A socio-ecological analysis of *Mikania micrantha* management in eastern Nepal: perceptions, practices, and programs at local level

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Research

Abstract

Background: Invasive alien species threaten biodiversity, ecosystem services, and forest-dependent livelihoods, yet integrated socio-ecological management approaches remain limited. We combined local ecological knowledge (LEK) with field experimentation to evaluate and manage the invasive vine *Mikania micrantha* in eastern Nepal's lowland forests, to develop a scalable, community-led control model.

Methods: We employed a socio-ecological design integrating household surveys (n=129) across seven Community Forest User Groups (CFUGs) with a 15-month (October 2020 to December 2021) randomized block experiment testing three mechanical treatments (slashing, uprooting, burning) against an untreated control across 96 plots (1-m²). Ordinal logistic regression identified sociodemographic drivers of perceived invasiveness and livelihood impacts. Vegetation monitoring assessed treatment efficacy and native species recovery, and labor inputs were used to estimate management costs.

Results: Our study revealed that 94.6% of respondents were aware of the species, and 57.4% reported high livelihood impacts. Occupation emerged as the strongest predictor of perceived spread and livelihood effects, with laborers and office workers reporting significantly higher perceived impacts ($p < 0.01$). The ethnobotanical survey showed widespread usage (93.7%), mainly used for feeding livestock (fidelity level = 71.3%), followed by bedding material (13.2%), medicinal uses (6.2%), and manure (3.1%). The use of mechanical control measures led to an increase in the number of native species ($p < 0.001$), which more than doubled within one year, while M. micrantha cover decreased by 57% due to uprooting. However, management costs varied substantially (USD 176-425/ha). Crucially, the community-preferred method (uprooting; 46% perceived efficacy) aligned with experimental evidence of maximum effectiveness, validating LEK as a reliable guide for intervention design.

Conclusions: Combining LEK with experimental verification provides an approachable way for community-driven management. A zonation approach involves zoning of areas where slashing is cost-effective in outer zones, along with focused uprooting efforts in zones with rich biodiversity, which can result in ecological restoration while being financially manageable by forest-dependent communities.

Keywords: Ecological Knowledge, Invasive Alien Species, Mechanical management, Uprooting, Cost Efficiency

Background

Invasive Alien Plant Species (IAPs) emerged as major threats to global biodiversity, ecosystem stability, and human well-being (IPBES 2023). These species act as the main causes of biodiversity loss and directly affect the ecosystem functions and socio-economic structure using different ecological processes (Rai & Singh 2020). Other than ecological problems, the cost involved due to invasion is high, as recent studies have shown that the global financial losses due to rapid invasions are over US$1.288 trillion in the last few decades, with more spending done on damage control than in management procedures (Diagne *et al.* 2021, Heringer *et al.* 2024). In Nepal, biological Invasions have also become a serious concern that directly impacts protected areas and livelihoods (i.e., CFUGs, Private Forests) (Shrestha & Shrestha 2019). In the current state, 29 invasive plant species have been recoded, and most of them are projected to expand their ranges toward higher elevations due to the synergistic effects of climate change and habitat disturbance (Karki *et al.* 2022, Shrestha *et al.* 2025).

Among these, *Mikania micrantha* Kunth (Family: Asteraceae), commonly known as “mile-a-minute,” is ranked the “100 of the World’s Worst Invasive Alien Species” (Holm *et al.* 1977, IPBES 2023). The vine is characterized by rapid growth, up to 20 cm daily, due to physiological adaptations related to carbon fixation and nitrogen nutrition (Clements & Kato-Noguchi 2025, Liu *et al.* 2020). *M. micrantha* was introduced in Nepal as early as 1963 through the importation of tea seedlings (Sapkota 2007, Chaudhari *et al*. 2021).

The invasive plant grows vigorously in the lowland forest and competes with native species that form the diet of key flagship species such as the one-horned rhinoceros (*Rhinoceros unicornis*) and thus affects the entire food web (Khadka 2017). Recent studies conducted in the Jalthal forest show that the invasion of *M. micrantha* poses severe challenges to the regeneration of native species, including *Rauvolfia serpentina*, by limiting the number of seedlings and competing with native plants for light in the forest canopy (Kaur *et al.* 2012, Sharma *et al.* 2021, Chen *et al.* 2024). Not only do ecological threats to the local ecosystem but also disrupts natural resource utilization patterns and threaten human populations whose livelihoods depend on the forest. The destruction of native plant communities compromises access to forest-based food sources, medicines, and timber products, thus directly threatening the socioeconomic well-being of forest-dependent families.

Despite the growing recognition of these threats, the response from management practices in Nepal has been insufficient. The current methods of manual removal and composting have had varying degrees of success, but there is no empirical evidence of their efficiency and cost-effectiveness in terms of ecology (Yadav *et al.* 2024). Management of invasive species is a socio-ecological problem in its nature since it calls for not just biophysical control but also community involvement, considering that the well-being of such communities depends on these forests (IPBES 2023, Rai & Scarborough 2015). Local Ecological Knowledge (LEK) is the collective body of knowledge, practices, and beliefs evolving through adaptive processes and transmitted culturally that represents an underutilized resource for invasive species management (Berkes 2018). However, LEK is not uniformly distributed across communities; it differs among communities depending on several factors, and it might become vulnerable due to sociocultural change (Rai 2021, Shrestha *et al.* 2021).

Several studies have been conducted on the spatial extent, habitat preference, ecological impacts, and biodiversity loss caused by *M. micrantha* (Shrestha & Shrestha 2019, Uprety *et al.* 2010, Dulal *et al.* 2022, Kunwar *et al.* 2022, Yadav *et al.* 2024), and some have explored perceptions of biodiversity loss (Poudel *et al.* 2019). However, the main knowledge gaps in the current studies are as follows: (i) lack of quantitative assessment of the relationship between socio-demographics and Local Ecological Knowledge (LEK), level of awareness, and ethnobotanical use of *M. micrantha*. (ii) an absence of integrated studies that examine management measures and perception patterns of people at once. This study supports invasive species research by (i) experimentally evaluating community-centered management interventions for *M. micrantha*, (ii) quantitatively modeling socio-demographic drivers of awareness and perceived impacts using ordinal logistic regression, and (iii) explicitly linking ecological management outcomes with Local Ecological Knowledge and livelihood dependency patterns. By integrating experimental ecology with socio-economic modeling, this research moves beyond descriptive invasion studies. It provides a strong, evidence-based foundation for community-led governance of invasive species in South Asian lowland forests.

Materials and Methods

Study area

This study was conducted in the Jalthal Forest, Nepal. It is one of the historical forests also known as "Char Koshe Jhadi," a historical forest located in the lowland of eastern Nepal (26.446°–26.531° N, 87.930°–88.066° E; area ~6005 ha) (Figure 1). It is a moist tropical forest that features a mean annual temperature of 25°C and precipitation of 2300 mm, with floristic elements from the Indo-Malayan floristic region (Thapa *et al.* 2003). This forest is rich in biodiversity with a heterogeneous composition of forest types, around 15% is mixed species, over 52% *Shorea robusta*, 11% shrubs, 11% degraded forest, and the remaining 13% other areas, including wetlands (Sharma *et al.* 2021). Despite high species richness, the forest faces disturbances from anthropogenic activities, alien species invasions, and fires (Bhattarai 2017, Sharma *et al.* 2024). Among 21 recorded invasive species in the Jalthal forest, *M. micrantha* and *Chromolaena odorata* dominate, covering more than 30% of the area (Regmi *et al.* 2023, Sharma *et al.* 2024). Management of the forest is performed by 22 Community Forest User Groups (CFUGs) and supports the livelihoods of more than one million people depend on important resources like timber, fodder, and medicinal plants (Sharma *et al.* 2021). Organizations such as the District Forest Office and ForestAction Nepal actively conserve the forest through targeted capacity building and awareness programs. The diversity of the forest creates favorable gradients for studying invasion and restoration processes, while high levels of human dependency and CFUGs management create rich socio-ecological dynamics where local knowledge influences and is influenced by management decisions (Sharma *et al.* 2024).

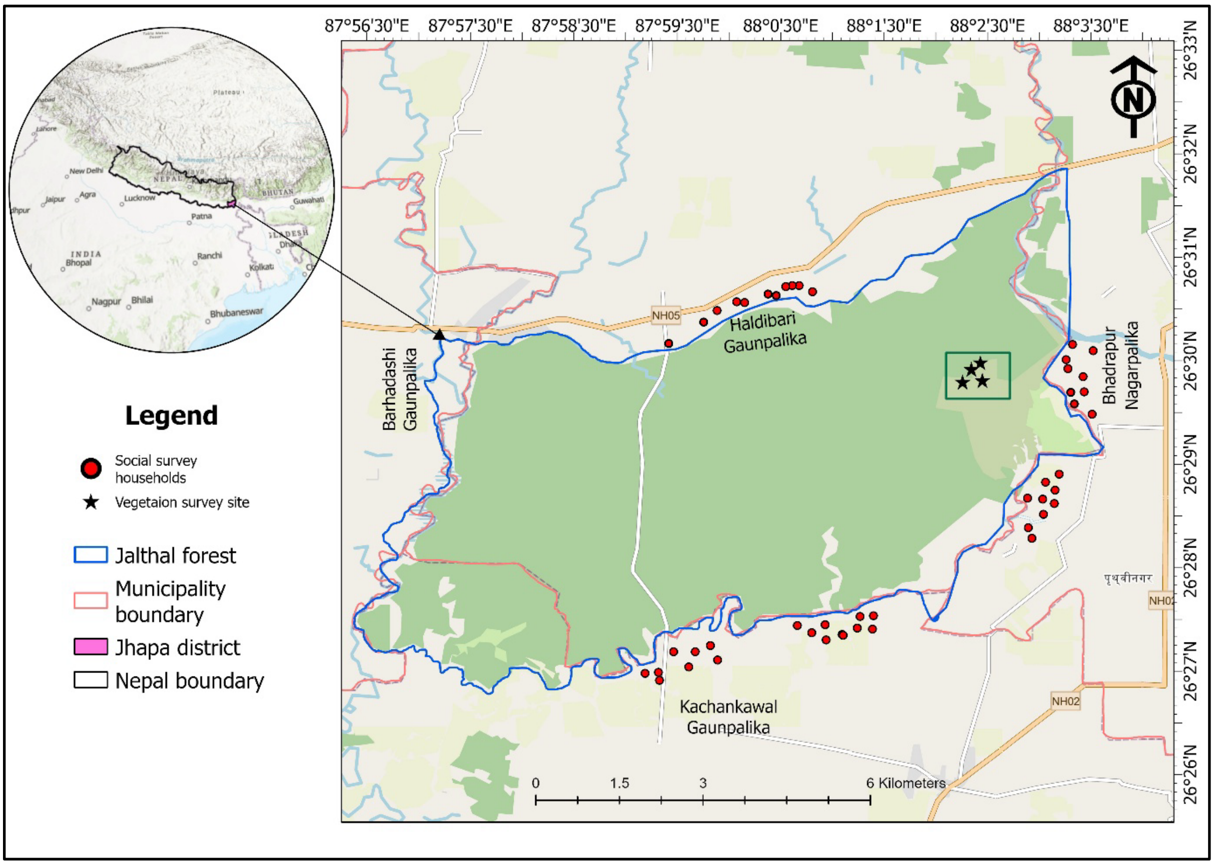

Figure 1. Maps representing the location of plots in the study area in Jalthal forest in the Jhapa district, Nepal

Ecological sampling and data collection

Evaluation of management efficiency in severely invaded sites where ecological and livelihood impacts are most pronounced, we focused on high-density invasion areas (>80% cover) using a stratified random sampling approach, combining GPS ground verification (Garmin eTrex) with Google Earth imagery (Goldsmith & Harrison 1976). We considered high-density areas to have urgent control needs, but this may limit direct applicability to low- or medium-density areas. Four experimental blocks (50 m × 20 m = 1000 m²) were established for vegetation survey, at least 1 km apart to minimize spatial autocorrelation (Lichstein *et al.* 2002). Each block was divided into 10 plots (10 m × 10 m = 100 m²). Three plots per block were randomly assigned to treatments: slashing (cutting stems at ground level), uprooting (complete removal including roots), and burning (controlled fire on dried biomass). A fourth untreated control plot (no intervention) was placed 500 m from each treatment block to minimize treatment spillover. Each plot was subdivided into four macro-subplots (5 m × 5 m, 25 m² each); further, macro-subplot divides into two micro-plots (1 m × 1 m) for detailed measurements, yielding 8 micro-plots (4 macro × 2 micro). Across 4 blocks, 96 microplots were monitored for species richness and *M. micrantha* coverage. Plots were monitored quarterly from October 2020 to December 2021 to track seasonal variation in regrowth and treatment efficacy, aligning with standard monitoring frequencies for *M. micrantha* eradication (Brooks *et al.* 2008).

The percentage cover of *M. micrantha* was used as the primary response variable and as a measure of control efficiency. Coverage of *M. micrantha* was recorded using mean values of cover classes: 1: 0–5% cover (mean: 3%); Class 2: 5–25% (mean: 15%); Class 3: 25–50% (mean: 37.5%); Class 4: 50–75% (mean: 62.5%); Class 5: 75–95% (mean: 85%); Class 6: 95–100% (mean: 97.5%) as in Daubenmire (1959). The surrounding area coverage of *M. micrantha* and the tree canopy were also observed. Ethnobotanical and ecological validation, voucher specimens of *M. micrantha* and associated species were collected from each plot during surveys, and herbaria were prepared according to standard herbarium protocols. Species taxonomic identifications were conducted using literature (Shrestha *et al.* 2022) and comparing them with reference specimens at the National Herbarium and Plant Laboratories (KATH), Lalitpur, Nepal.

Social Survey

For the social survey, a semi-structured questionnaire was prepared to evaluate local knowledge, perceptions, and practices of *M. micrantha*. The questionnaire was designed according to standard ethnobotanical protocols (Alexiades, 1996) and converted into the local language. Initially, the questionnaire was tested with 10 non-sampled households and refined for clarity. Ethical protocols were followed: Free, Prior, and Informed Consent (FPIC) was obtained orally from each participant before interviews, ensuring full disclosure of study objectives, potential risks/benefits, voluntary participation, and rights to withdraw in accordance with the International Society of Ethnobiology (ISE) Code of Ethics (2006, 2008). Mutually Agreed Terms (MAT) were established with the CFUGs executive committees, outlining data usage, confidentiality, and acknowledgement opportunities for community representatives

Social surveys were conducted face-to-face in local languages from June to August 2021. We employed a two-stage random sampling strategy: First, seven Community Forest User Groups (CFUGs) were randomly selected from the 22 managing Jalthal forest, spanning three municipalities (Bhadrapur Municipality, Haldibari Rural Municipality, and Kachankawal Rural Municipality). Second, 18–20 households per CFUG were chosen from CFUG members, a total of 129 respondents. This sample size adequately represents the Jalthal forest communities, as the stratified random sampling approach captured geographic and socioeconomic diversity across homogeneous forest-dependent populations that share similar cultural practices and livelihood dependencies on forest resources. Prior ethnobotanical and invasive species perception studies in lowland forest and buffer zone forests have shown representativeness (e.g., n=150 households in Paudel *et al.* 2024). The questionnaire categorized into five sections: (1) sociodemographic characteristics (age, gender, ethnicity, occupation, education); (2) knowledge and awareness of *M. micrantha* (identification, local names, perceived spread dynamics); (3) ethnobotanical uses, purpose, frequency, preparation methods (4) perceived impacts on livelihoods and forest resources; and (5) traditional management practices employed. Free-listing was used to document use categories, followed by detailed probing for each reported use (Martin, 2010). Three Focus Group Discussions (FGDs) with 6-10 participants each were organized to validate individual responses. FGDs included separate groups of women, elderly community members, and CFUGs executive committee members to ensure diverse perspectives.

Data Analysis

To quantify the relative importance of different use categories, we calculated the Fidelity Level (FL) for each reported use (fodder, bedding, medicinal, manure) following equation (1) (Friedman *et al.* 1986) and (Gouwakinnou *et al.* 2011);

$$\text{Fidelity Level}(\%) = \frac{(n \text{ X } 100)}{N} \qquad (1)$$

Where n = number of informants reporting a specific use category, and N = total number of informants reporting any use of *M. micrantha*. FL indicates the degree of consensus among informants regarding a particular use, with higher values indicating greater cultural significance.

This study employed ordinal logistic regression (OLR) models to identify the variables that influence the effects of a particular IAP (Ei). The regression was based on the following model equation. (2);

$$E_i = \alpha+\beta_1 S_i+ \beta_2 O+ \beta_3 G+ \beta_4 A+ \beta_5 E+ \beta_6 K_i+ \beta_7 U_i+ \beta_8 D \qquad (2)$$

where α is a constant term, and the β1 to β6 are the coefficients of the explanatory variables; status of *M. micrantha* (Si), primary occupation of the respondents (O), gender of the respondents (G), Age group of respondents (A), ethnicity of respondent (E), Knowing about the plant (Ki), plant use (Ui) and distance between the forest and house in km (D). We evaluated the proportional odds assumption and fit (Nagelkerke pseudo-R^2 and Cox & Snell). OLR models are among the most commonly used statistical methods in ecology, particularly in this study, where independent variables are used to assess the effects of *M. micrantha* at the study site. We tested the proportional odds assumption using the Brant test ($p > 0.05$) and assessed multicollinearity (VIF < 5). Qualitative responses on uses and control practices were quantified and integrated into descriptive statistics.

For ecological data, we explored the nature of the data distribution through the Shapiro test and Q-Q plot. The nature and variation of the data were analyzed using descriptive statistics. To assess the efficacy of the untreated control strategy, the influence of treatment, the types of treatments, different time intervals, and categories of environmental factors were evaluated. Since the data were not normal, the Kruskal-Wallis rank test was used to see a difference among the different treatments. The significant differences between the control and treatment were tested by the Mann-Whitney U. A box plot was used to compare the cover differences between pre and post-treatment plots. All statistical analyses were conducted using R 4.2.2 (R Core Team, 2024). The management costs were estimated based on labor hours per plot (converted to days/ha) and local wages (NRs 500/day; ~USD 4.17 at 1 USD =120 NRS).

Results

Plant Species Richness

We recorded 30 species as baseline data and, after treatment, recorded 71 species within a year. Out of the total species, 41 (57.74%) were herbaceous and 30 (42.25%) were woody species. There were 66 native (92.95%) and only 5 (7.05%) invasive species (Figure 2). The mean number of species (mean ± SD) was 19 (2±0.74), 16 (2±0.81), 22 (2±0.59), and 18 (2±0.66) for slashing, uprooting, fire, and untreated control, respectively, before any treatment. Post-treatment species richness was 39 (4±0.91), 37 (4±0.22), 34 (3±0.54), and 23 (2±0.71) for slashing, uprooting, fire, and untreated control, respectively. *M. micrantha*, *C. odorata*, and L. camera were the common invasive plant species in the study site. Native species richness increased significantly following all treatments ($p < 0.001$), with post-treatment richness more than doubling compared to pre-treatment baselines. There were significant differences in species richness among treatment plots ($\chi2$= 3.813, df = 3, $p>0.05$).

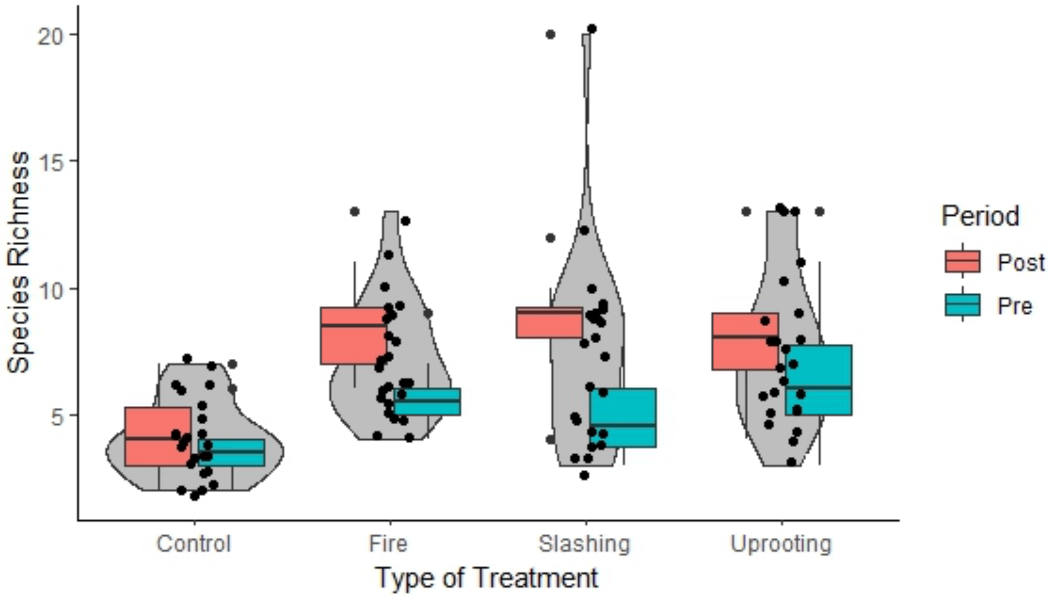

Figure 2. Violin-box plot shows the species richness among the different types of treatments.

The average value of herbaceous species richness was 8 ± 0.35 in the treatment plot, and 5 ± 0.52 in control plots (Fig. 3). Treatment-wise herbaceous species richness was highest in the slashing plot (8 ± 0.74) and lowest in the uprooting plot (8 ± 0.63). The herbaceous species richness was significantly different ($\chi2$ = 27.24, df = 10, $p <0.001$) between the untreated control and treatment plots. The herbaceous species richness was significantly different (Kruskal-Wallis = 15.76, df = 3, p =

0.001) among the treatment plots. Slashing, uprooting, and fire were significantly different (t=3.96, p<0.0001), (t=3.41, p<0.001), and (t=2.84, p<0.001), respectively, supporting herbaceous richness. These species richness outcomes directly relate to our primary objective of experimentally evaluating community-centered management interventions for *M. micrantha*, as the significant post-treatment increases (more than doubling from baseline) demonstrate the efficacy of mechanical treatments in promoting native biodiversity recovery and reducing invasive dominance in invaded lowland forests.

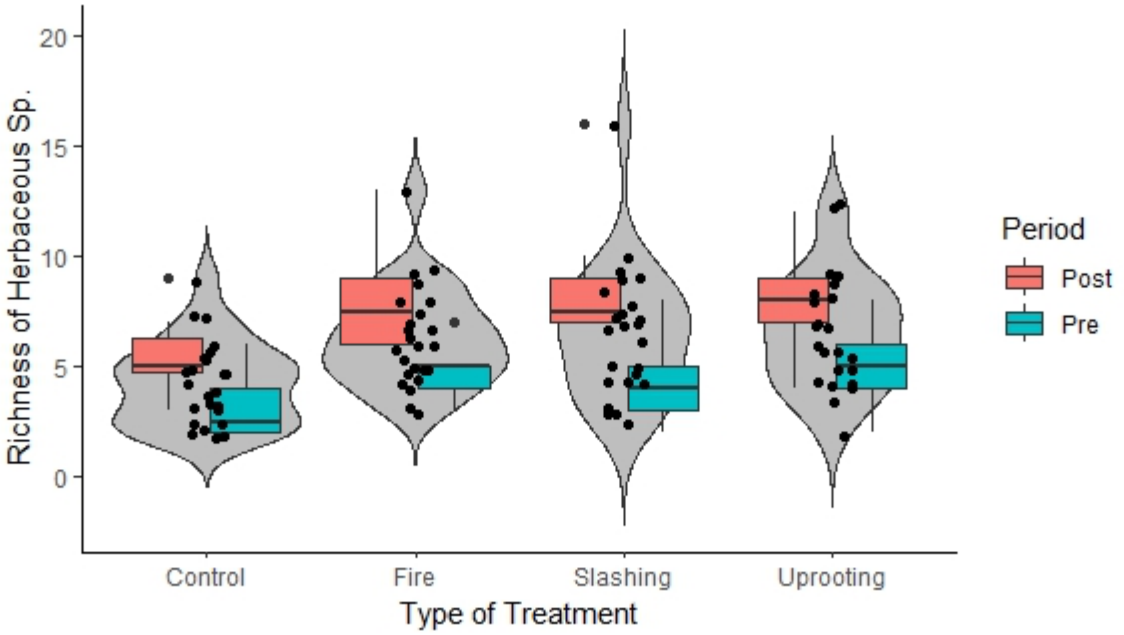

Figure 3. Violin-box plot showing herbaceous species richness between untreated control and treatment plots.

Abundance of *Mikania micrantha*

Mikania species cover (%) was 69 ± 3.1, 58 ± 5.36, 56 ± 6.46, and 54 ± 5.82 in slashing, uprooting, fire, and control plots respectively before treatment (pre-treatment) (Fig. 4). Post-treatment cover (%) were 35 ± 7.4, 25 ± 3.5, 30 ± 7.8 and 45 ± 4.11 in slashing, uprooting, fire and untreated control respectively. Cover of *M. micrantha* did not differ significantly between control plots and treatment plots before intervention (χ2 = 2.9777, df = 3, p> 0.05), confirming baseline uniformity and significant differences between pre and post-treatments (p-value <0.001).

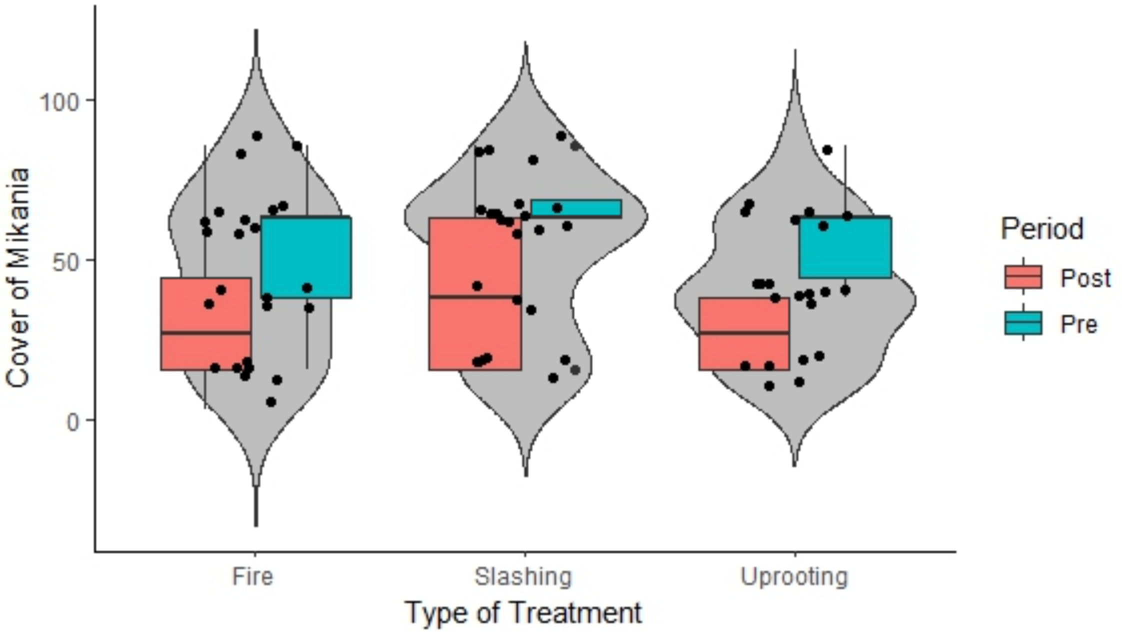

Figure 4. Violin-box plot showing the coverage of *M. micrantha* among different treatments.

Local Ecological Knowledge and Ethnobotanical Significance

A total of 129 households from seven Community Forest User Groups (CFUGs) were surveyed, with a balanced gender representation (51.9% male, 48.1% female) (Table 1). The majority of respondents were middle-aged (61.2%) and primarily engaged in subsistence farming (85.3%). Local knowledge of *M. micrantha* was nearly universal (94.6%). Respondents used evocative local names such as Lahare Banmara ("Forest Killer") and Maobadi Jhar ("Maoist Weed"), reflecting the plant's rapid and aggressive expansion. While 78.3% of households reported utilizing the plant for fodder or bedding, a significant portion (38.8%) observed that its spread is "rapidly increasing," and 57.4% reported a "high effect" on their primary livelihoods. To examine differences in local knowledge, chi-square tests of independence revealed significant differences in awareness by gender ($p = 0.014$), with 100% of females aware compared to 89.6% of males. There are no significant differences in knowledge found for age group ($\chi^2 = 4.18$, df = 2, $p = 0.124$) and occupation ($\chi^2 = 4.82$, df = 3, $p = 0.185$).

Table 1. Socio-demographic profiles and perceptions of *Mikania micrantha's* impacts, illuminating how livelihoods shape awareness in Nepal's forest-dependent households.

Variable	Type	Description	Code, category, and range	Frequency	Percentage
Effects of *M. micrantha*	Ordinal	How do people perceive the effects of the *M. micrantha* on their livelihoods based on the forest products, condition of the forests, and wildlife crop raiding?	1= No effect	18	13.95
			2= Low effect	20	15.5
			3= Medium effect	17	13.17
			4= High effect	74	57.36
Status of *M. micrantha*	Ordinal	How has the IAP spread in the landscape over the last 5-10 years, according to the individual evaluation of the respondents?	1= Don't Know	10	7.75
			2= Decreasing	19	14.73
			3= No Change	9	6.98
			4= High effect	41	31.7
			5= Rapid increasing	50	38.76
Gender	Nominal	Household interview heads, whether male or female	1= Male	67	51.94
			2= Female	62	48.06
Age	Ordinal	Age of interview respondents	1= Young (18-35)	17	13.18
			2=Middle-aged (36-59)	79	61.24
			3=Old (>60)	33	25.58
Occupation	Nominal	The primary occupation of the respondent	1=Business	10	7.75
			2= Farming	110	85.27
			3= Government Jobs	4	3.1
			4= Daily wages	5	3.88
Ethnicity	Nominal	Group sharing culture, ancestry, and identity	1= Brahmin	49	37.98
			2= Chettri	56	43.41
			3= Dalit	8	6.2
			4= Madhesi	8	6.2
			5= Newari	8	6.2
Invasive plant use	Ordinal	Households use the *M. micrantha* to meet the demand for their household needs	1=Not use	8	6.3
			2=Use	121	93.7
Know about the Plant	Ordinal	Familiar with plants and their pro and cons	1=No	7	5.43
			2= Yes	122	94.57
Distance	Numeric	Walking distance between respondents' households to their respective community forest in minutes. (range: 10–120)	45 ± 15 (Mean ± SD)		

Ethnobotanical utilization of *M. micrantha* in Jalthal

Ethnobotanical surveys revealed widespread utilization of *M. micrantha* by 93.7% respondents (Table 2), with fodder for livestock (goats and cattle) dominating frequency of citation and a fidelity level (FL=71.31%), underscoring its role as a vital dry-season forage. Bedding material ("Sotar") followed (FL=13.17%), enhancing livestock management, while medicinal applications for wound healing, antiseptic poultices, and minor bleeding control (FL=6.2%) highlighted enduring traditional knowledge, and manure composting ranked lowest (FL=3.1%). Fodder and bedding use predominated in high-density invasion areas due to abundant biomass availability, contrasting with low-density areas where medicinal uses were more selectively reported. These LEK insights directly inform management interventions by guiding utilization-based control strategies, such as targeted harvesting for fodder to limit spread while strengthening community resilience.

Table 2. Purpose of use, frequency citation, and fidelity level (FL) of uses of *M. micrantha*

Uses of *M. micrantha*	**Purpose of use**	**Frequency of citation (FC)**	**Fidelity level (%)**
Fodder	Livestock feed (goats, cows, cattle)	92	71.31
Bedding (Sotar)	Cattle Bedding	17	13.17
Medicinal use	Wound healing, antiseptic poultice, stopping minor bleeding	8	6.2
Manure	Making compost/organic fertilizer	4	3.1
	Total	**121**	**93.7%**

Traditional Management Practices and Perceived Efficacy

Respondents employed self-initiated control strategies, reflecting a lack of external support for managing the spread of invasive plants. Among all respondents, 92% of households implemented various measures to limit the proliferation of *M. micrantha* (Figure 5). The primary methods adopted by rural households (76%) in farmlands and community forests included uprooting, cutting, and burning. In terms of perceived efficacy, 46% of respondents identified uprooting as the most effective approach for constraining infestations, followed by burning (16%), slashing (13%), grazing (6%), and chemical/herbicide application (3%).

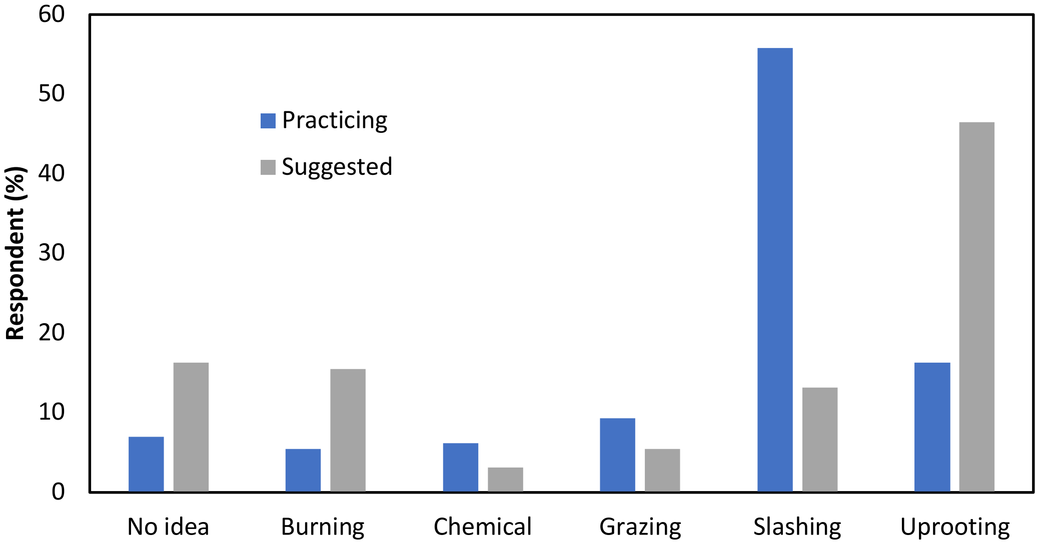

Figure 5. Number of households practicing and suggested the control measures.

The total labor required for uprooting was 85, followed by slashing 40 and fire 35. Among the three treatments, uprooting was more expensive at 425 $ /ha, followed by slashing at 202.08 $ /ha and fire at 176.04 $ /ha (Table 3). The costs of the mechanical treatment operation were NRs (Nepalese Currency-Nepalese Rupees (NRs); 1 US$-NRs. 120.00 during the experimental period).

Table 3. Comparative costs of mechanical treatments, revealing labor demands and USD/ha expenses to guide cost-smart strategies for invasive species control

Treatment	**hours/plot**	**Labor Day/ha**	**Cost (US $)**
Slashing	3.23 ± 0.35	40.41	202.08
Uprooting	6.8 ± 0.3	85	425
Fire	2.8 ± 0.18	35.2	176.04

Determinants of Perceived Invasiveness and Livelihood Impact

The results of the ordinal logistic regression analysis (Table 4), factors influencing perceptions of the spreading status of *M. micrantha*. Occupation was a prominent factor, with farming associated with an odds ratio (OR) of 10.7 (β = 2.371, SE = 0.696, P < 0.001), labor with an OR of 20.64 (β = 3.02, SE = 1.22, P < 0.01), and office work with an OR of 15.11 (β = 2.7, SE = 1.17, P < 0.01), indicating respondents are more likely to see the plant as aggressively spreading than others. Similarly, these groups reported heightened livelihood disruptions (farmers OR=4.287, p<0.1; laborers OR=9.43, p<0.01; office workers OR=9.254, p<0.05), yet prior knowledge of the plant (OR=0.298, p<0.01) and prolonged exposure duration (OR=0.971 per year, p<0.01) significantly attenuated perceived threats, highlighting familiarity's role in fostering resilience. These findings advocate for occupation-tailored interventions to mitigate invasive species burdens in vulnerable socio-economic strata.

Table 4. Ordinal logistic regression unveiling key socio-demographic drivers of *M. micrantha*'s perceived spread and livelihood effects

Indicator	Variables	Categories	Coefficient (β)	Standard Error (SE)	Odds Ratio (OR)	P
Spreading Status	House to Forest	House to Forest	-0.031	0.026	0.969	0.24
	Ethnicity	Chettri	-0.297	0.381	0.743	0.44
		Dalit	-1.014	0.801	0.362	0.21
		Madhesi	-0.157	0.808	0.855	0.85
		Newar	-0.623	0.746	0.536	0.4
	Gender	Male	-0.299	0.354	0.742	0.4
	Age Group	Middle age	0.068	0.479	1.071	0.89
		Old age	0.383	0.303	1.466	0.21
	Occupation	Farming	2.371	0.696	10.708	***
		Labour	3.028	1.228	20.644	**
		Office work	2.716	1.177	15.119	**
	Know About Plant	Yes	-0.196	0.739	0.822	**
	First time see plant	Years	-0.032	0.015	0.969	*
Effect on Livelihood	House to Forest	House to Forest	-0.029	0.028	0.972	0.31
	Ethnicity	Chettri	0.269	0.402	1.309	0.5
		Dalit	-0.852	0.866	0.427	0.33
		Madhesi	-0.777	0.865	0.46	0.37
		Newar	0.885	0.819	2.423	0.28
	Gender	Male	-0.284	0.378	0.753	0.45
	Age Group	Middle age	0.408	0.506	1.504	0.42
		Old age	-0.219	0.314	0.803	0.49
	Occupation	Farming	1.456	0.779	4.287	.
		Labour	2.244	1.269	9.43	**
		Office work	2.225	1.134	9.254	*
	Know About Plant	Yes	-1.211	0.727	0.298	**
	First time see plant	Years	-0.029	0.016	0.971	**

Note: * p<0.05, ** p<0.01, *** p<0.001, p<0.1

Spreading Status: X2= 66.35***, Cox & Snell Pseudo R2: 0.289, Nagelkerke Pseudo R2: 0.293

Effect on Livelihood: X2= 24.33**, Cox & Snell Pseudo R2: 0.449, Nagelkerke Pseudo R2: 0.381

Discussion

Plant Species Recovery Following Mechanical Treatments

Our study shows that mechanical removal of *M. micrantha* restores native biodiversity in the invaded area by doubling species richness. This recovery, dominated by native species (92.95%), demonstrates that even severe invasions need not result in permanent biodiversity loss when communities intervene. The magnitude of recovery exceeds that reported in similar studies globally (Hejda *et al.* 2009, Inderjit *et al.* 2011), likely reflecting both the effectiveness of mechanical removal and the resilience of native propagule sources in Jalthal forest. We identified a threshold effect; native species richness did not differ significantly at low invasion levels (1-25% cover) but declined substantially when *M. micrantha* exceeded 26%

cover. This non-linear impact pattern, consistent with Gordon's (1998) observations from Florida ecosystems, has profound management implications. Early detection and rapid response of invasion with limited resources would be more cost-effective than intensive control of established infestations at CFUGs (IPBES 2023). The absence of significant differences in species richness among treatment types; initiating removal through any available method triggers ecological recovery. With the adaptive management principles, such findings would be aligned by analysis and support immediate action (Rai *et al.* 2012). Herbaceous species responded strongly, with significantly higher richness in treatment plots compared to control plots; ecologically significant given the herbaceous layer's role in habitat structure, soil stabilization, and forage provision (Kowarik *et al.* 2019). These suggest that adaptive management and immediate action are preferable to prolonged planning delays.

Treatment Efficacy and the Cost-Efficacy Trade-Off

Management treatments significantly reduced *M. micrantha* cover; uprooting's efficiency reflects complete root removal, preventing rapid spreading (Clements & Kato-Noguchi 2025). However, this ecological gain comes at a high cost, which is prohibitive for most CFUGs. Slashing treatment is a realistic alternative at half the cost, consistent with Lian *et al*. (2006), who found periodic cutting effectively suppressed *M. micrantha* in China. Slashing effects remained consistent across varying canopy openness, suggesting broad applicability. Fire treatment; a cheapest method, with potential damage to soil biota and tree regeneration requiring cautious application (Murphy *et al.* 2013). These costs contextualize within global invasion economics, biological invasions have cost USD 1.288 trillion globally (Diagne *et al.* 2021), with *M. micrantha* alone causing ~USD 1.2 billion annually in China (Clements & Kato-Noguchi 2025). For Nepal's CFUGs managing an average of 0.73 ha/household (DoF 2008), the 85 labor days/ha required for uprooting demands differentiated strategies.

Awareness percentage (94.6%) demonstrates that invasive species recognition is embedded in local ecological knowledge (LEK). Local names Lahare Banmara ("Forest Killer"), Maobadi Jhar ("Maoist Weed"), Bhede Lahara ("Goat Vine"), reveal how communities conceptualize invasions through ecological observation and cultural-historical experience (Berkes 2018). "Maoist Weed," an illustration of the similarity between the plant's spread and revolution, how environmental change is interpreted through lived sociopolitical experience, is a novel finding in regional invasive species literature.

utilization of *M. micrantha* despite recognizing its invasiveness "utilitarian adaptation" (Shackleton *et al.* 2019). The exceptional FL for fodder indicates deep cultural embedding over five decades since introduction (Sapkota, 2007), with collection increasing during dry season forage scarcity, similar patterns observed in China (Zhang *et al.* 2004). Medicinal uses like wound healing, antiseptic poultices, and hemostatic applications permit attention. While phytochemical studies confirm *M. micrantha* contains antimicrobial alkaloids, flavonoids, and terpenoids (Poudel *et al.* 2019), our study supports that these properties are locally recognized in Nepal. The persistence of this knowledge among older respondents suggests potential risk, consistent with global patterns of traditional knowledge loss (Berkes 2018). Bedding use simultaneously serves management goals by removing biomass, suggesting potential for "utilization-based control" creating livelihood co-benefits, an approach gaining traction, such as in Chitwan, where briquette production reduces labor costs by 20-30% (Shrestha *et al.* 2024).

Community Preferences Validate Experimental Evidence

Most of the households start self-initiated control, challenging narratives showing communities as passive victims and revealing them as active environmental managers (Rai & Scarborough 2015). Community perceptions aligned precisely with experimental evidence; uprooting was both most practiced and highly perceived for effectiveness, followed by burning and slashing. This alignment validates LEK as a reliable guide for intervention design and suggests that community-led programs building on existing knowledge are more likely to achieve sustained adoption (Li *et al.* 2021). Qualitative insights revealed sophisticated reasoning: "Uprooting is hard work, but it's the only way to keep the forest clean. If you just cut, it grows back thicker within months". These narratives demonstrate understanding of treatment efficacy and regrowth dynamics, knowledge developed through decades of experiential learning. The minimal use of chemical controls reflects environmental perception ("Poison kills everything, even the good plants") and aligns with global calls for integrated approaches prioritizing mechanical and biological control in sensitive ecosystems (IPBES 2023).

Occupation Drives Perception of Invasion Impacts

Ordinal logistic regression identified occupation as the most significant predictor of both perceived spread and livelihood impacts, offering quantitative support for the "Direct Dependency Hypothesis". Labourers exhibited the highest odds of perceiving aggressive spread and livelihood impacts, reflecting their daily engagement with forest resources for fodder and fuelwood, which makes them directly vulnerable to resource depletion. Farmers also showed increased perceptions of spread and impacts, aligning with *M. micrantha's* encroachment on agricultural margins (Yadav *et al.* 2024). Notably, office workers also demonstrated significantly heightened perceptions of livelihood impacts despite not being directly dependent on the forest. This indicates that *M. micrantha* affects ecosystems in ways that extend beyond direct users, through diminished ecotourism potential or concerns about wildlife habitat degradation, which can impact flagship species such as the one-horned rhinoceros (Khadka 2017).

Knowledge of the plant increased awareness of its spread, underscoring the role of environmental awareness in risk perception. However, the negative association between exposure duration and perceived urgency suggests "shifting baselines syndrome," prolonged exposure leads to gradual acceptance of degradation as normal (IPBES 2023). Communities living with *M. micrantha* for decades may underestimate impacts, potentially reducing control motivation, a critical management challenge requiring targeted environmental education. Ethnicity, gender, age, and distance were non-significant, contrasting with some studies (Paudel *et al.* 2024). This likely reflects universal forest dependence across social groups in Jalthal.

Policy and Management Implications and Limitations

Plans for using zonation methods prioritizing uprooting in biodiversity hotspots and slashing in surrounding areas to enhance ecological results and labour efficiency. Local Ecological Knowledge (LEK) can assist in monitoring, early detection, and prioritizing treatments, ensuring community-led and context-specific actions. Cooperative labour-sharing or targeted subsidies can help lower the costs of intensive efforts, while sustainable biomass use for fodder and bedding supports “utilization-based control” programs, benefiting livelihoods. Integrating invasive species management into national biodiversity, climate change, and forest policies, along with partnerships among communities, researchers, and policymakers, will boost the long-term resilience and success of control strategies.

This study has some limitations. Monitoring was carried out over just one year, leaving long-term regrowth and treatment success uncertain. Emphasizing high-density invasions (>80% cover) might lead to an overestimation of treatment effectiveness in areas with lower invasion levels. Economic analyses included labour and local wages but did not account for opportunity costs or seasonal labour constraints. LEK data, while validated through Focus Group Discussions, may still be subject to recall bias or cultural interpretation. Finally, results are specific to Jalthal forest and its CFUGs structure, limiting direct extrapolation to other ecological or social contexts.

Conclusion

This study presents a transformative approach to invasive species management by integrating rigorous ecological experimentation with Local Ecological Knowledge. In Jalthal forest, mechanical treatments doubled native species richness and reduced *M. micrantha* cover by up to 57% within a year. Community awareness is high, and occupation strongly shapes perceptions of invasion impacts, highlighting socio-economic vulnerabilities. Cost considerations indicate that a zoned strategy targeted at uprooting in priority areas and affordable slashing in peripheral zones offers a feasible pathway for CFUGs. LEK-aligned interventions enhance adoption and effectiveness, supporting the transition from fragmented control efforts to coordinated, community-led management. Integrating invasive species management into national biodiversity and climate adaptation frameworks ensures long-term resilience. Future research should extend monitoring beyond one year to capture regrowth dynamics and seasonal variation, assess treatment efficacy in areas with lower invasion density, and broaden economic analyses to include opportunity costs and seasonal labour constraints. A systematic evaluation of LEK across social groups and age cohorts will clarify knowledge retention and the risk of erosion. Finally, integrating experimental biocontrol measures with mechanical treatments could help identify safe, cost-effective, and scalable management strategies.

Declarations

List of abbreviations: IAS-Invasive alien species; CFUGs- Community Forest User Groups; LEK- Local Ecological Knowledge; FPIC- Free, Prior, and Informed Consent; MAT- Mutually Agreed Terms

Ethics approval and consent to participate: Oral informed consent was obtained from all participants prior to data collection. The study adhered to the principles outlined in the Code of Ethics of the International Society of Ethnobiology (ISE 2008).

Consent for publication: Not applicable

Availability of data and materials: All data generated or analyzed during this study are included in this published article. Additional datasets are available from the corresponding author upon reasonable request.

Competing interests: Not applicable

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