

Strengthening community engagement as a pathway to effective forest fire management and resilient forests in Nepal

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Summary

Forest ecosystems are indispensable for planetary health. They provide sustenance for around a quarter of global population. Forest fire is an important ecological disturbance; however, it can cause ecological and societal harm due to anthropogenic mismanagement and natural adversities leading to long-term socio-economic and environmental consequences. Extreme wildfire events have increased worldwide over the last decade, and events in Nepal are consistent with this trend. Nepalese forestry practices have already set an example of successful forest management through local stakeholder and community participation and thus demonstrate precedent in effective community mobilization. However, recent reports suggest declines in community participation in forest management process and overall weakening people-forest relationships. Here, we argue on why Nepal should work on strengthening its long legacy of people-forest interactions

and how community engagement can support sustainable forest fire management. In our opinion, community led fire management is among the most viable approaches, with primary focus on preventive measures, i.e., reducing fuel loads in the forests. However, the Government of Nepal should provide clear policies and strategic frameworks to create such an environment where forest scientists, private sectors and non-profits can contribute to a national goal.

Keywords: wildfires; healthy forests; fire-resilient forests; sustainable forest management; community engagement; forest fuel reduction

Background and context

Forest ecosystems are vital hotspots for biodiversity and regulators of the global carbon budget. Globally, forests cover around one third of Earth's land surface yet support more than 80% of terrestrial biodiversity by providing a variety of habitats and resources for diverse organisms (CBD, 2024; FAO, 2022; Parajuli and Markwith, 2023; Stokland *et al.*, 2012). Forests also play critical role in regulating global carbon by absorbing atmospheric CO₂ and storing it as biomass as well as transferring it to the soil via various chemical and biological processes (FAO, 2022; Lorenz and Lal, 2010; Ryan *et al.*, 2010). However, various natural and anthropogenic disturbances influence forests' ability to regulate atmospheric carbon, and wildfires are chief among them (FAO, 2022; Williams *et al.*, 2016). Importantly, how forest management also determines whether they act as net carbon sinks or sources, suggesting the critical importance of management practices and anthropogenic influences

for practical applications like forest carbon budgets, risk reduction and environmental restoration and mitigation (Kaarakka *et al.*, 2021; Parajuli *et al.*, 2025).

The overarching idea of forest management is to design and implement certain practices that are sustainable and appropriate for achieving specific economic, socio-cultural and environmental services from a given forest ecosystem (FAO, 2022). Similarly, one of the key ecological goals is to maintain healthy and resilient forests that can continue to provide optimal ecosystem services and can cope with disturbances (Cantarello *et al.*, 2024; Messier *et al.*, 2019; Mina *et al.*, 2022). With around 25% of the world population directly relying on forest resources for their livelihoods, rising demand for carbon sequestration and Nature-based Solutions to reducing atmospheric CO₂, and the ongoing climate crisis leading to unprecedented changes in global forests, sustainable management of forests has been more important than ever for planetary health and human wellbeing (FAO, 2022; Kaarakka *et al.*, 2021; UNFFS, 2021). Due to forests' potential as a natural climate solution (Griscom *et al.*, 2017), the Paris Accord and later United Nations conventions continued to highlight the importance of sustainable forest management to reduce carbon emissions and enhance sequestration as a fight against global warming and its worst impacts (IPCC, 2018; UNFCCC, 2015).

The last two decades have witnessed an increase in the frequencies and intensities of devastating wildfires globally, with recent years being most extreme (Cunningham *et al.*, 2024). While uncharacteristically large fires with extreme behavior were observed in the temperate conifer forests of the United States and boreal forests of North America and Russia, wildfires have generally become larger and more severe around the world

(Cunningham *et al.*, 2024; Hagmann *et al.*, 2021). In addition to an increasing pattern of frequencies and area burned, Nepal has also experienced some of the worst forest fires recently (Mishra *et al.*, 2023; Nepali Times, 2021). For example, the catastrophic wildfire in Gatlang area of Rasuwa district destroyed the forest stand with long-term effects on soil and vegetation still evident even after one and half decades (Dhungana *et al.*, 2024).

Wildfire behavior is governed primarily by three major elements, famously called the ‘fire triangle’, namely fuel (or vegetation), topography, and weather (or climate); and fuel is always a dominant factor controlling fire at different spatial and temporal scales (Keeley, 2009; Moritz *et al.*, 2005; Pyne *et al.*, 1996). Since fuels (i.e., vegetation, living or dead) are the components that humans can most directly influence, effective management of forest structure and vegetation plays a crucial role in reducing wildfire impacts (Parajuli *et al.*, 2025). Various management tools, technically referred to as ‘fuel reduction treatments’, are used to reduce fuel that helps to minimize the risk for devastating fires and associated hazards and maintain healthy forests. In developed countries such as United States and Canada, forest fuel reduction most commonly involves mechanical treatments such as thinning (tree removal), mastication (flailing, chipping and breaking), raking (collecting/piling), often combined with prescribed burning (Agee and Skinner, 2005). Whereas in developing countries, such as Nepal, India and Mexico, active community engagement for regulated resource extractions e.g., timber and fuelwood via thinning and pruning, and surface dead fuel and fodder collection, as well as some controlled or community-led burning are common and generally effective in fire management (Charmakar *et al.*, 2021; Dogra *et al.*, 2018; Pandey *et al.*, 2022; Van Vleet *et al.*, 2016).

Regular harvesting of surface biomass such as leaf litter and dead woody materials by local peoples, either as a part of the subsistence farming or for various innovative uses, contribute to reduced dry fuel loads in the Himalayan forests (Chandran *et al.*, 2011; Charmakar *et al.*, 2021). However, recent research shows declining community involvement, that is, a weakening people-forest interactions, in community managed forests of Nepal, contributing to increased fire events (Tiwari *et al.*, 2022), despite a recognized need to strengthen people-forests relationships (Baral *et al.*, 2025; Poudyal *et al.*, 2023).

Why is maintaining people's interaction with forests critically important?

Nepal's community forestry is a globally recognized success story of forest user groups' (i.e., local peoples') involvement in regenerating and conserving forests and at the same time supporting livelihood and local economy. Over 23,000 community forest user groups, largely self-governing local institutions, engage more than 16 million people to manage around 35% of country's forest resources (Gentle *et al.*, 2020). Being within the guidelines set by operational plans, users routinely harvest forest resources such as timber, fuelwood, fodder, dead leaves and beds, and non-timber products, and in return voluntarily contribute to various forest management activities. Such community-led forest biomass removal interventions, essentially equivalent to modern mechanical fuel reduction treatments in many developed countries that cost billions of dollars (Chang *et al.*, 2023; Wibbenmeyer *et al.*, 2025), contribute to lowering fuel loads and thus reduce forest fire hazards (Charmakar *et al.*, 2021; Markwith and Paudel, 2022; Pandey *et al.*, 2022; Parajuli *et al.*, 2025). For example, local people's regular harvesting of firewood from

community forests in Dolakha has been shown to effectively reduce wildfire risk
(Charmakar *et al.*, 2021).

Box 01: Traditional Farm-Forest interactions maintain low-severity fires and lower forest fire hazards

Hile Jaljale community forest (CF) 'Kha' is in Kavrepalanchok district of Nepal, spanning from 1500 to 2000 meters above sea level with an area of 190 hectares. It is a mixture of both planted and natural stands of pine and broad leaf tree species. This CF has 430 household user members from various settlements close to Banepa town center, around an hour of driving distance from Kathmandu – the capital city. People -forests interactions are quite frequent and regular, yet systematically regulated through CF operational plan, as local users largely depend on forestry resources such firewood, timber, fodder and leaf litter. By capitalizing their proximity to markets CF users are heavily engaged in animal husbandry and vegetable production as a major source of income. They produce milk, fresh vegetables, potatoes and various cash crops and all go to the market centers in Banepa and Kathmandu. Their active interactions with the nearby forest, mainly to extract resources to sustain animal husbandry and farming, have significantly contributed to maintaining both live and dead biomass in the forest. Although forest fires are common during dry season, users of Hile Jaljale CF consider that wildfires are not hazardous, i.e., low-severity fires without any serious threats to forest health and local communities. Key to such successful fire management lies in adequate fuel load management. Local people regularly harvest leaf litter and dead woods to keep alive their animal husbandry and agricultural production. Leaf litter is first used as animal bedding, which is then converted into compost and goes to the field, thereby adding nutrients and organic matter, a major portion of this is carbon, to the soil. While timber and firewood harvest is done at certain times of the year, leaf-litter collection is allowed all year around. These kinds of healthy people-forest interactions generate multiple socio-ecological benefits including sustaining the local economy and enhancing carbon benefits through soil-amendment and reduced pyrogenic emissions due to low severity forest fires. Similar to Hile Jaljale CF, where traditional farm-forest interactions are well maintained benefiting both local people and forests, if communities' engagements are sustainably intact, wildfire should not be an issue to worry about at all.

The role of local communities in reducing forest fuel continuity – horizontal and vertical distribution of flammable materials – and supporting effective fire management is not unique to Nepal; similar patterns are observed in other countries such as India (e.g., (Chandran *et al.*, 2011), Mexico (e.g., (Van Vleet *et al.*, 2016), and historically in Australia (e.g., (Mariani *et al.*, 2024) and among Native American societies in the pre-Columbian era in North America (e.g., (Anderson and Moratto, 1996; Markwith and Paudel, 2022). Most importantly, the case of Mexico is worth highlighting here, as it illustrates how community engagement should extend beyond ecological goals to also include substantial economic benefits for local communities. Mexico’s community forestry model, that integrates technical forest management, indigenous governance and community owned forest enterprises, has proven highly effective in ensuring the economic resilience of participating communities while simultaneously enhancing ecological resilience and promoting sustainable forest management (Cubbage *et al.*, 2015; Mitchell, 2006; Van Vleet *et al.*, 2016). For example, in Sierra Norte of Oaxaca, Mexico, community-managed forests supported increased biodiversity, experienced fewer large wildfires, and supported livelihoods and local economy (Farthing, 2024; Van Vleet *et al.*, 2016). The success story of this Mexican example could be relevant for Nepal, where similar enterprise-based community forestry approaches that maximize economic benefits for local communities may help strengthen peoples’ engagement in forest management (Cook *et al.*, 2025). This approach could help address the issue to greater extent, as recent research from Nepal indicate that people’s interest in managing community forests is eroding because of insufficient economic benefits and lack of employment opportunities (Cook *et al.*, 2025;

Poudyal *et al.*, 2023). Additionally, with clear guidelines and policy frameworks for sustainable harvesting and processing, scientifically and socio-economically informed timber entrepreneurship could help meet national timber demand and reduce current imports (Dangi, 2025).

While Nepal's efforts in increasing forests and enhancing carbon sequestration, including a recent US\$9.4 million carbon credits grant (World Bank, 2025), can be considered as a success, it is equally concerning that fuel loads are accumulating in Nepalese forests, especially in the mid-hills. Without timely intervention, these fuel loads could reach hazardous levels, and if burned, may release large amounts of carbon, negating decades of sequestration gains within weeks. Global evidence shows that elevated forest fuel loads, intensified by climate change, are driving uncharacteristically large and destructive wildfires that convert forests into net carbon sources and cause severe ecological and long-term socio-economic impacts (Jaffe *et al.*, 2020; Phillips *et al.*, 2022; Roces-Díaz *et al.*, 2022). Once a forest attains hazardous fuel conditions, restoring it to healthy and resilient status is very challenging and often requires substantially greater effort and cost than maintaining it through regular management and fuel treatments (Alcasena *et al.*, 2022; Chang *et al.*, 2023). This is evident in the United States, which is constantly fighting devastating wildfires each year and spending up to \$7 billion annually on fire management interventions (US Congress, 2024).

With declining community and stakeholder participation due to several factors including less reliance on forest resources, increased use of alternative sources of household energy, outmigration, weak governance, low financial benefits and lack of clarity

on policies (Benedum *et al.*, 2025; Cook *et al.*, 2025; Poudyal *et al.*, 2023), if proactive early measures are not implemented, forest fires could be a major nationwide problem in near future. The recent increase in frequency and severity of forest fires in Nepal (Mishra *et al.*, 2023), has already signaled that we are already in that direction. Since Nepal currently has very limited technical and financial strength to manage catastrophic large wildfires, strengthening people's interactions with forests and mobilizing communities for forest and fire management appears to be the most viable strategy. India, the world's third largest economy, has also recognized community involvement as one of the top strategies for effective fire management, given that many rural people have close ties with forests and rely on forest resources for their livelihoods, making their engagement essential for the success (Dogra *et al.*, 2018).

Considering the changing socio-economic dynamics in Nepal associated with outmigration and remittance income, which affect affordability and promote alternative energy choices such as LPG, questions remain about whether strengthened community engagement can ensure full local utilization of forestry products. First, although firewood use may have declined and will likely continue to do so, it still remains a dominant source of household energy especially for cooking and heating (Kandel *et al.*, 2016; Paudel *et al.*, 2021). Second, recent technological advancements allow forest residues, including fine and coarse down woody materials, to be converted into carbon-friendly products such as biochar, biofuels and coco peat. Experiences from developed countries demonstrate that forest biomass conversion into biochar through the process called pyrolysis is cost effective and technically feasible (Cabiyo *et al.*, 2021; Shabangu *et al.*, 2014). This can be

implemented through private sector and business entities; however, the Government of Nepal should provide clear policy guidance. Additionally, invasive species issues in forests can also be addressed using this approach, as any forest residue and waste can be converted into biochar via pyrolysis. Biochar soil amendments can store carbon for many years, help mitigate climate change, improve soil fertility in agricultural lands, and partially substitute chemical fertilizers (Bai *et al.*, 2022; Shyam *et al.*, 2025).

Box 02: Harvesting forest residue to convert into compost helped in reducing forest fires

Multiple incidents of forest fire were common each year during dry season, generally between January to May, in Jalthal remnant forest of Jhapa, Southeastern lowland of Nepal. Those highly-frequent fire events were a main challenge in forest restoration where invasive alien plant species (IAPS) mainly *Chromolaena odorata* (L.) R.M.King & H.Rob., *Mesosphaerum suaveolens* (L.) Kuntze and *Mikania micrantha* Kunth, have a large share in total biomass that serve as surface and ladder fuel loads, particularly in the invaded patches. Generally, encroachment by IAPS is an unnatural addition and alteration of fuel loads in forested and grassland ecosystems. Local communities-initiated compost manure production using forest residue primarily focusing on the biomass of IAPS in four different community forests (CFs) namely Diyalo, Bishal, Pathibhara Kalika and Kamaldhap Rampokhari CFs of Jalthal between December 2019 to October 2025. Although *Lantana camara* L. is also present in the forest, this invasive species was not used considering its potential allelopathic effect that may result in poor quality manure. As a part of this pilot innovative initiative, CF user groups (CFUGs) collected forest biomass and converted into compost manure and applied in local farms that helped improve fertility and soil health. During this trial period, approximately 75 metric tons of forest biomass (mix of both semi-dried and dried) harvested from 50 hectares of forest patches invaded by IAPS have been converted into compost manure. Over the years, local people have witnessed and reported reduced fire incidents in forest patches where such an innovative biomass harvesting approach is being implemented. Additionally, this biomass management initiative has created jobs for local people, promoted organic farming and reduced

chemical fertilizer use. Most importantly, this had aided in forest restoration by supporting seedling growth while reducing fire incidences in forests.

Should controlled burning be an option?

Traditionally, fire has been used as a management tool in different countries around the globe and stands as a successful strategy to maintain fuels, resources and services (Anderson and Moratto, 1996; Long *et al.*, 2021; Mariani *et al.*, 2024). Occurrence of fire is inevitable in ecosystems ranging from grasslands to forests with the variations in fire return interval (Lauvaux *et al.*, 2016; Mariani *et al.*, 2024). For example, grasslands are well adapted and can be burned on yearly basis while forested ecosystems such as conifers have average return interval of 11 years and that of shrubland of 25 years (Lauvaux *et al.*, 2016). There is rich evidence of how local people inherited the traditional knowledge of fire ecology to keep their natural areas adapted to specific type of fire frequencies and severities (Christianson *et al.*, 2022). This pattern of human interactions with fire ranges broadly from pine savannas of Florida and mixed-conifers of California in the United States, bushland of Australia to forests and pastures of India and Nepal (Burrows *et al.*, 2020; Dogra *et al.*, 2018; Mukul and Byg, 2020; Paudel *et al.*, 2022, 2020).

There are examples in Nepal where people have been using fire as a tool to manage forests, rangelands, and pastures to promote various ethnobotanically useful plants, prepare agriculture land (e.g., shifting cultivation), regenerate palatable species and maintain overall ecosystem health (Lama *et al.*, 2001; Mukul and Byg, 2020; Paudel *et al.*, 2020). However, the complexity of using fire as a management tool and generalizing its role

to all ecosystems and across forest types can be misleading. Here, Nepal can learn from the experiences of the U.S. Forest Service and the consequences of their decades-long fire suppression policy, which aimed to extinguish fires as quickly as possible, regardless of its ecological role (Pyne, 1982). This resulted in extreme changes in historical vegetation dynamics and fire regimes, creating a highly challenging situation despite continued efforts by U.S. federal agencies to introduce prescribed burning to mimic pre-Columbian Indigenous fire practices, manage fuel loads, and restore historical norms. In U.S., forest and fire management actions are often criticized for not making a significant difference in reducing fuels even though they are resource-intensive, and they are often constrained by safety concerns associated with the urban-wildland interface and risks to recreational and critical biodiversity areas (North *et al.*, 2015). Prescribed burning is also increasingly called into question for high pyrogenic emissions and negative impacts on air quality and public health (Campbell *et al.*, 2012; Ravi *et al.*, 2019). Therefore, given the country's high biological diversity and the long-standing interactions between people, forests, and rangelands, a landscape specific as well as ecologically and culturally informed approach to fire management is vital in Nepal, specifically weighing both the risks and benefits of fire.

Historical community-led fire in Nepal is a deliberate and carefully managed technique that often tied to agropastoral livelihoods, seasonal grazing patterns, and Indigenous land-management systems that rely on intimate knowledge of vegetation cycles, microclimates, and fuel conditions (Mukul and Byg, 2020; Schmidt-Vogt, 1990). In this context, controlled or managed burning is not simply an operational activity; it is a culturally rooted practice integrated into community norms, collective decision-making,

and generational ecological understanding. Where these traditions persist, there is strong justification for supporting their continuation as a management tool. Community-led burning can maintain open rangelands, promote fresh grass growth, limit encroachment by shrubs and invasive species, promote forest regeneration, and enhance habitat heterogeneity. Community elders and traditional practitioners often possess tacit knowledge such as appropriate seasons, ideal humidity and wind conditions, burning intervals, and safe ignition patterns that allow them to manage fire in ways that align with local ecological dynamics. Safeguarding these practices helps preserve cultural and community identities while utilizing traditional ecological knowledge that modern fire management frameworks often undervalue.

Box 03: Community-led burning prior to the dry season reduces wildfire incidences and helps forest regeneration

Forest fire used to be a regular phenomenon during dry season, with high incidences in March-April, every year in Ranikhola Community Forest (Ranikhola CF) in Chitwan district, Nepal. Leaf litter and dry biomass from the invasive species *Chromolaena odorata* acted as an unnatural and excessive addition to the fuel load, a problem that is especially severe in the degraded forest patches. Regeneration of trees in these areas has been disrupted by annual wildfires, which have intensified in recent decades with the increasing infestation of invasive weeds. Aiming to support forest restoration, local communities initiated experimental control burning in six hectares of degraded patches before and during the dry season as a part of Participatory Action Research (PAR). In January 2023, Ranikhola CF engaged its members in collecting leaf litter and invasive species biomass. The collected dry biomass, apart from some fraction that was used as animal bedding and ultimately converted to compost manure, was piled up in safe sites and cautiously burnt in small heaps considering the suitable weather conditions – a community led controlled burning initiative technically referred to as pile burning. Another round of accumulated biomass was safely burnt again in February. During peak dry season of that year the controlled-burning

302 experimented forest patch remained safe from fire, while adjoining areas and similar landscapes
303 experienced several incidences of wildfire. By preventing fire event, this controlled burning helped
304 protect over 5000 naturally regenerated tree seedlings. Although this was a pilot initiative and one
305 year of experience may not be sufficient to draw firm conclusions, pile burning is a proven
306 technique for fire management through the reduction of fuel loads in forests. Therefore, this case
307 demonstrates that community-led burning and fuel reduction treatments conducted in advance
308 can help reduce fire risk during the dry season.

309 In the global North, the United States has experienced forest destruction from
310 devastating wildfires linked to historical fire mismanagement and disconnected people-
311 forest interactions that recent research urges reviving for better fire management, risks
312 reduction, and broader benefits (Markwith and Paudel, 2022; Parajuli *et al.*, 2025). On the
313 other side, in global South countries like Nepal, India, and Mexico, there is rich evidence of
314 communities utilizing their traditional ecological knowledge in maintaining healthy forests,
315 promoting biodiversity and sustaining their livelihoods through regular engagement with
316 forests, including the use of fire as a management tool (Dogra *et al.*, 2018; Farthing, 2024;
317 Pandey *et al.*, 2022; Sharma *et al.*, 2021; Van Vleet *et al.*, 2016). By valuing its own
318 traditions and strengthening the long-standing community-based practices, Nepal can set
319 good examples of people led-sustainable forest fire management.

320 **Closing remarks**

321 The core principle of creating fire-resilient forests through various fuel-reduction
322 activities aims to decrease biomass on the ground (i.e., surface fuel), in the crown (i.e.,
323 canopy fuel), and in the layers between (i.e., ladder fuel). Nepal's long legacy of community
324 engagement, which blends traditional knowledge of sustainable resource extraction with

technical assistance from government and other partner agencies including non-profit organizations, has ensured that these principles are applied and has helped prevent large devastating wildfires. It is vital to maintain the intricate ties between people and forests for mutual benefits: people contribute to healthy ecosystems that sustain essential services for humankind, and forests support local livelihoods and continue to provide diverse ecosystem services. Anthropogenic or controlled burning can help manage surface and ladder fuels and be ecologically beneficial in certain landscapes, and therefore, it should be continued where it has been historically practiced and informed by traditional and modern ecological knowledge. However, initiating new burning practices is generally not recommended, at least warrants well thought research and planning, because: a) not all landscapes are adapted to fires, and b) escaped fires can lead to severe impacts on biodiversity, carbon budgets, infrastructures and public health and safety. Moreover, experiences from developed countries show that the technical and financial resources required for managed burning are substantial, making such approaches economically less feasible for a developing economy like Nepal.

Nepal's forests are experiencing increased fire risks driven by multiple factors, including shifting fuel patterns and changing climatic conditions. Weakening people-forest interactions, partly due to low economic benefits and reduced dependence on forest resources, underscore the urgency of national strategies for sustainable forest and fire management. Here, we emphasize the need for collaborative action among government agencies, scientists, non-profits, the private sector, and local institutions to support communities through research, technical and financial assistance, and pragmatic policies

that strengthen fire-resilient forest management, and most importantly, keep healthy people-forest relationships intact. In addition to acknowledging community-based forest management as an entrepreneurial endeavor, the Government of Nepal should timely introduce policies and regulations that create enabling environments for forest-based enterprises and private-sector investments in modern technologies capable of converting forest residues into net carbon-beneficial products such as biochar.

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