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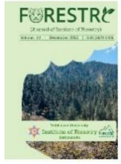

Original research article

Effects of fire intensity on post-fire regeneration in Nawalpur District, Nepal

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A R T I C L E I N F O

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A B S T R A C T

Forest fires are one of the major ecological disturbances that affect forest composition, structure and regeneration patterns in Nepal's fire-prone habitats. In this study, post-fire regeneration patterns of forests in Nawalpur District, where repeated wildfires are increasingly threatening biodiversity, were examined. Based on MODIS satellite information and field observations of 217 sample plots, regeneration responses were analysed under varying fire intensities (very low, low, medium and high). The Kruskal–Wallis test revealed that sapling density, seedling density and total regeneration significantly varied among the fire intensities, whereas, species richness did not differ significantly. Canopy cover was significantly and positively correlated with species richness. Seedling density significantly declined in very low and low fire intensities but increased under moderate to high fire intensity, likely due to enhanced light availability and nutrient release following higher burn severity. In contrast, sapling density was higher in areas with very low fire intensity, possibly reflecting reduced mortality of established individuals. Regeneration felling and felling duration have no significant effect on regeneration. This research contributes to finer understanding of forest fire ecology in the Chure region of Nepal, providing region-specific insights that support the development of sustainable forest management policies. Long-term monitoring of forest fires, along with future research incorporating fire frequency, is imperative to fully understand forest resilience and recovery tracks in Nepal's

INTRODUCTION

Nearly one-third of the global terrestrial surface is covered by forest ecosystems, which provide essential ecological, economic and cultural services and are vital for achieving sustainable development (Keenan et al., 2015; FAO, 2020). However, these ecosystems are increasingly threatened by deforestation, land cover changes, climate extremes, insect outbreaks and especially wildfires (van Lierop et al., 2015). Among these, wildfires represent one of the most significant ecological disturbances, impacting the forest regeneration process, altering forest structure and affecting species composition (Bargali et al., 2023).Globally, an estimated 350 million hectares (ha) of vegetation burn each year, with considerable inter-annual variation (typically 250–450 million ha), largely influenced by climate variability and land-use changes (Chen et al., 2023). Over the last two decades (2001–2020), global fire activity has shown high spatial and temporal variability, which is more pronounced in regions such as the Amazon, Africa, Australia, North America and Southeast Asia, where wildfire occurrences are frequent (Silva et al., 2018). Between 2003 and 2017, over 30.5% of south and southeast Asian countries experienced recurring fires annually with approximately 170,000 fire incidents each year. The Deccan central lowlands and Hindu Kush Himalayan regions account for nearly 34% and 56% of these occurrences respectively (Vadrevu et al., 2019).

In south Asia, and particularly in Nepal, wildfires predominantly occur during the pre-monsoon dry season, triggered by prolonged droughts, human

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negligence and poor forest management practices (Matin et al., 2017; Pandey et al., 2022). Nepal has witnessed more than 375,000 ha of forests burn over the last 15 years and over 22,700 forest fire incidents in the past decade, with a sharp increase in 2023 (Thapa et al., 2025). Between 2001 and 2024, the country lost around 7.48 thousand hectares (ha) of forests to wildfires, in addition to 50.8 thousand ha to other drivers of deforestation. These fires have caused significant degradation of soil quality, biodiversity loss and disruption of forest regeneration process (Acharya et al., 2011).

Forest regeneration is the process by which forests reproduce themselves spontaneously through the use of seedlings, saplings and vegetative shoot growth, either naturally or resulting from disturbances like storms, fires, or logging (Pausas & Keeley, 2019). Forest regeneration has a critical role in understanding ecosystem resilience and biodiversity conservation and in developing forest management plans (Liu, 2025). For instance, low-intensity forest fires can increase regeneration in fire-adapted vegetation, while high-intensity forest fires can destroy seed banks and damage root systems, decreasing vegetation recovery (Diaz-Delgado et al., 2004). Since forest fires in Nepal are in an increasing trend, it is imperative to be aware of forest regeneration patterns and the impact of fire severity (Sapkota et al., 2025).

Post-fire recovery is influenced by multiple factors, including fire severity, vegetation type and management practices (Pausas & Keeley, 2019). Although fire is a natural component of many forest ecosystems, its ecological effects vary, depending on fire regime (intensity, frequency and duration), species composition and anthropogenic intervention. In fire-prone regions such as Chure and mid-hills of Nepal, regeneration following fires is increasingly constrained by the spread of alien species, erosion and a lack of forest management practices (Bhatta et al., 2021). Despite the government's Forest Fire Management Strategy and the engagement of over 22,000 community forest user groups (CFUGs), wildfire occurrences continue to rise, revealing policy gaps and limited local capacity for effective prevention and fire control (Pandey et al., 2022). In recent years, several studies have examined wildfire dynamics and forest conditions in Nepal (Paudel et al., 2020; Bhatta et al., 2021). However, localized empirical evidence linking specific fire intensity with post-fire regeneration patterns, species composition and canopy structure remains scarce. This has limited our understanding of how regeneration responds across varying levels of fire intensities. This knowledge gap hinders the development of evidence-based forest management strategies aimed at enhancing post-fire recovery and strengthening ecosystem resilience across Nepal's diverse landscapes. Hence, the aim of this study was to assess the effects of forest fire on regeneration (seedlings, saplings, species richness and total regeneration) in the fire-affected forests of the Nawalpur Chure region, with the following research hypotheses:

H0: There is no significance difference in species richness/Number of seedlings/Number of saplings/Number of regenerations across various fire intensities.

H1: There is significance difference in species richness/Number of seedlings/Number of saplings/Number of regeneration across various fire intensities.

MATERIALS AND METHODS

Study area

The research was conducted in the forested Chure region of Nawalpur District. The district lies between 27.8149° N and 85.6281° E, covering approximately 1,331.16 km² (Figure 1). Nawalpur is situated in the western part of central Nepal, serving as a strategic link between the Terai plains and the hilly region. The forest types in the district is diverse and dominated by *Shorea robusta, Terminalia alata, Castanopsis indica, Albizia spp., Alnus nepalensis*, *Schima wallichii*, *Quercus lanata*, etc. The landscape ranges from 999 to 2,212 metres above sea level, encompassing substantial variations in temperature, moisture and soil characteristics.

Nawalpur District was selected for this study for two key reasons. First, the district contains 48.59% forest cover, making it one of the most forested districts in the region. Second, it experiences frequent forest fires and has been identified as one of the high-risk districts in Nepal by the national forest fire risk mapping (Forest Fire Detection and Monitoring System in Nepal, 2024). As of April 29, 2024, Gandaki Province had recorded 467 wildfire incidents, burning approximately 8,277 ha of forests. Among these, Nawalpur alone experienced 80 fire incidents, affecting nearly 2,553 ha of land (Radio Nepal, 2024).

Given these conditions, understanding how varying fire intensities influence forest regeneration is essential for mitigating wildfire risks and supporting both ecological integrity and human well-being.

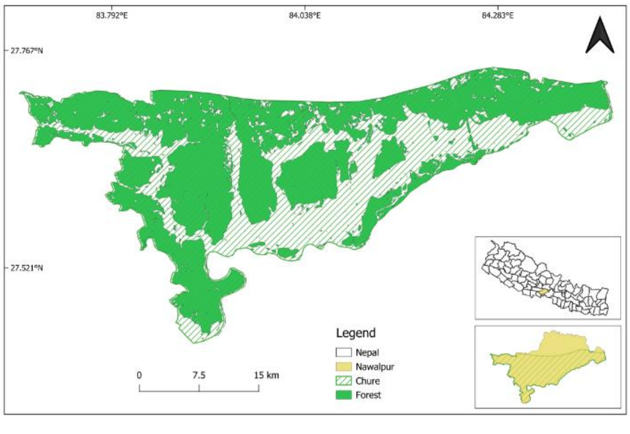

Figure 1.Map of study area showing forest area of Chure region in Nawalpur, Nepal

Data collection

Information on forest fires was obtained using satellite-based fire detection data and integrated with field observations. Active fire data were acquired from the

MODIS sensor through NASA's Fire Information for Resource Management System, which has been widely used in forest fire studies in Nepal and elsewhere (Matin et al., 2017; Thapa et al., 2021; Mishra et al., 2023). MODIS fire points were spatially overlaid with a forest cover map in QGIS, and detections located in non-forest areas were excluded to retain only forest fire events within the Chure forests of Nawalpur District.

Fire intensity classes were derived using MODIS fire detection confidence values, which represent the probability that detected hotspots correspond to actual fire events. Based on confidence threshold and supported by field verification, fire intensity was categorized into four classes: very low, low, medium and high. This classification approach allowed spatial differentiation of fire severity across the study area. Fire sensitivity (intensities) was derived from MODIS detection confidence value and categorized as Very Low (0%), Low (< 50%), Medium (50–70%) and High (> 70%). A total 217 fire-affected plots were identified during the study period, ie October 2023–October 2024, and each plot was assigned a corresponding fire class.

For systematic sampling, a 5 km × 5 km GIS grid was overlaid across the study area. In each grid cell, five standardized plots of 1 m^2 each were established: one at the centre and four 500 m away in the cardinal directions, totalling 49 grid cells. However, in case of very low fire intensity, since the affected fire area was very small, establishing plots at 500 m around it was not feasible. Therefore, we placed only one plot at the centre of the very low fire site. To account for unequal sample sizes across fire intensity classes, non-parametric tests (Kruskal–Wallis and Mann–Whitney U) were used for statistical comparison, as these methods do not assume equal replication. In this way, a total of 217 sample plots were established (Figure 2). Consultations with CFUGs provided information on forest management activities, such as thinning and cleaning. Each selected plot allowed a detailed assessment of forest regeneration, including species richness, number of seedlings and saplings (regeneration), regeneration feeling [absence (0) or presence (1)], tree canopy cover, distance from road (km), distance from settlement (km) and duration of regeneration felling (years).

Method

After recording the GPS coordinates of each sample plot, seedlings and saplings were counted separately within a 1 m^2 quadrat placed in each sample plot. Species richness was measured by identifying and counting all unique plant species within the same quadrat. Data on forest management practices and regeneration felling were obtained through field observations and consultations with the CFUGs concerned. Canopy cover was visually estimated using a densiometer. Distances from roads and settlements were measured using GIS tools by calculating the straight-line distance from the centre of each plot to the nearest road and settlement.

Limitation

This research has several limitations. First, it assessed overall forest regeneration but did not analyse species-specific regeneration patterns in detail. Second, although fire intensity was included, other fire characteristics such as duration and severity were not evaluated, despite their strong influence on soil conditions and regeneration. Third, the study used only one year of data (2024/025), limiting the ability to capture long-term ecological trends, since forest recovery is gradual and may show delayed responses. Fourth, while the MODIS hotspot data helped categorize fire frequency during the study period, long-term fire recurrence was not examined, restricting insights into cumulative ecological impacts. Regarding the instrument used for observing canopy, canopy cover was visually measured using a densiometer. Due to resource limitations, more precise methods were not used, which may introduce minor observer bias.

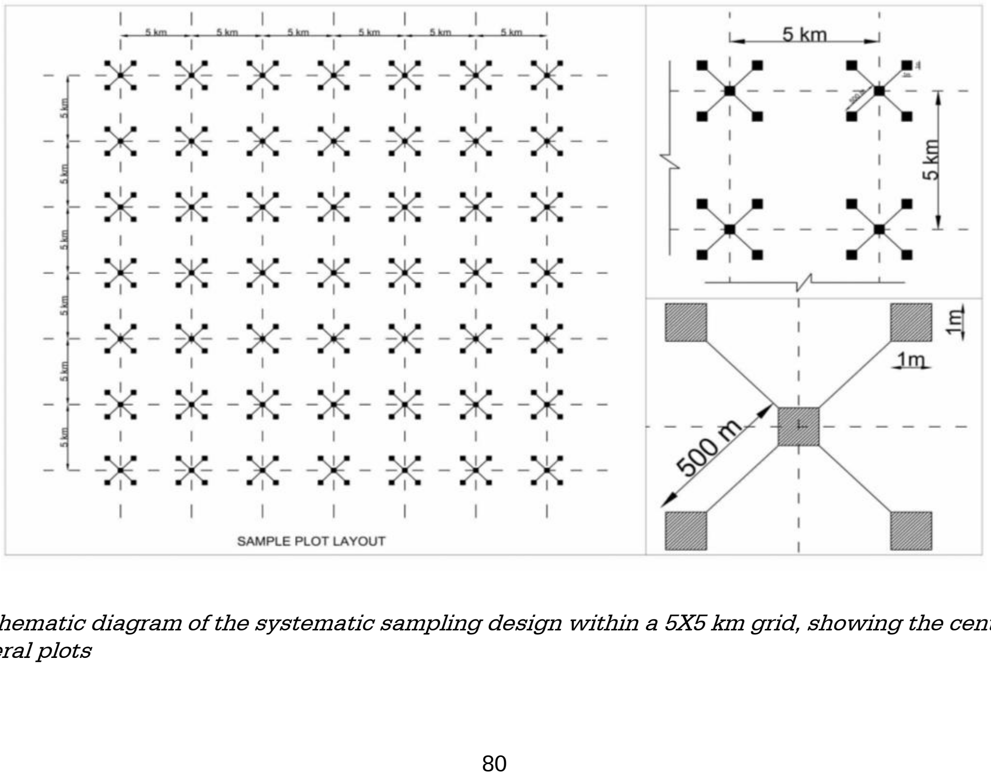

Figure 2. Schematic diagram of the systematic sampling design within a 5X5 km grid, showing the central plot and four peripheral plots

Finally, key environmental variables such as elevation, climate extremes and soil characteristics were not incorporated, even though they strongly influence post-fire regeneration. Therefore, the findings should be viewed as an initial assessment, and future research incorporating long-term monitoring, detailed fire histories, species-specific responses and broader environmental factors is needed for a more comprehensive understanding of forest resilience and recovery in Nawalpur District.

Data Analysis

Data from all sample plots were compiled and analysed, focusing on seedlings, saplings and overall regeneration on SPSS. The parameters found to be most vital were fire intensities, canopy cover and distances from roads and settlements. Initially, data were tested for normality, and as most of the variables were not normally distributed ($p < 0.05$), non-parametric tests were conducted. The non-parametric counterpart of one-way ANOVA, ie the Kruskal–Wallis test, was used to compare species richness, seedling and sapling densities, and total regeneration across different fire intensities. For pairwise comparison, the Mann–Whitney U test was employed as a substitute for the independent t-test, suitable for non-normal data without assuming equal variance. Since regeneration data represent counts, Poisson regression was used to examine its relationship with fire intensity, canopy cover, regeneration felling and felling duration.

$$\log(y_i) = \beta_0 + \beta_1 * Fire\ intensity + \beta_2 * Canopy\ cover + \beta_3 * Regeneration\ felling + \beta_4 * Duration\ of\ regeneration\ felling + \epsilon_i$$

Where y_i is the expected count of yi

ϵ_i is the error

RESULTS

Forest fire intensity and regeneration structure

The Kruskal–Wallis test indicated that fire intensity had a significant effect on seedling density, sapling density and total regeneration, whereas species richness did not differ significantly among fire intensity classes (Table 1). Seedling density varied significantly across fire intensities ($p < .001$). Sapling density also showed significant variation, although the effect was weaker ($p = .043$). Total regeneration differed significantly among fire intensity categories ($p < .001$). In contrast, species richness did not show a significant difference across fire intensity levels ($p = .280$).

Pairwise comparison of species richness, seedling and sapling counts and total regeneration across different fire intensities

Pairwise comparison using the Mann–Whitney U test further clarified differences among fire intensity classes (Table 2).

Table 1: Kruskal–Wallis test showing comparison between seedling density, sapling density, total regeneration (number per m²), and species richness across fire intensity categories.

S.N	Null Hypothesis	df	p-Value	Chi-square
1	The Distribution of species richness is the same across fire intensity	3	0.280	3.834
2.	The Distribution of the Number of seedlings is the same across fire intensity	3	0.000***	32.555
3.	The Distribution of the Number of Saplings is the same across fire intensity	3	0.043**	8.154
4.	The Distribution of Regeneration is the same across fire intensity	3	0.000***	25.170

*Note: *, **, and *** denote significance at the 0.10, 0.05, and 0.01 levels of significance.*

Table 2: Mann–Whitney U test showing pairwise comparison of species richness, number of seedlings, saplings, and total regeneration among fire intensity classes

Pair	Species Richness		Number of seedlings		Number of saplings		Number of regeneration	
	U	p	U	p	U	p	U	p
0-1	168	0.14	146.50	0.076*	147	0.05*	200	0.419
0-2	130	0.085*	66.50	0.003**	137.50	0.11	101.50	0.025**
0-3	195	0.16	83	0.002**	128.50	0.006***	113	0.008***
1-2	1872.5	0.26	1332.50	0.00***	1995	.581	1384	0.001***
1-3	2759.5	0.87	1540.5	0.00***	2534	.241	1641.5	0.000***
2-3	2190	0.35	2076	0.168	2045	.085	2244.5	0.508

Note: *, ** and *** denote significance at the 0.01, 0.05, and 0.1 level of significance

(*U* represents the Mann–Whitney U statistic, and *p* indicates the significance level)

Species richness did not differ significantly between any fire intensity pairs ($p > .05$), although slightly higher richness was observed at medium fire intensity compared to very low fire intensity. Seedling density differed significantly across several fire intensity pairs. Significant differences were observed between very low and medium fire intensities ($p = .003$), very low and high ($p = .002$), low and medium ($p < .001$), and low and high fire intensities ($p < .001$). A marginal difference was also detected between very low and low fire intensities ($p = .076$). Overall, seedling density increased with increasing fire intensity. Sapling density showed fewer significant pairwise differences. Significant differences were found between very low and low fire intensities ($p = .050$) and between very low and high fire intensities ($p = .006$). A marginal difference was observed between medium and high fire intensities ($p = .085$). In general, sapling density decreased as fire intensity increased. Total regeneration density was significantly influenced by fire intensity and peaked at medium fire intensity. Significant differences were observed between very low and medium fire intensities ($p = .025$), very low and high ($p = .008$), low and medium ($p = .001$), and low and high fire intensities ($p = .001$). No significant difference was detected between medium and high fire intensities ($p = .508$).

Factors affecting the regeneration composition

Poisson regression analysis identified canopy cover, regeneration felling, felling duration and fire intensity as explanatory variables influencing regeneration attributes (Table 3). The analysis found that the key factors influencing forest regeneration included canopy cover, regeneration felling, felling duration and fire intensity levels.

Table 3: Regression analysis of the number of seedlings/saplings/species richness as the dependent variable

Variables	Seedling (Y1)	Sapling (Y2)	Species Richness (Y3)
Intercept	2.354(0.2592)***	-1.353(.965)**	.354(.54)
Canopy cover (%)	.000 (0.0021)	0.008(.0088)	.008(.004)*
Regeneration Felling(No)	.048(.2251)	-0.66(.7778)	-0.207(.46)
Regeneration felling duration	-.015(0.0392)	0.24(.1361)	-.012(.0803)
Fire intensity (Very Low)	-.333(.1589)**	.924(.4636)**	-.405(.3573)
Fire intensity (Low)	-.179(0.593)***	.240(.2487)	-.129(.1292)
Fire intensity (Medium)	-0.31(0.580)	.389(.2508)	.034(.1290)

Note: *, ** and *** denote significance at the 0.01, 0.05, and 0.1 level of significance

Canopy cover showed no significant effect on seedling density ($p = .906$) or sapling density ($p = .351$), but it had a positive significant effect on species richness ($p = .094$), indicating higher species richness with increasing canopy cover. Regeneration felling had no significant effect on seedling density ($p = .832$), sapling density ($p = .932$), or species richness ($p = .654$). Similarly, regeneration felling duration did not significantly influence seedling density ($p = .711$), sapling density ($p = .859$), or species richness ($p = .884$).

Fire intensity significantly affected seedling and sapling density. Seedling density was significantly lower under very low ($p = .036$) and low fire intensity ($p = .003$) compared to high fire intensity, indicating an increasing trend in seedling density with increasing fire intensity. Conversely, sapling density was significantly higher under very low fire intensity ($p = .046$) and declined as fire intensity increased. Fire intensity did not have a significant effect on species richness ($p > .05$).

DISCUSSION

Forest fires tend to be viewed as an enemy to regeneration as they are viewed as forces of destruction halting new growth (Agbeshie et al., 2022; Matin et al.,2017; Sapkota et al., 2025). The study results contradict the traditional understanding by showing that forest fires can facilitate regeneration processes. High-intensity fire-affected areas had greater regeneration density than areas burned by low-intensity fires. We observed a substantial difference in seedling density, sapling density and overall regeneration. Furthermore, our results suggest that regeneration composition was strongly influenced by canopy cover and forest management practices, particularly regeneration felling and the duration since felling.

Fire intensity and regeneration

The result revealed that high-intensity fire-affected areas had greater regeneration density than the areas burned by low-intensity fires. This observation may partly reflect a classification effect, as the fire intensity categories were determined based on visible characteristics and burn severity (Lentile et al., 2006; Keeley, 2009). It is also possible that the high-intensity fires here were not intense enough to destroy regrowth vegetation, but instead facilitated regeneration by removing leaf litter and other surface debris, thereby creating better seed germination and seedling establishment conditions (Certini, 2005; Pausas & Keeley, 2009).

Total regeneration was observed to increase with rising fire intensity, potentially due to improved nutrient availability, reduced presence of pathogens, breaking of seed dormancy and greater exposure of mineral soil following the fire (Verma et al., 2017; Halofsky, Peterson and Harvey, 2020). In *Shorea robusta*-dominated forests, fires typically occur as surface or ground fires and primarily impact regeneration layers. Dhungana et al. (2023) reported that post-fire conditions reduce species richness but enhance *Shorea robusta* dominance, creating favourable conditions for regeneration by minimizing competition for survival. This effect may be attributed to the fire-resistant characteristics of the *Sal* species.

Seedling density was significantly low under very low and low fire intensities compared to high fire intensities, ie seedling density is high in high fire intensity. This could be attributed to prolonged surface heating in low-intensity fires, damaging emerging seedlings, while high-intensity fires may promote seedling establishment by creating favourable seedbed conditions through litter removal and nutrient release (Dhungana et al., 2023). Such changes can enhance soil health and perception of light, thereby promoting germination and growth. Similarly, Kennard and Gholz (2001) found that high-intensity fires initially promote seedling establishment by loosening soil and increasing nutrient availability, although these benefits may diminish over time due to soil structure degradation and nutrient decline.

This study's findings are based on one-year post-fire observations, and the apparent patterns in sapling or seedling density might differ over longer time scales. Areas with low sapling density under high-intensity fire could have experienced repeated low-intensity burns in the past, while those with higher sapling density in low-intensity zones might have undergone earlier intense fires.

Forest fires also play a significant role in shaping sapling abundance and species composition. In general, increasing fire severity or frequency tends to reduce both sapling density and species richness. Our findings indicate that areas with high fire had lower sapling density and species diversity, whereas very low fire sites had the highest sapling abundance and species richness. Similar patterns were observed by Keeley et al. (2011), who found that frequent fires reduce the survival of regenerating individuals, particularly saplings, which are more vulnerable to repeated fire disturbances than seedlings or mature trees. The greater susceptibility of saplings may result from cumulative physiological stress, root damage and reduced nutrient availability.

Additionally, as noted by Gill and Beardall (2001), intense competition for light, water and nutrients during the transition from seedling to sapling stage limits recruitment, especially in undisturbed forests.

Although higher regeneration was recorded under high-intensity fires in this study, it is important to note that moderate-intensity burns are often considered ecologically optimal, as they stimulate regeneration processes without causing excessive mortality or nutrient depletion.

Canopy cover and regeneration

Our study found that species richness increased significantly with higher canopy cover, suggesting that dense canopies support greater plant diversity. This may be due to the moderate microclimatic conditions of decreased temperature fluctuations and higher soil moisture, which enhance understorey growth (Kokila et al., 2024). Moreover, a well-developed canopy facilitates the regeneration of light-demanding and shade-tolerant species, enhancing species richness (Sangry et al., 2024). Sharma et al. (2016) also documented the same findings, showing that canopy cover positively influences species richness of Nepalese forests. They attributed this relationship to stable microclimatic conditions that promote understorey diversity. Light-demanding species, like Sal (*Shorea robusta*), Saj (*Terminalia tomentosa*), Katus (*Castanopsis indica*), Kharane (*Macaranga denticulata*), and Siris (*Albizia species)* and some shade-tolerant species, like Chilaune (*Schima wallichi*), Utis (*Alnus nepalensis*), Phaledo (*Sapium insigne*) and Banjh (*Quercus spp.)*, are found in this study.

Forde et al. (2013) established a positive correlation between seedling and sapling densities and canopy cover. Devkota et al. (2025) reported higher seedling density under closed canopy classes in *Shorea robusta* and other forest types. This may be because seedlings benefit from closed canopies through improved soil moisture retention and reduced competition from understorey vegetation (Devkota et al., 2025). Canopy closure may still allow intermittent light penetration, supporting seedling establishment even under denser canopies (Mestre et al., 2017).

Forest management practices and regeneration

We found that seedling density was higher in areas where regeneration felling had not occurred, indicating a positive regeneration response in undisturbed sites. However, sapling density was lower in the same locations, suggesting a negative correlation between the absence of felling and sapling abundance. This pattern implies a recruitment bottleneck, where seeds and seedlings are abundant, but few individuals survive or progress into the sapling stage likely due to limited light and strong competition under a closed canopy (Clark et al., 1999). A similar seedling–sapling decoupling has been reported by Clark et al. (1999), where stage-specific mortality and resource competition restricted recruitment.

In contrast, several research studies in Nepal have shown higher seedling and sapling densities after regeneration felling. Khanal & Adhikari (2018) in Rupandehi and Awasthi et al. (2020) in Lumbini collaborative forest both observed enhanced regeneration in managed blocks and emphasized the importance of regeneration felling to maximize forest productivity. A canopy opening is responsible for these effects, which improve light availability and create favourable conditions for seedling and sapling establishment. Similarly, Kharel et al. (2021) in Sunsari District found significantly higher regeneration under an irregular shelter wood system in managed plots, although species diversity was lower due to the dominance of desirable species favoured by silvicultural practices. Overall, managed forests tend to promote both seedling and sapling densities through increased light and reduced competition, whereas undisturbed stands accumulate seedlings but limit their upward growth due to canopy closure.

Species richness was slightly lower in non-regeneration felling sites, although the difference was not statistically significant. Temporary declines in diversity after felling have also been reported by Chaudhary et al. (2016). Similarly, Kharel et al. (2021) noted that while managed blocks support higher regeneration, unmanaged blocks maintain greater species richness and diversity of shrubs, grasses and non-target tree species. The dominance of selected commercially desirable species in managed areas results from periodic silvicultural interventions such as weeding and removal of unwanted vegetation, which can reduce overall diversity. Conversely, unmanaged areas maintain a broader mix of species, including shade-tolerant and pioneer types. The slightly lower richness observed in non-felled sites in this study may also reflect that anthropogenic disturbances can promote the arrival and establishment of new species, as suggested by Rabha (2014).

Regeneration felling duration and regeneration

Our results show that the time since regeneration felling had no significant effect on seedling density, sapling density, or species richness. Seedling density decreased, density of saplings increased and richness of species remained mostly stable. These patterns are consistent with Maes et al. (2019), who reported similar trends. The lack of significant effects may be due to the complex interactions of ecological factors, where seedling loss is offset by sapling growth (Maes et al., 2019), and environmental conditions like soil fertility and seed availability have greater influence than felling duration. The slight decrease in species richness most likely reflects successional change as pioneer species are shade-tolerant ones, while general diversity is maintained (Zenner et al., 2012). Nevertheless, we observed a decline in seedling density and species richness alongside an increase in sapling density. This pattern is consistent with successional and biotic processes in regenerating forests: early cohorts of seedlings may suffer density-dependent mortality or browsing, while a subset that escapes these filters grows into the sapling class, resulting in higher sapling counts but reduced species richness (Comita et al., 2014).

CONCLUSION

Forest fires have increasingly been recognized as a pressing environmental challenge with wide ecological implications. Regeneration in the forests of Nawalpur District is shaped by multiple factors, including species richness, seedling and sapling densities, forest management practices, canopy cover, proximity to roads and settlements, and the duration since regeneration felling. Seasonal fire patterns play a decisive role in influencing plant propagation, survival and recruitment.

This study quantified post-fire regeneration trends and found that a single fire event can produce highly variable impacts across tree species. Seedling density generally increased in burned areas, suggesting favourable conditions for new growth, while sapling density varied according to fire severity. Both seedling and total regeneration were highest under high fire intensity, whereas species richness increased only slightly with fire intensity. In contrast, sapling density was greater in low-intensity fire sites, likely due to reduced mortality and lower competition. Canopy cover supported species diversity by moderating microclimate and providing favourable conditions for understorey growth.

Forest management practices, particularly regeneration felling, influenced fire behaviour by increasing fuel accumulation, though they had no statistically significant direct effect on regeneration indicators. The duration since felling was positively correlated with fire intensity, pointing to the importance of timely cleaning and litter management. Distance to roads emerged as a major driver of fire risk due to human access and negligence, underscoring the need for targeted fire prevention strategies along road corridors.

Overall, the study highlights fire intensity, canopy cover and human activity as key determinants of post-fire regeneration. While fire can act as a regenerative force, its positive role depends on appropriate silvicultural practices, such as litter removal, post-felling cleaning and fire hazard reduction. These insights provide a foundation for adaptive forest management in fire-prone regions of Nepal, emphasizing the integration of ecological principles with community-based practices.

Future research should focus on long-term monitoring of fire impacts, species-specific regeneration responses and the cumulative effects of repeated fires. Such efforts will deepen understanding of forest recovery processes and guide the development of resilient, biodiverse and sustainably-managed forests.

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