (0.24)	0.11
Cleaning Choromolaena in CF	0.24 (0.19)	0.21	0.68 (0.46)	0.14
Controls				
Caste: Hill Janajati^	0.39 (0.18)	0.04*	0.10 (0.17)	0.53
Caste: Dalit^	0.92 (0.19)	<0.01*	0.56 (0.17)	<0.01*
Caste: Newar^	0.53 (0.36)	0.15	−0.37 (0.32)	0.25
Caste: Terai Janajati^	1.01 (0.17)	<0.01*	0.78 (0.16)	<0.01*
HH income >50,000 NPR	−0.20 (0.14)	0.15	−0.03 (0.26)	0.91
Female HH head^^	0.07 (0.14)	0.62	0.27 (0.14)	0.05*
Intercept	4.28 (0.40)	<0.01*	3.14 (0.39)	<0.01*

* 95 % confidence interval excludes zero.
^ Reference group for dummy variable is "Caste: Brahmin (high Hindu)."
^^ Reference group for dummy variable is "gender of household head: male."

Table 5
Multivariate regression results for fodder collection distance: baseline (2014) and change from 2014 to 2017 ($n = 656$).

Variables	Fodder Baseline		Fodder Change	
	Estimate (SE)	p-value	Estimate (SE)	p-value
Livelihood Strategies				
Foreign income main source	57.94 (58.82)	0.32	−789.82 (300.04)	<0.01*
Small business main source	−42.50 (66.07)	0.52	−214.89 (324.91)	0.51
Wage job main source	−69.60 (62.06)	0.26	115.18 (304.04)	0.70
Has savings	42.09 (54.67)	0.44	741.56 (381.66)	0.05*
Socioeconomic Status				
Single-family home	−114.26 (151.29)	0.45	875.53 (617.30)	0.16
Land size (kitta)	−5.13 (21.28)	0.02*	19.27 (13.33)	0.15
Primarily using firewood for cooking	260.77 (70.57)	<0.01*	−140.18 (313.53)	0.65
Men volved in firewood collection	−52.39 (59.72)	0.38	−330.92 (304.58)	0.28
Purchasing firewood from market	73.14 (56.41)	0.20	−513.53 (342.80)	0.13
Perceived Ecological Stressors				
Perceives invasive plant impacts	73.13 (59.34)	0.22	875.17 (296.06)	<0.01*
Wildlife is a problem	−46.22 (33.77)	0.17	−94.14 (183.72)	0.61
Management Interventions under SFM-Inspired Silvicultural Practices				
Forest fires in CF	431.26 (65.87)	<0.01*	2862.32 (533.32)	<0.01*
New plantations in CF	−371.02 (95.09)	<0.01*	1813.95 (749.15)	0.02*
Cleaning Mikania in CF	72.90 (74.02)	0.33	−6751.60 (904.40)	<0.01*
Cleaning Lantana in CF	47.06 (70.13)	0.50	1694.43 (572.21)	<0.01*
Cleaning Choromolaena in CF	−101.25 (79.02)	0.20	5317.67 (1132.42)	<0.01*
Controls				
Caste: Hill Janajati^	84.40 (81.42)	0.30	542.54 (427.36)	0.20
Caste: Dalit^	−38.12 (94.62)	0.69	647.82 (495.05)	0.19
Caste: Newar^	−30.66 (165.95)	0.85	388.79 (848.58)	0.65
Caste: Terai Janajati^	120.32 (78.79)	0.13	−34.56 (422.84)	0.93
Household income >50,000 rupees	−111.35 (61.25)	0.07	−2184.31 (776.90)	0.01*
Gender of household head: female^^	−25.20 (58.43)	0.67	330.53 (332.25)	0.32
Intercept	453.13 (183.98)	0.01*	1416.89 (1067.82)	0.19

* 95 % confidence interval excludes zero.
^ Reference group for dummy variable is "Caste: Brahmin (high Hindu)."
^^ Reference group for dummy variable is "gender of household head: male."

Table 6
Multivariate regression results for firewood collection distance: baseline (2014) and change from 2014 to 2017 ($n = 616$).

Variables	Firewood Baseline		Firewood Change	
	Estimate (SE)	p-value	Estimate (SE)	p-value
Livelihoods				
Major income from working in a foreign country	78.04 (112.79)	0.49	−69.84 (124.53)	0.58
Major income from owing small business	−38.80 (129.18)	0.76	66.12 (138.01)	0.63
Major income from a wage job	41.08 (119.20)	0.73	−201.88 (123.04)	0.10
Having savings in a financial institution	−0.05 (103.97)	0.99	−12.61 (145.56)	0.93
Living in a single-family house	216.67 (260.1)	0.41	−63.67 (245.25)	0.80
Land size (kitta)	−8.24 (3.67)	0.03*	16.97 (4.87)	<0.01*
Natural resources management				
Primarily using firewood for cooking	244.50 (151.69)	0.11	−172.70 (135.10)	0.20
Men involved in firewood collection	−108.66 (111.74)	0.33	−83.30 (124.54)	0.50
Purchasing firewood from market	112.12 (116.39)	0.34	−298.68 (172.53)	0.08
Relationships with the nature				
Invasive plant species having an impact	−219.25 (116.76)	0.06	67.32 (121.89)	0.58
Wildlife attack is a problem	90.70 (64.68)	0.16	191.08 (74.53)	0.01*
Silviculture activities from digital mapping				
Forest fires in CF	258.61 (129.42)	0.05	−505.08 (221.79)	0.02*
New plantations in CF	292.52 (183.96)	0.11	−448.57 (330.05)	0.17
Cleaning Mikania in CF	60.71 (146.47)	0.68	−910.81 (390.29)	0.02*
Cleaning Lantana in CF	162.63 (141.27)	0.25	759.37 (265.75)	<0.01*
Cleaning Choromolaena in CF	120.46 (158.62)	0.45	157.94 (493.27)	0.75
Controls				
Caste: Hill Janajati^	249.72 (157.60)	0.11	−111.09 (178.06)	0.53
Caste: Dalit^	778.78 (160.13)	<0.01*	−312.85 (182.45)	0.09
Caste: Newar^	343.99 (308.14)	0.26	−256.09 (340.21)	0.45
Caste: Terai Janajati^	369.52 (144.99)	0.46*	171.07 (166.21)	0.30
Household income >50,000 rupees	−85.91 (114.44)	0.45	−141.72 (275.60)	0.61
Gender of household head: female^^	128.26 (115.74)	0.26	146.60 (140.99)	0.30
Intercept	−78.99 (344.16)	0.82	−487.57 (406.47)	0.23

* 95 % confidence interval excludes zero.
^ Reference group for dummy variable is "Caste: Brahmin (high Hindu)."
^^ Reference group for dummy variable is "gender of household head: male."

activities reported significantly longer firewood collection distances ($p < 0.05$), while larger land sizes were associated with shorter travel distance. By 2017, the concurrent implementation of conservation practices, such as controlled forest fires and the clearing of Mikania, had reduced the travel distance required for firewood collection, suggesting that these interventions improved accessibility in some areas. However, the perceived wildlife threat and Lantana cleaning were linked to increased travel distance, reflecting a change of preferred locations for collecting firewood under the concurrent implementation of CF and silviculture.

4.5. Variable importance: random forest results

We assessed the importance of predictors by comparing variable importance scores, measured as the percentage increase in mean squared error (%IncMSE), using a random forest approach. This method enables us to assess how each predictor influences the accuracy of travel distance predictions beyond what is captured by traditional regression coefficients. Focusing on the top five predictors for each outcome and year, we found that land size, use of firewood for cooking, income level, and male involvement in firewood collection were consistently among the most influential variables. These patterns were robust across models of fodder and firewood collection, as well as across two waves of the CNH survey.

Notably, several of the top-ranked predictors relate to silvicultural practices, including silvicultural activities such as invasive plant species removal and plantation establishment. These patterns suggest that management actions in one part of the landscape may unintentionally displace resource collection to neighboring forests with fewer restrictions or degraded conditions. Although our study was not designed to model spatial interaction effects explicitly, the variable importance results suggest that policy or ecological changes in one location influence behaviors in adjacent areas. This finding highlights the need for integrated planning across community forests and buffer zones to reduce unintended consequences and promote equitable access to forest resources.

Detailed variable importance plots for each model are provided in Appendix Figures, summarizing the top five predictors for each outcome and year. These figures support the above interpretation without duplicating regression results already presented in Tables 3 and 4.

5. Discussion

Our analysis reveals that the concurrent implementation of Community Forestry (CF) and SFM-inspired silvicultural practices in western Chitwan, Nepal, produced contrasting outcomes for local livelihoods. While the new management regime appeared to ease the burden of fodder collection for some households, it simultaneously made firewood collection more burdensome, especially for socially and economically disadvantaged households. The divergent outcome is rooted in the distinct functions of two essential forest resources. Fodder is a critical resource for income-generating livestock, whereas firewood serves as a primary energy source for subsistence, making it particularly important for households lacking access to more expensive fuels (Nepal et al., 2011; Bharadwaj et al., 2021). Understanding these opposing impacts on different categories of households is crucial for evaluating the net effect of overlapping conservation initiatives.

5.1. Fodder collection: a positive outcome from interactions between conservation initiatives

Our findings suggest that the interaction of CF governance and SFM-inspired practices had a positive influence on fodder collection travel distances for some households. Fires in human-managed forests, commonly implemented as controlled burning in grassland and shrub landscapes of CFs, enhance the regeneration of grasses and shrubs (Peet et al., 1999), which are key sources of livestock fodder (Thapa et al., 2021). These practices, potentially inspired or expanded by SFM's promotion of silvicultural practices, appear to have made fodder more available in locations around burned areas within a CF-managed landscape and may have incentivized some disadvantaged households to travel slightly farther to access fodder resources from burned areas, as compared to the shorter travel distance observed in 2014 before the promotion of the SFM-inspired practices in Chitwan.

Under the single CF regime in 2014, the distance to collect fodder was significantly associated with indicators of socioeconomic disadvantage, including firewood reliance for cooking and Terai Janajati caste membership. However, after the promotion of SFM-inspired practices, these associations weakened or disappeared, suggesting a potential shift in the underlying drivers of fodder access and mobility.

This shift may reflect how integrated forest management interventions reshaped the distribution of usable vegetation and, in turn, reduced inequality in access.

Further evidence from the analysis based on the 2017 dataset indicates that households with male members involved in firewood collection or those purchasing firewood had shorter fodder collection distances. In rural Nepal, firewood collection is typically a female-dominated activity; thus, male involvement can signal disruptions to traditional labor divisions, often due to economic distress or social vulnerability. Meanwhile, firewood purchasing, although indicative of forest resource dependency, also suggests a relatively better-off household able to afford market alternatives. Together, these patterns indicate that the interaction of CF and SFM-inspired silvicultural practices has not only altered ecological access but also supported more adaptive and equitable livelihood strategies by easing pressure on disadvantaged groups to access fodder for livestock-related income. Thus, for fodder collection, the SFM-inspired practices may have inadvertently created a more equitable landscape of resource access, changing the previous patterns of socioeconomic disadvantage.

5.2. Firewood collection: a negative outcome from interactions between conservation initiatives

In contrast to patterns observed for fodder, the interaction of CF and SFM-inspired practices appears to have negatively impacted household firewood collection efforts, particularly for socioeconomically marginalized groups. Under the single CF regime in 2014, firewood collection distance was shaped by a range of factors, including the presence of forest fires, invasive species clearing (notably Lantana), reliance on firewood for cooking, firewood purchases from the market, and caste affiliation (Hill Janajati, Dalit, and Terai Janajati). This diverse set of associations highlighted structural inequalities in access to forest resources, as disadvantaged households were bore a disproportionately higher burden due to the need to travel significantly longer to obtain firewood for subsistence needs.

After the introduction of SFM-inspired silvicultural practices, however, the range of factors shaping firewood collection distance became more narrowly tied to socioeconomic disadvantage. Notably, the removal of Mikania in CF areas was negatively associated with travel distance. While Mikania is most aggressive in riverine mixed forests (Dai et al., 2020), it also invades Sal-dominated stands, particularly those with frequent human use and fire exposure (Murphy et al., 2013). Removing Sal forests, especially in easily accessible or degraded areas, may have reduced household use of these regions, leading to increased collection in more remote and intact mixed forests.

At the same time, socioeconomic challenges, such as negative perceptions of invasive plants, concerns about human-wildlife conflict, Dalit and Terai Janajati caste membership, and female-headed households, remained positively associated with longer firewood collection distances. These findings align with the theory that economically disadvantaged households are more dependent on firewood collection, reflecting their vulnerability to resource availability and environmental challenges (Baland et al., 2010). These longer trips suggest that, for firewood, the new management regime did not alleviate but may have reinforced existing inequalities, forcing marginalized households to seek firewood in more distant or non-CF-managed forests, such as government forests or buffer zone forests of CNP (Matthews et al., 2000).

5.3. Livelihood implications of outcomes from interactions between conservation initiatives

Reinforced by random forest variable importance scores, our analysis reveals that the concurrent influence of CF and SFM-inspired silvicultural practices played an important role in reshaping household resource collection behaviors. For both firewood and fodder, key predictors included not only traditional socioeconomic drivers, such as land size and caste identity, but also specific silvicultural practices, including the use of fire and removal of invasive species. These results suggest that the interaction between forest governance regimes, rather than their individual effects, was a primary driver of change in travel patterns for resource collection. Notably, these effects sometimes outweighed traditional socioeconomic drivers such as income or housing type.

From a livelihood perspective, these interaction effects had contrasting implications for the supply of fodder and firewood to households. For fodder, practices, such as forest fires likely enhanced the regeneration of grass and understory shrubs, potentially increasing availability and benefiting some households by allowing them to travel shorter distance for collection. In contrast, for firewood, the same silvicultural interventions appeared to have limited access, especially for marginalized households, they traveled longer to collect firewood between the two survey years. These divergent outcomes highlight the importance of evaluating conservation interventions not in isolation but as interacting systems that shape household decisions in complex and sometimes contradictory ways.

The contrasting outcomes for fodder and firewood collection demonstrate that the actual impact of concurrent conservation initiatives lies in their interaction effects, which can outweigh traditional socioeconomic drivers. Our findings emphasize the urgent need for carefully coordinated forest conservation policies that recognize and address the cumulative and often contradictory impacts of overlapping conservation initiatives. The implications extend well beyond the CF-SFM interaction. Other prominent concurrent programs in Nepal, such as the Reducing Emissions from Deforestation and Forest Degradation (REDD+) program (Neupane and Shrestha, 2012) and smaller Payments for Ecosystem Services (PES) programs (Khanal and Devkota, 2020), such as the Nepal Biogas Support Program for biofuel promotion (Gautam et al., 2009), are also built upon the existing CF framework (Salzman et al., 2018). Our results serve as a cautionary wake-up call: without addressing the fundamental inequalities within CF user groups, layering new financial incentives or management programs onto flawed foundations may fail to achieve equitable outcomes. The Chitwan case illustrates that to enhance forest policymaking, the interaction effects between conservation programs must be understood or under control, not just to leverage co-benefits but to mitigate unintended social harm (An et al., 2024). Ultimately, this study calls for more adaptive and socially inclusive approaches to forest management in Nepal and across the Global South.

5.4. Study limitations and directions for future research

While this study provides critical insights into how overlapping conservation initiatives influence household efforts to collect forest resources, we acknowledge that this study has several limitations. First, although the use of tablet-assisted mapping provided unique household travel distance data, this approach still relies on participants to recall and self-report locations, which are subject to cognitive biases or social desirability effects. Households may also underreported firewood or fodder collection from restricted areas despite the use of de-identified satellite imagery to reduce such biases.

Second, our observational design and reliance on existing variation in conservation programs could limit our ability to make causal claims about the effects of these conservation programs on household efforts to collect forest resources. While we identified the associations between forest management activities and changes in household travel distance, we cannot definitively attribute these changes to specific interventions or forest management practices without a randomized or quasi-experimental design. Moreover, while we attempted to identify the SFM-inspired influences, in practice, we do not have qualitative data based on focus group interviews with the forest managers working on developing the specific forest management plans for these CFs. We inferred that under the nationwide promotion of the SFM program, silvicultural practices would be more commonly adopted by CFs, as the

Nepalese government used the CF regime to facilitate the introduction of silvicultural practices.

Third, although the study leverages longitudinal household survey data from two years (2014 and 2017), this three-year window may not fully capture the long-term effects of forest policy transitions. Delayed ecological responses or gradual shifts in institutional enforcement of silvicultural practices may require longer timelines to manifest fully. Additionally, during this period, other contextual changes, such as migration, market access, or shifting agricultural practices, may have independently influenced household collection behavior but were not systematically measured.

Lastly, our analysis focuses on travel distance as a proxy for effort in accessing subsistence needs, but it does not fully capture qualitative aspects of household resource use, such as the quality, quantity, or cultural value of collected firewood and fodder. These dimensions are essential for understanding of impacts on forest-adjacent households' livelihoods and deserve future attention, ideally through a mixed-methods approach that incorporates ethnographic or participatory insights into household decision-making.

Building on this study, we can explore several avenues for future research that address the limitations above. To overcome the reliance on self-reported data, future work could employ more advanced spatial methods, such as providing households with individual GPS trackers, to validate resource collection sites and routes. While our study effectively identified associations between interacting conservation efforts and resource collection patterns, it would be beneficial to establish more robust causality from quasi-experimental designs that compare CFs with and without formal SFM adoption. A critical next step is to integrate these quantitative findings with qualitative interviews with CF officials. Doing so could uncover the nuanced decision-making and social dynamics that drive the behavioral changes we observed. Finally, longitudinal studies extending beyond the current three-year window from more recent years are needed to assess the long-term ecological and institutional consequences of the interactions between CF and SFM policies.

6. Conclusion

In conclusion, this study demonstrates that the interactions between Nepal's Community Forestry (CF) and concurrently implemented SFM-inspired silvicultural practices led to contrasting livelihood outcomes. Our findings indicate that while some silvicultural practices, such as forest fires, may have improved the availability of fodder, the overall shift in forest management appears to have made firewood collection more burdensome, particularly for disadvantaged social groups. These divergent results for essential forest resources highlight the importance of analyzing the interaction effects of conservation initiatives, as evaluating them in isolation can mask significant and unequal impacts on local communities.

Moreover, our findings reveal that the impacts of these technical forestry innovations are deeply embedded within local social structures in Nepal, with outcomes varying by caste, source of income, and gender. This finding highlights that the seemingly neutral forest management practices can have unforeseen and inequitable social consequences. As integrated forest conservation approaches become increasingly common, policymakers must account for the unintended outcomes of interacting programs to enable better coordination between programs, reduce conflicts, and make sure that conservation efforts align with the livelihood goals of local communities without undermining subsistence livelihoods. Overall, this paper makes a timely contribution to the emerging efforts to understand and manage the interaction effects across conservation initiatives by providing rare empirical evidence of their distributional consequences, advancing the broader goal of developing more socially equitable and ecologically effective forest management policies in Nepal and across the Global South.

Data statement

The de-identified dataset generated and analyzed for this study has been deposited in the openICPSR repository and is accessible via the following persistent link: **doi:** https://doi.org/10.3886/E236987V1. Due to the sensitive nature of the original data, which included precise household locations and resource collection sites, variables that could pose a risk to participant confidentiality have been removed or generalized. To ensure participant safety and privacy, direct public access is restricted. Access to the de-identified data can be requested through the repository's project page.

CRediT authorship contribution statement

Ren Cao: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Li An:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Li An reports financial support was provided by National Science Foundation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.forpol.2025.103597.

Data availability

Data will be made available on request.

References

Acharya, K.P., 2002. Twenty-four years of community forestry in Nepal. Int. For. Rev. 4 (2), 149–156. https://doi.org/10.1505/IFOR.4.2.149.17447.

Adam, I.A.A., Adam, Y.O., Olumeh, D.E., Mithöfer, D., 2024. Livelihood strategies, baobab income and income inequality: evidence from Kordofan and Blue Nile, Sudan. Forest Policy Econ. 158, 103116. https://doi.org/10.1016/j.forpol.2023.103116.

Adhikari, S., Harada, K., Dahal, N.K., Gurung, R., 2024. Scientific forest management practices in Nepal: perceptions of forest users and the impact on their livelihoods. J. For. Res. 29 (3), 159–168. https://doi.org/10.1080/13416979.2023.2275901.

Agrawal, A., Gupta, K., 2005. Decentralization and participation: the governance of common pool resources in Nepal's Terai. World Dev. 33 (7), 1101–1114. https://doi.org/10.1016/j.worlddev.2005.04.009.

Agrawal, A., Chhatre, A., Gerber, E.R., 2015. Motivational crowding in sustainable development interventions. Am. Polit. Sci. Rev. 109 (3), 470–487. https://doi.org/10.1017/S0003055415000209.

Amadu, F.O., Miller, D.C., 2024. The impact of forest product collection and processing on household income in rural Liberia. Forest Policy Econ. 158, 103098. https://doi.org/10.1016/j.forpol.2023.103098.

An, L., Song, C., Zhang, Q., Bohnett, E., 2022. Conservation Effectiveness and Concurrent Green Initiatives. Routledge. https://doi.org/10.4324/9781003290292.

An, L., Liu, J., Zhang, Q., Song, C., Ezzine-de-Blas, D., Dai, J., Zhang, H., Lewison, R., Bohnett, E., Stow, D., Xu, W., Bryan, B.A., 2024. Global hidden spillover effects among concurrent green initiatives. Sci. Total Environ. 917, 169880. https://doi.org/10.1016/j.scitotenv.2024.169880.

Axinn, W.G., Yabiku, S.T., 2001. Social change, the social organization of families, and fertility limitation. Am. J. Sociol. 106 (5), 1219–1261. https://doi.org/10.1086/320818.

Baland, J., Bardhan, P., Das, S., Mookherjee, D., Sarkar, R., 2010. The environmental impact of poverty: evidence from firewood collection in rural Nepal. Econ. Dev. Cult. Chang. 59 (1), 23–61. https://doi.org/10.1086/655455.

Bastakoti, R.R., Davidsen, C., 2014. REDD+ and forest tenure security: concerns in Nepal's community forestry. Int. J. Sustain. Dev. World Ecol. 21 (2), 168–180. https://doi.org/10.1080/13504509.2013.879542.

Baynes, J., Herbohn, J., Smith, C., Fisher, R., Bray, D., 2015. Key factors which influence the success of community forestry in developing countries. Glob. Environ. Chang. 35, 226–238. https://doi.org/10.1016/j.gloenvcha.2015.09.011.

Bharadwaj, B., Pullar, D., Seng To, L., Leary, J., 2021. Why firewood? Exploring the co-benefits, socio-ecological interactions and indigenous knowledge surrounding cooking practice in rural Nepal. Energy Res. Soc. Sci. 75, 101932. https://doi.org/10.1016/j.erss.2021.101932.

Clark, W., Harley, A., 2019. Sustainability Science: Towards a Synthesis. Sustainability Science Program Working Papers. https://dash.harvard.edu/handle/1/42574531.

Dai, J., Roberts, D.A., Stow, D.A., An, L., Hall, S.J., Yabiku, S.T., Kyriakidis, P.C., 2020. Mapping understory invasive plant species with field and remotely sensed data in Chitwan, Nepal. Remote Sens. Environ. 250, 112037. https://doi.org/10.1016/j.rse.2020.112037.

Gautam, Y., Andersen, P., 2016. Rural livelihood diversification and household well-being: insights from Humla, Nepal. J. Rural. Stud. 44, 239–249. https://doi.org/10.1016/j.jrurstud.2016.02.001.

Gautam, R., Baral, S., Herat, S., 2009. Biogas as a sustainable energy source in Nepal: present status and future challenges. Renew. Sust. Energ. Rev. 13 (1), 248–252. https://doi.org/10.1016/j.rser.2007.07.006.

Ghimire, P., Lamichhane, U., 2020. Community based Forest Management in Nepal: current status, successes and challenges. Grassroots J. Nat. Resour. 3 (2), 16–29. https://doi.org/10.33002/nr2581.6853.03022.

Guneratne, A., 2007. The Tharu of Chitwan, Nepal. In: Disappearing Peoples? Routledge.

Joshi, O., Parajuli, R., Kharel, G., Poudyal, N.C., Taylor, E., 2018. Stakeholder opinions on scientific forest management policy implementation in Nepal. PLoS One 13 (9), e0203106. https://doi.org/10.1371/journal.pone.0203106.

Kanel, K.R., Dahal, G.R., 2008. Community forestry policy and its economic implications: an experience from Nepal. Int. J. Soc. Forestry 1 (1). Article 1.

Khanal, Y., Devkota, B.P., 2020. Farmers' responsibilization in payment for environmental services: lessons from community forestry in Nepal. Forest Policy Econ. 118, 102237. https://doi.org/10.1016/j.forpol.2020.102237.

Laudari, H.K., Sapkota, L.M., Maraseni, T., Subedi, P., Pariyar, S., Kaini, T.R., Lopchan, S. B., Weston, C., Volkova, L., 2024. Community forestry in a changing context: a perspective from Nepal's mid-hill. Land Use Policy 138, 107018. https://doi.org/10.1016/j.landusepol.2023.107018.

Lehmkuhl, J.F., 1994. A classification of subtropical riverine grassland and forest in Chitwan national park, Nepal. Vegetatio 111 (1), 29–43. https://doi.org/10.1007/BF00045575.

Matthews, S.A., Ganesh, P.S., Chhetri, N., 2000. Population forces and environmental change: observations from western Chitwan, Nepal. Society & natural resources 13 (8), 763–775. https://doi.org/10.1080/089419200750035610.

McGinnis, M.D., Ostrom, E., 2014. Social-ecological system framework: initial changes and continuing challenges. Ecol. Soc. 19 (2). https://www.jstor.org/stable/26269580.

McLean, J., 1999. Conservation and the impact of relocation on the Tharus of Chitwan, Nepal. HIMALAYA 19 (2), 8. https://digitalcommons.macalester.edu/cgi/viewcontent.cgi?article=1628&context=himalaya.

Murphy, S.T., Subedi, N., Jnawali, S.R., Lamichhane, B.R., Upadhyay, G.P., Kock, R., Amin, R., 2013. Invasive mikania in Chitwan National Park, Nepal: the threat to the greater one-horned rhinoceros Rhinoceros unicornis and factors driving the invasion. Oryx 47 (3), 361–368. https://doi.org/10.1017/S003060531200124X.

Nepal, M., Nepal, A., Grimsrud, K., 2011. Unbelievable but improved cookstoves are not helpful in reducing firewood demand in Nepal. Environ. Dev. Econ. 16 (1), 1–23. https://doi.org/10.1017/S1355770X10000409.

Neupane, S., Shrestha, K., 2012. Sustainable Forest Governance in a Changing Climate: Impacts of REDD Program on the Livelihood of Poor Communities in Nepalese Community Forestry (SSRN Scholarly Paper No. 2048675). Social Science Research Network. https://papers.ssrn.com/abstract=2048675.

Nirmal, K.B.K., Shrestha, R.K., Acharya, S.G., Ansari, A.S., 2009. Maoist conflict, community forestry and livelihoods: pro-poor innovations in forest management in Nepal. J. For. Livelihood 8 (2). https://doi.org/10.3126/jfl.v8i2.2311. Article 2.

Ojha, P., Acharya, K.R., Subedi, A., Regmi, S., 2023. Impact of silviculture system on regeneration status and species diversity: reflection from far-western lowland, Nepal. Banko Janakari 33 (2), 24–37. https://doi.org/10.3126/banko.v33i2.58280.

Ojha, H., Persha, L., Chhatre, A., 2009. Community forestry in Nepal: a policy innovation for local livelihoods, 913. International Food Policy Research Institute, pp. 1–29.

Oniki, S., Berhe, M., Negash, T., Etsay, H., 2023. Do economic incentives crowd out motivation for communal land conservation in Ethiopia? Forest Policy Econ. 150, 102948. https://doi.org/10.1016/j.forpol.2023.102948.

Pattanayak, S.K., Sills, E.O., Kramer, R.A., 2004. Seeing the forest for the fuel. Environ. Dev. Econ. 9 (2), 155–179. https://doi.org/10.1017/S1355770X03001220.

Paudel, G., Carr, J., Munro, P.G., 2022. Community forestry in Nepal: a critical review. Int. For. Rev. 24 (1), 43–58. https://doi.org/10.1505/146554822835224810.

Peet, N.B., Watkinson, A.R., Bell, D.J., Sharma, Uday.R., 1999. The conservation management of *Imperata cylindrica* grassland in Nepal with fire and cutting: an experimental approach. J. Appl. Ecol. 36 (3), 374–387. https://doi.org/10.1046/j.1365-2664.1999.00405.x.

Poudyal, B.H., Maraseni, T., Cockfield, G., 2020. Scientific forest management practice in Nepal: critical reflections from stakeholders' perspectives. Forests 11 (1). https://doi.org/10.3390/f11010027 article 1.

Salzman, J., Bennett, G., Carroll, N., Goldstein, A., Jenkins, M., 2018. The global status and trends of payments for ecosystem services. Nat. Sustain. 1 (3), 136–144. https://doi.org/10.1038/s41893-018-0033-0.

Sharma, U.R., 1990. An overview of park-people interactions in Royal Chitwan National Park, Nepal. Landsc. Urban Plan. 19 (2), 133–144. https://doi.org/10.1016/0169-2046(90)90049-8.

Sharma, S., Yadav, P.K., Dahal, R., Shrestha, S.K., Bhandari, S., Thapaliya, K.P., 2021. Agriculture in relation to socioeconomic status of Tharu in Chitwan of Nepal. J. Agric. Food Res. 6, 100243. https://doi.org/10.1016/j.jafr.2021.100243.

Shova, T., Hubacek, K., 2011. Drivers of illegal resource extraction: an analysis of Bardia National Park, Nepal. J. Environ. Manag. 92 (1), 156–164. https://doi.org/10.1016/j.jenvman.2010.08.021.

Spiteri, A., Nepal, S.K., 2008. Distributing conservation incentives in the buffer zone of Chitwan National Park, Nepal. Environ. Conserv. 35 (1), 76–86. https://doi.org/10.1017/S0376892908004451.

Stræde, S., Helles, F., 2000. Park-people conflict resolution in Royal Chitwan National Park, Nepal: buying time at high cost? Environ. Conserv. 27 (4), 368–381. https://doi.org/10.1017/S0376892900000424.

Strobl, C., Boulesteix, A.L., Kneib, T., Augustin, T., Zeileis, A., 2008. Conditional variable importance for random forests. BMC Bioinform. 9 (1), 307. https://doi.org/10.1186/1471-2105-9-307.

Terrenato, L., Shrestha, S., Dixit, K.A., Luzzatto, L., Modiano, G., Morpurgo, G., Arese, P., 1988. Decreased malaria morbidity in the Tharu people compared to sympatric populations in Nepal. Ann. Trop. Med. Parasitol. 82 (1), 1–11. https://doi.org/10.1080/00034983.1988.11812202.

Thapa, S.K., de Jong, J.F., Subedi, N., Hof, A.R., Corradini, G., Basnet, S., Prins, H.H.T., 2021. Forage quality in grazing lawns and tall grasslands in the subtropical region of Nepal and implications for wild herbivores. Glob. Ecol. Conserv. 30, e01747. https://doi.org/10.1016/j.gecco.2021.e01747.

Thoms, C.A., 2008. Community control of resources and the challenge of improving local livelihoods: a critical examination of community forestry in Nepal. Geoforum 39 (3), 1452–1465. https://doi.org/10.1016/j.geoforum.2008.01.006.

Varughese, G., Ostrom, E., 2001. The contested role of heterogeneity in collective action: some evidence from community forestry in Nepal. World Dev. 29 (5), 747–765. https://doi.org/10.1016/S0305-750X(01)00012-2.

Yabiku, S.T., Glick, J.E., Wentz, E.A., Ghimire, D., Zhao, Q., 2017. Comparing paper and tablet modes of retrospective activity space data collection. Surv. Res. Methods 11 (3), 329–344. https://doi.org/10.18148/srm/2017.v11i3.6741.

Yabiku, S.T., Sullivan, A., York, A.M., Zhao, Q., Glick, J.E., Hall, S.J., Ghimire, D.J., An, L., 2022. Drivers of prohibited natural resource collection in Chitwan National Park, Nepal. Environ. Conserv. 49 (2), 114–121. https://doi.org/10.1017/S0376892922000121.