scientific reports

OPEN

Perceived adverse impacts undermine socio-economic benefits of resin tapping to the rural livelihood in far-western Nepal

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Chirpine (*Pinus roxburghii*), also known as longleaf Indian pine, is the most tapped pine species in several Asian countries, including Nepal, for its high resin yield. Resin tapping in Chirpine trees has been a longstanding practice in mid-hills of Nepal for the last several decades. This study aimed to evaluate the social impacts of resin tapping from Chirpine forests on the rural socio-ecological dynamics of Nepal's mid-hills. Using a representative sample of 302 forest users from 20 community forest user groups in three far-western districts, we applied the structural equation modeling approach to examine both the positive and negative perceived effects of resin tapping on the rural livelihoods. While respondents acknowledged the positive impacts of resin tapping on local employment and community development activities, many respondents stressed the negative environmental outcomes, including increased fire incidents, water scarcity, and higher mortality of pine trees. Results suggest that rich and male respondents are less likely to realize the negative impacts of resin tapping, whereas a member of community forest user groups is more likely to view resin tapping favorably. Understanding the perspectives of forest users on resin tapping within evolving socio-ecological dynamics shaped by changing social, demographic, and economics factors is critical for ensuring the sustainability of Chirpine based human-nature interactions.

Keywords Non-timber forest products, Chirpine, Structural equation modeling, Community forest user groups, Human-nature interactions

The contribution of non-timber forest products (NTFPs) to socio-cultural, political, ecological and economic fronts of rural livelihoods is well documented globally[1–3]. A recent estimate suggests that up to 5.8 billion people across the world use NTFPs in some fashion, and about half of them are from the rural regions of the Global South[2]. The literature is rather mixed in terms of the role of NTPFs on poverty alleviation, with an assertion that the reliance on NTFPs might lead to a poverty trap[3,4]. Some of the reported challenges in the sustainability of NTFPs include forest degradation led by overharvesting, lack of regulations and monitoring, market barriers, and limited external support[3,4]. As rural communities seek to harness NTFP markets for livelihood support, it becomes crucial to examine how social factors along with the socio-ecological interactions influence the management and extraction of these products while achieving complementary objectives of sustainable resource management and conservation[1,5–7]. However, the increasing pressures of climate change and excessive resource extraction threaten the health of the forest ecosystems, exacerbating vulnerabilities for forest-dependent communities[8,9].

Chirpine (*Pinus roxburghii*), longleaf Indian pine, is the mostly tapped pine species in several countries, including Nepal, for its high resin yield. Resin is a valuable raw material for various industries, including paper, chemicals, and biorefineries, with applications ranging from adhesives to detergents[10–12]. Dominating the subtropical pine forest ecosystem in the Indo-Pacific region[13,14], Chirpine forests are often found in the mid-hills region in Nepal, representing about 8.45% of the total forests[15]. Chirpine forests have been intensively managed for resin production and timber supply in Nepal[16–18], along with other ecosystem services such as wildlife habitat and carbon sequestration[19–21].

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About 29% of the national forests, predominantly in the mid-hills region of Nepal, are managed under the community forestry (CF) program, and nearly 75% of the community managed forests are located in the middle hills[22,23]. These forests provide many vital goods and services that directly influence the livelihood of millions of rural people, significantly contributing to poverty reduction[24,25]. The Forest Policy 2015 and Forest Sector Strategy 2016 emphasized forest-based enterprises as instrumental for enhancing livelihood[26]; while NTFPs plays a significant role in supplementing rural income and livelihood support[27–29]. The commercial collection and harvesting of NTFPs in rural areas engage up to 80% of households[30] and support up to 50% of the household income[29–31]. The revenue collected by community forestry user groups (CFUG) is utilized as a fund to organize various community and economic development efforts, including skill development workshops, training, and income-generating activities to help improve the livelihood of rural communities.

Because of high resin demand, pine trees are often excessively tapped to extract more resin without considering tree conditions, stand structure, and climatic stress on growth and productivity. While the government of Nepal has developed the resin tapping guidelines 2007[32], poor or limited implementation and the lack of proper administrative monitoring often led to negative consequences for Chirpine forest ecosystem[33]. Excessive resin tapping poses serious threats to pine species, impacting rural communities that rely on forests for their livelihoods[34,35]. This socio-ecological interaction has become a key challenge to sustainable forest ecosystem management in a developing country like Nepal, where one-third of people live subsistence livelihood[36], depend on natural resources, and have differentiated social structures[37–39].

The main purpose of this study was to evaluate the social impacts of resin tapping in Chirpine forests on the rural socio-ecological dynamics in mid-hills of Nepal. Using a representative purposive sample of 302 forest users from 20 CFUGs across three far-western districts in the mid-hills region, we specifically explored both positive and negative perceived impacts of resin-tapping on the rural livelihood. Based on the perceptions of local forest users who directly interact with Chirpine forests regularly, we documented both socio-economic benefits as well as adverse impacts of resin-tapping from Chirpine forests on the socio-ecological system in rural livelihood. Understanding the perspectives of forest users on resin tapping under the varying socio-ecological dynamics driven by changing social, demographic, and climatic factors is critical for ensuring the long-term sustainability of Chirpine forests and their socio-ecological and economic functions. Additionally, critical assessments of how local communities manage natural resources for NTFPs are necessary to identify the policy and program revisions that accommodate changing community perspectives, which are crucial for sustaining their livelihoods and promoting sustainable management practices of natural resources. Moreover, what happens if communities become reluctant to manage pine forests due to low resin yields and less quality forest products with increasing negative environmental outcomes? Evaluating such concerns will provide valuable insights into the strengths and weaknesses of existing policies and programs pertaining to forest management and community engagement aimed at conserving and managing natural resources for multiple end-use benefits. Therefore, assessing social perception is vital for developing effective natural resource management strategies and policies that enhance the sustainability of socio-environmental systems in the face of changing conditions. Although this study focused on Nepal, the ecological and social questions are quite applicable to most of the resin-tapped pine tree species worldwide and the communities involved in this NTFP extraction and management.

Materials and methods

Theoretical background: a socio-environmental framework

This study is fundamentally guided by the forest-based human-ecological interactions in Nepal, as depicted in Fig. 1. Following[1] closely, various socio-ecological interrelationships such as socio-ecological system[40] and land use change sciences are considered to ascertain the sustainability of NTPF use in Nepal. Forests and other natural resources are a critical component of the rural livelihood, where the majority of households rely heavily on natural resources for sustaining their daily rural needs, such as fuelwood for cooking and heating, fodder for livestock and animal bedding, and leaf litter for composting[41,42]. NTFPs are a significant source of rural income with up to 80% of rural households engage in the collection and commercialization of NTFPs[30]. Therefore, two broader human and ecological systems interact with a dynamic feedback loop influencing the functions of both systems significantly. The sustainability of forests is, by and large, shaped by ecosystem services or disservices realized by the human system, and the human system also directly alters the Chirpine based ecosystem by natural, social and economic factors[43,44]. The community-based forest management models often promote the use and commercialization of NTFPs to improve rural people's livelihood, and this forest conservation approach has significant socio-ecological implications and challenges[25,45]. However, improper and intensive tapping, including excessive use of high concentrations of stimulus to increase resin yield, has affected the tree physiology, leading to mortality and more fire-prone which ultimately results in ecosystem disservices in the rural livelihood[46]. Given the changing socio-demographic, cultural, and climatic contexts in the middle-hills of Nepal, this framework aims to explore the perceived impacts, challenges, preferences, and opportunities within the Chirpine-based socio-ecological system and its sustainable management.

Study area

Three far-western districts, Kailali, Doti, and Dadeldhura from the mid-hill region of Nepal, where the resin-tapping enterprise has mostly been concentrated for several decades, were selected for a representative household survey (Fig. 2). The selection of these districts is based on three key factors: (1) all three districts have forests as the main land use with a significant share of Chirpine stands; (2) resin tapping is widely practiced in this region, which hosts the first turpentine industry established in 1986 by the Government of Nepal; (3) the region has a large population of marginalized and rural communities which are by and large members of community forest user groups. The elevation gradient (1000–2200 m) of natural Chirpine stands begins in the southern district, Kailali to the northern district, Dadeldhura, representing the sub-tropical climate and mountainous topography

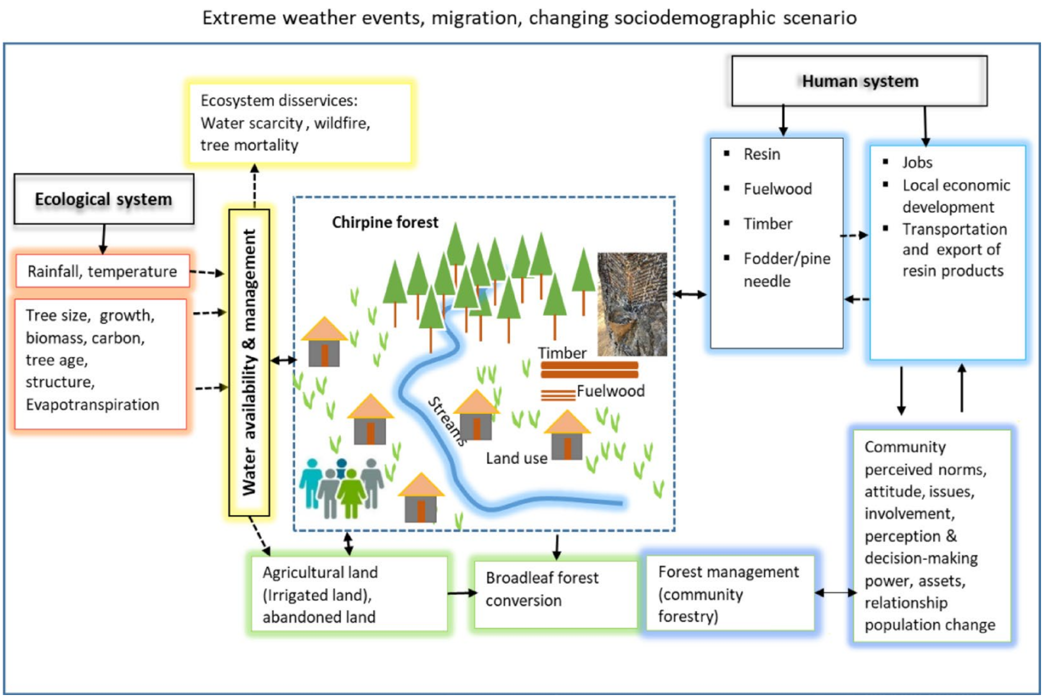

Fig. 1. Dynamic socio-environmental framework depicting the Chirpine-based human-ecological interactions in rural Nepal.

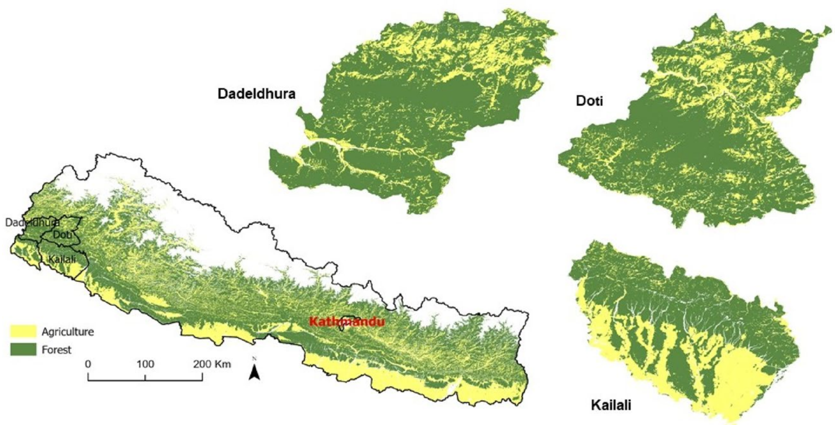

Fig. 2. Map of Nepal highlighting the study districts in the far-western region showing the primary land cover (forest and agriculture) based on annual land cover data (2000-2022). The map was customized in ArcGIS Pro 3 using processed remote-sensing data (Landsat) available at http://nepal.spatialapps.net/nlcms, National Land Cover Monitoring System of Nepal[82].

and exhibiting varying soil types and rainfall patterns. According to the records of three divisional forest offices, only 143 community forest user groups (CFUGs) out of 1246 CFUGs are actively involved in resin tapping as a forest-based enterprise in the study region (Unpublished sources, personal communication). About 25% of CFUGs in Dadeldhura district participated in resin-tapping from their Chirpine forests.

Figure 2. Map of Nepal highlighting the study districts in the far-western region showing the primary land cover (forest and agriculture) based on annual land cover data (2000–2022). The map was customized in ArcGIS Pro 3 using processed remote-sensing data (Landsat) available at http://nepal.spatialapps.net/nlcms, National Land Cover Monitoring System of Nepal[47].

Household survey of forest users

Based on the theoretical framework presented in Fig. 1, we developed a survey instrument for household survey of forest users to evaluate the social impacts of resin tapping and Chirpine forest management in the middle-hills of far-western districts. Several questions were developed to record the forest users' perceptions on the current condition of Chirpine stands, their management and uses including resin tapping, and the challenges and opportunities under the changing socio-demographic, economic, and climatic conditions in the region. Most of the questions were close-ended but a couple of open-ended questions were also included to provide the respondents with an opportunity to express their overall opinions on resin tapping as well as suggested activities to reduce the adverse impacts. The survey instrument also recorded various socio-demographic information including gender, age, education, and well-being status of each respondent. Questions were first drafted in English and later translated into Nepali. All the team members reviewed the survey instrument multiple times for clarity and translation, and it was also pre-tested with three respondents in the field in the beginning. Several questions were revised for clarity and consistency before fielding the survey.

In terms of the sampling frame, given the accessibility and prevalence of resin tapping in the certain regions of those districts, the purposive snowball sampling approach was adopted. Nepal has about 11% of Chirpine forests in terms of the total volume, which are mostly concentrated in far-western, mid-western and some eastern regions of the mid-hills landscape in Nepal[15]. Due to the non-random distribution of the forests as well as the communities involved in resin-tapping activities, standard probability-based sampling methods could be less appropriate to capture the perspectives of a specific targeted community. The purposive sampling method is commonly used for survey data collection in areas where a specific sampling framework cannot be adopted due to the non-random distribution of households[48–50]. This approach is also common globally such as[51,52] adopted the snowball sampling method in Kenya and Cameroon, respectively. To develop the purposive sampling frame, we had separate meetings and consultations with staff from the Division Forest Offices (DFOs) and resin tapping companies in each district to discuss the current state of resin tapping as well as identify the CFUGs and regions that are actively involved in resin tapping. Then, we selected 310 households purposively from 20 CFUGs with a broader representation of each social and economic status. The number of households sampled from each CFUG ranges widely from one to 40, depending on the representative households, the size of hamlets, accessibility, and the socio-economic status of the respondents. Four enumerators, who were junior forestry professionals working in DFOs, were trained in-person by the first author in the interview process, data recording, as well as data security steps before conducting household surveys in May-July 2024. We visited each respondent's house in person and obtained their informed consent to participate in the survey before proceeding with the data collection process. The participation was voluntary, and each survey took about 30 min, on average. The entire study protocol including the survey instrument, administration, and data collection, transfer and security steps was reviewed and approved with exempt by the North Carolina State University Institutional Review Board (IRB protocol # 26957). All the methodological procedures and data security steps were performed in accordance with the IRB guidelines and regulations.

Empirical model

We framed the perception analysis to evaluate the social impacts of resin tapping from Chirpine forests within the premises of the social exchange theory, which posits that people develop attitudes toward an activity within the context of their personal beliefs and potential costs and benefits coming from the interactions, if any[53]. Therefore, households have positive perceptions towards activities that are likely to generate net benefits. Conversely, those generating a net loss will likely form negative perceptions[54,55]. Additionally, our empirical framework is also backed by the human-environmental systems framework presented in Fig. 1.

The empirical framework was built within the premises of structural equation model, which analyzes relationships between unobserved latent constructs and directly observed measurement attributes[56–58]. Table 1 presents the latent and measurement variables used for structural equation path analysis, which is commonly adopted to examine socio-ecological complexities in natural systems. Among the attributes considered, three were designed as latent constructs. Two latent variables, positive and negative impacts, were primarily measured by the respondents' perceptions on three distinct perceived benefits and adverse effects of resin tapping on both aspects. The third latent construct named "commodity" was also created based on the level of importance the respondents place on three important forest products: firewood, timber, and fodder or leaf litter. Cronbach's alpha was used to assess the reliability of the statements used to generate these latent constructs.

As shown in Table 1, several other attributes served as measurement variables. These included socio-economic and demographic attributes, as well as the respondents' perception ratings on resin tapping and Chirpine management. These attributes were employed to evaluate the overall social impacts of resin tapping on rural livelihoods.

Results

After accounting for a few incomplete responses, a total of 302 responses were used for the descriptive and inferential statistical analysis. The results revealed that the average age of surveyed households was 42 years, with many of them (55%) being male. In terms of education, about one-fourth of the respondents never had a formal education, and only 17% completed their high school or above. On average, female respondents (38 years) were younger than male respondents and had a lower level of formal education. The average household size was more than six family members. In terms of their household well-being, about 71% of the respondents categorized themselves as a medium-income household, followed by 22% as a poor household. Nearly half (48%) of the respondents reported agriculture as their primary source of household income, while approximately one-fourth (23%) relied on remittances to sustain their livelihood. About 70% of the respondents were general members of CFUGs with an average membership duration of just over 11 years. Most of the survey participants revealed that they were actively involved in community forest management activities such as attending the meetings and volunteering in forest management activities.

The respondents' ratings of the various forest products and services from forests in their surroundings for their household are presented in Fig. 3. The major forest products: firewood, timber and fodder were found

Statements	Mean	Cronbach's alpha for indices
Perceived positive impacts of resin tapping from pine forests[a]		
Local jobs	3.81	0.53
Community development	4.31	
Support to local schools	4.43	
Perceived negative impacts of resin tapping from pine forests[a]		
Increased tree mortality	4.07	0.81
More fire prone forests	4.55	
Water scarcity due to pine trees	3.83	
Commodity collection from community and surrounding forests [b]		
Firewood	4.85	0.71
Timber	3.23	
Fodder	2.95	
Social, demographic, and economic factors		
Age (Respondent's age in years)	41.89	
Rich (household's perceived well-being, 1 = if rich, 0 = otherwise)	0.05	
Gender (1 = male, 0 = female)	0.55	
Irrigated field (Respondent's total land acres where irrigation is available for paddy production, measured in Ropani)	3.47	
Involvement (Respondent had an active involvement in community forestry activities (1 = yes, 0 = no)	0.89	
CFUG_member (respondent is a member of CFUG, 1 = yes, 0 = no)	0.70	
Abandoned land (respondent had any abandoned land, 1 = yes, 0 = no)	0.33	
Perceptions about Chirpine forest management		
Wildfire (respondent's belief that resin tapping is the reason for increasing fire incidents in their region, 1 = yes, 0 = otherwise)	0.78	
Reduced water availability (degree of challenge with the Chirpine forest management caused by perceived reduced availability of water)	4.28	
Unmanaged (perceived current Chirpine stand condition after resin tapping, 1 = if unmanaged, 0 otherwise)	0.65	
Replace pine (respondent's preference on replacing pine forests with broadleaved plantations, 1 = yes, 0 = no)	0.63	

Table 1. Various socio-economic and environmental attributes used to measure the social impacts of resin tapping in Chirpine forests in far-western Nepal ($n = 302$). a: Statements were measured using a 5-point Likert scale as 1 = Strongly disagree, 2 = Somewhat disagree, 3 = Neither disagree nor agree, 4 = Somewhat agree, 5 = Extremely positive. b: Statements were measured using a 5-point Likert scale as 1 = Not important at all, 2 = Slightly important, 3 = moderately important, 4 = Very important, 5 = Extremely important.

highly important for over 90% of the respondents in the study area. Similarly, respondents placed very high importance on the ecosystem services from their nearby forests, as over 95% of the respondents rated wildlife habitat and clean environment very important for their household and community. Medicinal values of forests received relatively lower importance among the survey participants, compared to their perceived values for other forest products and services.

We recorded respondents' opinions on various positive and negative impacts of resin tapping from Chirpine forests in their region (Fig. 4). About two-thirds of the respondents acknowledged that resin tapping in their region creates local jobs and most (86%) agreed that the revenue generated from resin tapping contributed to local community development activities as well as support to their local schools. In terms of the negative impacts, more than three-fourths of the total respondents agreed that resin tapping in Chirpine forests leads to more tree mortality, more fire prone forests, as well as aggravating water scarcity issues due to pine forests. More than 60% of the respondents revealed that the resin tapping procedure is not fully regulated and supervised by the authorities so that trees were over-tapped, leading to substantial adverse effects on trees and forest ecosystem.

As indicated by Pearson Chi-square tests in Table 2, the perception of respondents on negative impacts of Chirpine is statistically significantly different by their well-being status as well as education level at the 10% level of significance level. Medium-income and poor respondents reported their stronger agreement on the negative impact of resin tapping on increased tree mortality, wildfire propensity, and water scarcity. Similarly, in terms of the education level, less educated respondents, compared to the ones who had at least a high school degree of formal education, placed more value on the negative impacts of resin tapping from Chirpine forests in their region.

Figure 5 depicts the perceived current condition of Chirpine forests after resin tapping in the study area. Over 60% of the respondents noted that the forest condition is unmanaged with higher tree mortality and fire prone than before the resin tapping started in their region. Only less than 10% of the survey participants thought that pine forests are well managed now and about one-fifth of them noted that the forest condition remained the same as it was before the resin tapping.

In terms of the challenges associated with Chirpine forest management, approximately 85% of respondents argued that the challenge of increased risk of wildfire is extremely critical (Fig. 6). Similarly, reduced availability of water due to Chirpine forests was perceived as an extremely critical challenge for over two-thirds of the forest users in the study area. Moreover, due to lack of broadleaved forests in their community forests, more than 84%

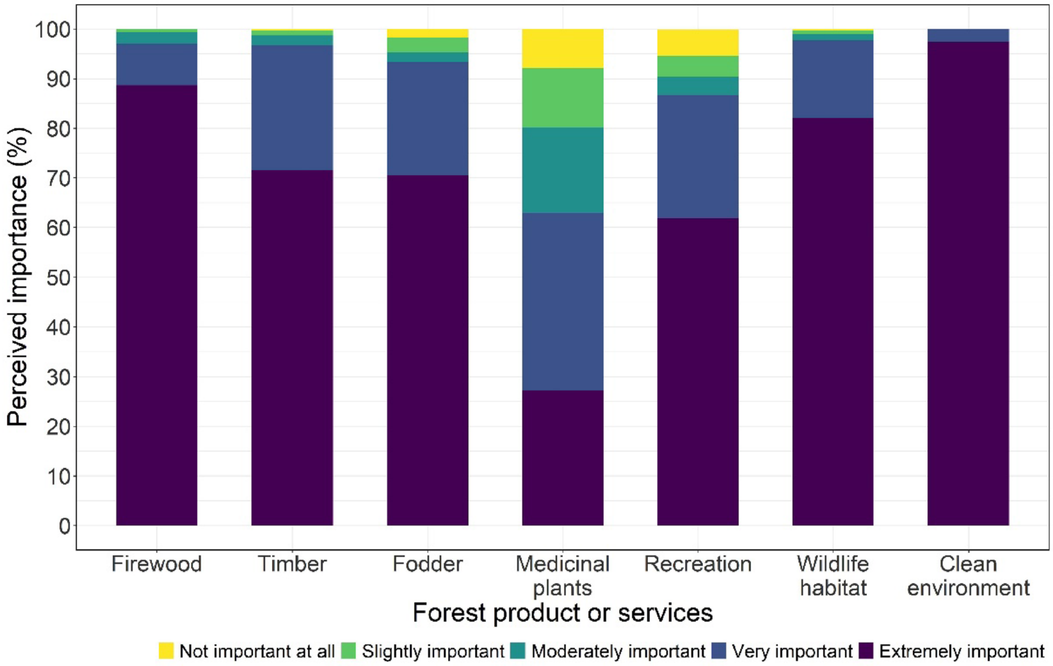

Fig. 3. Perceived importance of community forests and surrounding forests for forest products and services. The perception (%) is recorded on a five-point Likert scale ($n = 302$).

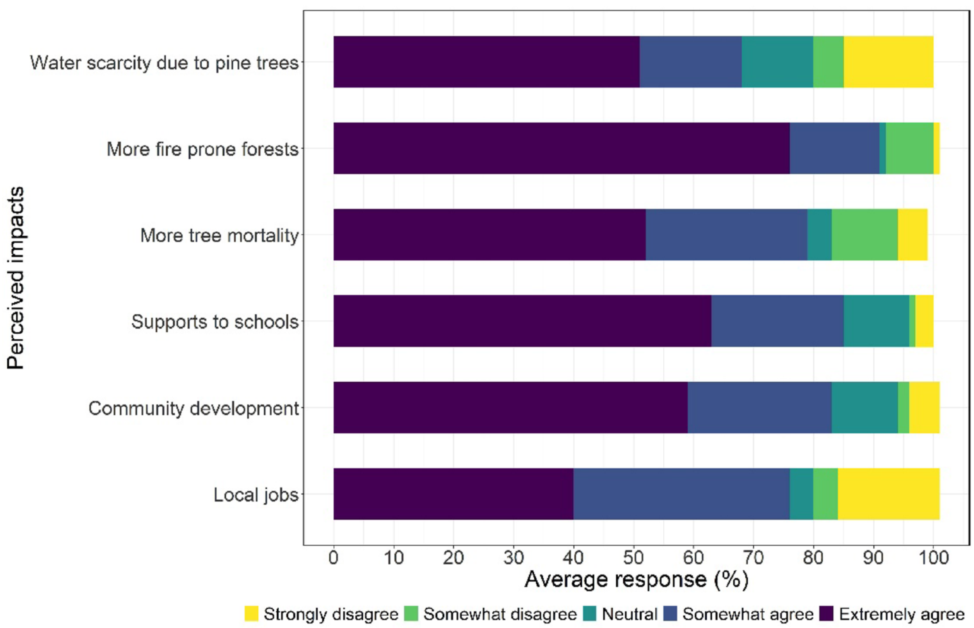

Fig. 4. Perceived impacts of resin tapping from Chirpine forests in the study area ($n = 302$).

of the respondents believed that there is a reduced interest in community forestry management among local users.

We employed the Structural Equation Modeling (sem) command in STATA to analyze the factors influencing the perceived positive and negative impacts of resin-tapping on rural livelihoods (Table 3). The likelihood ratio (LR) test and the Satorra-Bentler scaled test indicated an adequate model fit compared to the saturated model (p-value < 0.01). Additionally, diagnostic tests suggested overall model suitability, with a standardized Root Mean Square Residual (SRMR) value of 0.039 and a Comparative Fit Index (CFI) of 0.917.

Results from SEM indicated that socio-demographic attributes, such as gender ($p < 0.01$) and well-being status ($p < 0.01$), were statistically significant and negatively associated with perceived adverse impacts, whereas

Impacts	Well-being status				Education		
	Rich	Medium	Poor	χ^2 p-value*	High school or higher	Lower than high school	χ^2 p-value*
Local jobs	4.29	3.66	4.07	0.23	3.91	3.77	0.82
Fund for community development	4.76	4.37	3.94	0.00	4.34	4.28	0.55
Support to local schools	4.65	4.44	4.30	0.78	4.45	4.42	0.14
Increased tree mortality	3.23	4.16	4.11	0.08	3.47	4.24	0.00
More fire prone forests	3.71	4.66	4.44	0.00	4.23	4.63	0.04
Water scarcity due to pine trees	3.23	3.79	4.13	0.02	3.47	3.92	0.00

Table 2. Average perceived impacts of resin tapping from Chirpine forests in the study area, varied by well-being status and education level of the respondents ($n = 302$). The average responses in each impact are reported, which was recorded on a five-point likert scale (1-strongly disagree to 5- extremely agree). *P-values from the Pearson χ^2 test are reported.

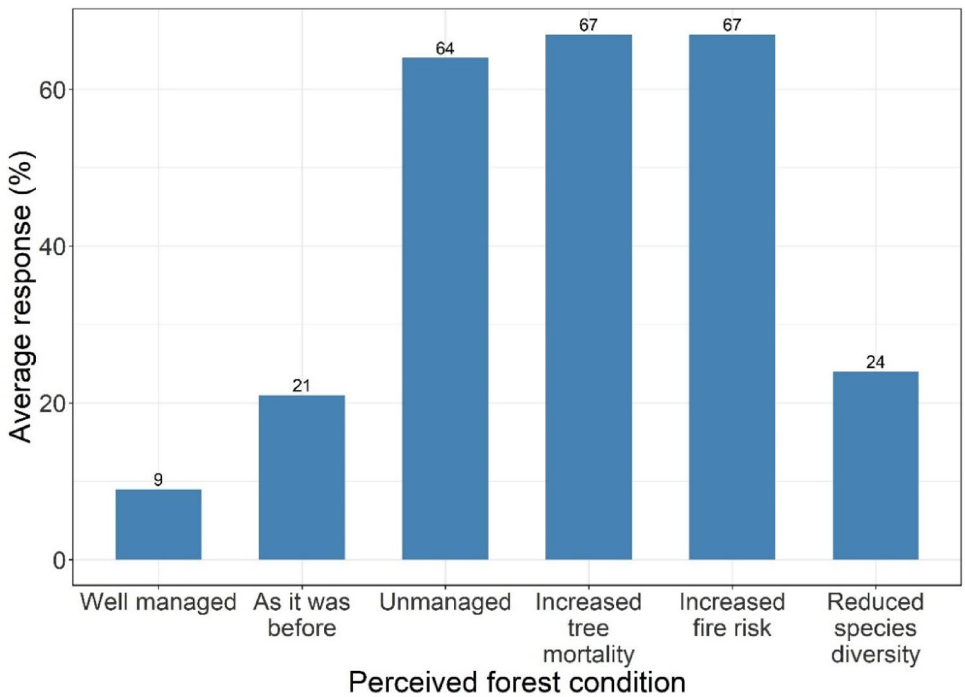

Fig. 5. Perceived current Chirpine forest condition after resin tapping ($n = 302$). Respondents were allowed to select multiple choices including open-ended options that were provided in a list.

respondent's age ($p < 0.01$) had a positive relationship with the adverse impacts. These results suggest that male or rich respondents are less likely perceive the adverse impacts of resin tapping, whereas relatively older respondents are more likely to perceive the adverse impacts of resin tapping from Chirpine forests in their region. However, none of these attributes were statistically significant in relation to perceived benefits from resin tapping. Respondents owning irrigation potential productive land for paddy production (irrigated field) were more likely to have a positive relationship ($p < 0.05$) with perceived benefits. Similarly, respondents' active involvement in community forestry activities was found to be statistically significant ($p < 0.01$) and exhibited a negative association with adverse impacts. Being a CFUG member was found to be positive and had a statistically significant relationship with benefits ($p < 0.01$) and a negative association with adverse impacts ($p < 0.1$). These results suggest that CFUG members are more likely to perceive the benefits of resin tapping, compared to the those who are not members of CFUGs.

The respondents who believed that resin tapping is the reason for increasing fire incidents in their region were found to negatively associate themselves ($p < 0.01$) with perceived benefits (Table 3). Similarly, the respondents who experienced the reduced availability of water due to Chirpine forests as a critical challenge were found to positively associate themselves ($p < 0.01$) with adverse impacts of resin tapping from Chirpine forests in their region. On the other hand, respondents who believed that the forest condition is unmanaged after resin tapping in pine forests, were more likely to have a positive relationship ($p < 0.01$) with perceived adverse impacts. Similarly, those who noted their preference of replacing pine forests with broadleaved plantations had a negative association ($p < 0.01$) with perceived benefits and a positive association ($p < 0.01$) with perceived adverse

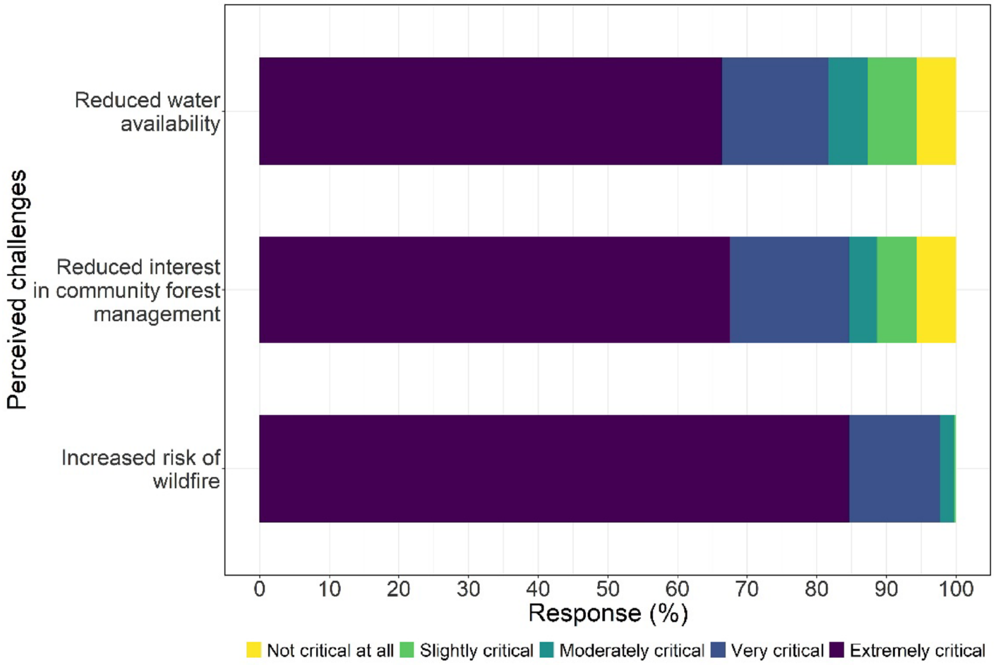

Fig. 6. Perceived challenges associated with Chirpine forest management in the study region ($n = 302$).

Variables	Positive impacts		Negative impacts	
	Standardized coefficient (S.E)	P-value	Standardized coefficient (S.E.)	P-value
Age	0.026 (0.07)	0.709	0.144 (0.05)	0.007
Rich	0.067 (0.05)	0.146	-0.156 (0.07)	0.027
Gender	0.013 (0.07)	0.848	-0.144 (0.05)	0.007
Irrigated field	0.131 (0.06)	0.026	0.049 (0.04)	0.186
Involvement_CF	0.123 (0.09)	0.179	-0.106 (0.05)	0.022
CFUG_member	0.136 (0.04)	0.001	-0.039 (0.03)	0.159
Land_abandoned	-0.040 (0.08)	0.615	-0.029 (0.05)	0.567
More_wildfire	-0.149 (0.05)	0.004	0.098 (0.06)	0.102
Reduced_water	-0.035 (0.06)	0.587	0.358 (0.06)	0.000
Unmanaged	0.048 (0.07)	0.492	0.206 (0.06)	0.000
Replace_pine	-0.275 (0.07)	0.000	0.187 (0.07)	0.011
Commodity index	-0.159 (0.07)	0.020	0.064 (0.06)	0.269

Table 3. Structural equation modeling results exploring the factors describing the perceived positive and negative impacts of resin tapping from Chirpine forests in far-western nepal.

impacts, suggesting that these forest users put a relatively less value on pine forests compared to broadleaved forests. Lastly, those who emphasized the importance of commodity benefits from their forests (e.g., fuelwood, timber, fodder) were less likely to view the impact of resin tapping favorably ($p < 0.05$), which indicates that these respondents perceive the less positive impacts of resin tapping.

Discussion

Our study results indicate that residents in far-western Nepal generally recognize the benefits of resin tapping in supporting local employment and generating funds for community development initiatives, such as water supply, road construction, and local schools. Although there was less agreement on the role of resin tapping on supporting local job opportunities, this was likely because resin collection companies usually outsource technical aspects of resin tapping such as tree marking and creating rills on tree boles. They often recruit trained laborers from other regions, while only low-wage local people are employed to transport the resin containers to road-accessible depots[18,59].

On the other hand, most respondents strongly believed that increased tree mortality, more fire prone forests, and heightened water scarcity are the most prominent negative impacts attributable to resin tapping and Chirpine forest management. Although there is limited research directly linking resin tapping to water availability, many respondents in our survey believe that it has negatively impacted water resources in their region. Consistent with previous studies (e.g[18,60]), our findings suggest that local residents continue to experience the negative ecological and climatic impacts of resin tapping, including its effects on timber quality and the increasing trend of tree mortality after resin extraction. A recent study by[61] also reported significantly adverse effects of resin tapping on basal area increment and radial growth of Chirpine forests in western Nepal. More biophysical research is warranted to explore the relationship between resin tapping, tree growth and structure, water quantity regulation, and the probability of fire incidences in Chirpine forests.

While NTFPs are a critical component of many rural livelihoods globally, their contribution to poverty alleviation is, by and large, questionable, or limited[3,5,62]. Our results also suggest that the perceived benefits and adverse effects of resin tapping from Chirpine are significantly varied by the well-being status of forest users. Poor and less educated forest users realize more pronounced negative impacts of resin tapping, while rich households were less likely to experience the adverse effects of resin tapping in their region. It could be possible that in the mountainous rural region, communities are often trapped due to geographic and climatic hurdles and inaccessibility, and their forest benefits are more likely guided by social and ecological values[4,63]. Moreover, the perceived financial contribution of resin tapping to community development activities was also found to differ between rich and poor respondents. More community development activities such as road construction and drinking water supply could be directed at the greater benefits of rich households, as rich and elite users are usually decision makers in CFUG executive positions[64,65].

Most of the respondents raised concerns about the adverse conditions of stands after they undergone resin tapping in the study region. The forests after resin tapping were perceived to be more unmanaged, more tree mortality and more fire prone. Excessive resin extraction from pine trees causes pine trees to dry and be vulnerable to external stressors such as unfavorable climate and fire[46]. Although Chirpine forests are susceptible to frequent low-intensity fire events[66], the interaction between human activities and climatic variability determines the fire severity[67]. Even surface fire could increase the fire hazard and mortality by burning the resin-tapped trees because of the presence of active resin channels. Over the last 20 years, increasing temperature and lower precipitation in Nepal have triggered a higher frequency (> 55%) of forest fire events during the pre-monsoon season, with an annual average increase of 0.6% fire events[68,69]. While fire severity tends to be higher in pine forests than broadleaved woodlands, this variation is shaped by stand structure, aspects, and slope of the terrain[70]. In the study region, the resin tapping activity typically spans over eight months, from the post-monsoon to the pre-summer[18,59]. While frequent low-severity fires can enhance pine tree's defensive mechanisms against the pest infestation by relaxing the resin duct[71,72], the open resin canals could make tapped trees highly vulnerable to anthropogenic fire[73]. These fires can ignite the resin-rich wood, resulting in high tree mortality[74].

While the Government of Nepal prepared the Resin Collection Procedures (2007) to regulate the resin tapping procedure and proper management of pine forests for minimizing the negative effects of resin tapping on trees and forest landscape[22], recent studies underscored the lack of implementation of the guideline as well as poor monitoring and supervision from government authorities[33,59]. To expedite the resin extraction from trees, it is often reported that the high concentration of stimulus acid mixture is applied on the resin tapping rills[33]. These practices negatively impact tree physiology, eventually leading to tree mortality and affecting rural livelihood[46,75]. Timely revision of the resin tapping guideline and its strict implementation should be the utmost priority of regulatory agencies in Nepal to minimize the adverse impacts of resin tapping while ensuring the sustainability of the resin enterprise and Chirpine forests in mid-hills.

Interestingly, being a member of CFUGs and active involvement of members in community forestry activities such as attending meetings and voluntary contribution to forest management are found to foster more positive and less negative perceived impacts of resin tapping in Chirpine forests. Community forestry in mid-hills of Nepal is regarded as one of the most successful participatory common pool resource management models in the world[41,76]. CFUGs receive all the revenues collected from resin collection in community forests, which is often invested in community development and forest management[18]. Active involvement in community forestry activities not only provides opportunities for members to interact and participate in social outreach activities but also helps disseminate better information about the revenues generated and employment opportunities created through resin tapping in rural communities.

The majority of forest users express the strong preference in replacing pine forests with broadleaved plantations in the study region. Despite the positive socio-economic impacts of resin tapping, forest users reportedly prefer broadleaved forests to pine stands because of higher fodder and fuelwood values as well as better water provisioning services[77]. Anecdotal observations suggest that communities are under the impression that the pine forest ecosystem caused groundwater depletion in the rural mountainous area of Nepal[60,75] because of the high evapotranspiration rate of pine forests than broadleaf forests that reduces water yield and downstream water flow[78,79]. Pine species, considered fast-growing species characterized by higher productivity and biomass, have higher canopy-stomatal conductance, resulting in higher annual transpiration rates and increased water use[80]. Recently, some national media outlets in Nepal covered this story by criticizing the rampant pine plantations in mid-hills of Nepal supported by various donor agencies in the past linking pine trees to increased droughts and water scarcity[81,82]. Since pine needles discourage other undergrowth grasses, the grazing value of pine forests is significantly low for local people. While pine replacement is preferred, the ecological feasibility and economic costs of replacing pine stands in high-slope mountainous regions could be insurmountable.

Conclusions

Resin tapping enterprise is an important source of revenue and employment in the mid-hills of Nepal. This study evaluates the perceived social impacts of resin tapping from Chirpine forests on rural livelihood in far-western Nepal. Results suggest that while resin tapping contributes to socio-economic development at the local level, perceived negative impacts on pine tree health and ecosystem disservices were profound in the study region.

Similarly, the perceived positive impact on local jobs was relatively less consequential, and poor and less educated forest users experienced more adverse impacts of resin tapping on the ecological condition of Chirpine forests. Our study findings are relevant to other subtropical regions of Nepal, as well as in India and Pakistan, where Chirpine trees are tapped, and local communities have been engaged in conservation for generations. Findings help advance critical knowledge about how resin tapping influences rural household livelihoods, and how the rural community engages in pine forest management for resin production. Since forest users in CFUGs are the primary stewards and key players in the sustainable forest management in Nepal, exploring their perceptions is crucial to understand the changing human-ecological interactions based on Chirpine forests in Nepal.

As a critical source of revenue for CFUGs in the mid-hills region, it is essential to ensure sustainable management and harvesting practices of Chirpine forests for resin production. The regulatory guidelines for resin production developed in 2007 should be frequently revised by incorporating social adoption, feedback, latest research, and direct participation of local forest users. Governments and all forestry stakeholders including local municipalities, CFUGs, and local forest users should be actively involved in not only the proper implementation of the guideline but also periodic monitoring and supervision of the overall resin tapping process and impacts on Chirpine forest ecosystems. Further biophysical and economic research is warranted to explore the feasibility of replacing pine forests with broadleaved plantations. Additionally, CFUGs should emphasize equitable benefit sharing mechanisms of the resin revenues so that members from all socio-economic spectra could realize the proportionate impacts of resin tapping.

In terms of a study limitation, our household survey is based on a purposive sampling of forest users in the premises of community forests in three far-western districts of Nepal where the Chirpine based resin tapping enterprise is widespread. However, it is not uncommon for a social survey where implementing a randomized sampling framework is problematic due to geographic terrain[48] and isolated patches of resin tapping businesses in the region. Moreover, our results are consistent with previous studies in the region[18,60]. Future research should build up on this pilot-scale study to expand its geographic horizon for broader representation as well as incorporate various socio-ecological factors governing the resin tapping enterprise in community forests in Nepal.

Data availability

The datasets used and/or analysed during the current study are available from thecorresponding author on reasonable request.

Received: 24 March 2025; Accepted: 25 June 2025
Published online: 02 July 2025

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Acknowledgements
This study is partly supported by the Goodnight Early Career Award at North Carolina State University (Parajuli), as well as the Sarkeys Distinguished Professorship Endowment in the Division of Agricultural Sciences and Natural Resources at Oklahoma State University (Joshi). We would like to sincerely acknowledge government representatives from Divisional Forest Offices in Kailali, Doti, and Dadeldhura districts and community forest user groups executives and members for their assistance and coordination in the field work. We also thank our survey enumerators for their contributions to the household survey.

Author contributions
R.P, P.S., O.J. wrote the main manuscript text, P.N. revised and assisted on revision, and R.P. and P.S. prepared all figures and tables. All authors reviewed the manuscript.

Declarations

Competing interests
The authors declare no competing interests.

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