



# Impacts of Adaptive Fire Management on Forest Structure and Regeneration: A Case Study from Ban Pak Thab Community Forest, Uttaradit Province, Thailand

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## Abstract

*There is an urgent need for innovative approaches to forest management given the increasing incidence and intensity of wildfire due to climate change. The impact of interacting prescribed burning, fuel reduction and natural fires on tree structure in Ban Pak Thab community forest; Thailand Twelve, 40 m × 40 m, experimental plots were studied for the ecological effects of four different management practices. The findings demonstrate that, not only do prescribed burning and fuel treatments significantly improve forest regeneration by decreasing inter-tree competition, enhancing nutrient recycling and encouraging superior sapling growth but also they also help to conserve species diversity as well as biomass accumulation. However, natural burning led to extensive reductions in tree density, species richness and total biomass. Extensive statistical analysis showed high relationships of the management practices tested on several ecological variables, and this demonstrated well the varying effects of these interventions. This result emphasizes the (compared to non-managed burns) advantageous effect of managed fire on other hand important information for sustainable development of management strategies concerning tropical forest ecosystems. This study highlights the potential benefit of adaptive management in reducing negative impacts of climate change on forest health and resilience.*

*Keywords: fire management, forest regeneration, community forest, ecological impact, sustainable forest management*

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## Introduction

Forest fires present significant ecological and environmental challenges worldwide, and their impacts vary greatly depending on the geographical and climatic conditions. In Thailand, forest fires are particularly prevalent during the dry season and cause extensive damage to the environment and local communities. Effective fire management strategies are crucial for mitigating these impacts and promoting the sustainability of forest ecosystems. This study focused on evaluating the ecological effects of prescribed burning and fuel reduction practices in the Ban Pak Thab Community Forest, Uttaradit Province, Thailand, a region highly susceptible to wildfires.

Prescribed burning, or controlled burning, involves deliberately setting fires under controlled conditions to reduce fuel loads, enhance ecosystem health, and prevent large-scale, uncontrolled wildfires. Research highlights the benefits of this practice, including nutrient recycling, habitat restoration, and increased biodiversity (Eales et al., 2018; López-Cruz et al., 2022; Burrows & McCaw, 2013). However, improper implementation can adversely affect soil properties and air quality (Guinto et al., 2001; Williams et al., 2012; Merino et al., 2019). Fuel management practices, such as selective harvesting and removal of combustible mate-

rials, also play a critical role in minimizing fire risk and promoting forest regeneration. These strategies have been demonstrated to increase forest resilience to disturbances and improve the diversity of plant and animal species when carefully planned and executed (Boer et al., 2009; Holland et al., 2017).

The environmental impacts of wildfires extend far beyond the immediate areas affected by the flames. They can disrupt the soil composition, degrade atmospheric quality, and reduce biodiversity. Unmanaged wildfires often lead to severe soil erosion, loss of organic matter, and increased carbon emissions, exacerbating climate change (Liu et al., 2017; Hyde & Strand, 2019). In contrast, adaptive fire management strategies, such as prescribed burning and fuel reduction, can mitigate these effects while supporting forest recovery and ecosystem stability (Boer., 2009; Schoennagel et al., 2017; Kiely et al., 2024).

This study aimed to evaluate the relative effectiveness of prescribed burning and fuel management in enhancing forest regeneration and minimizing the ecological damage caused by natural fires. Twelve experimental plots were established to analyze tree density, species richness, and biomass under different management practices. The findings of this study provide critical insights into fire management strategies

tailored to tropical forest ecosystems and contribute to global efforts to combat ecological threats posed by climate change.

## Methods

**Site description** The study focuses on selecting and managing community forest areas within Uttaradit Province, specifically within the Huai Chalong National Forest Reserve, located in the Huai Si Siat Forest. The Nan River right forest part, Huai Kiang Pha, and Nam Krai National Reserved Forests comprise the National Reserved Forest. Using the criteria set by the province, the study emphasizes deciduous forests that impact the residents of Mueang Uttaradit District. These forests must be utilized for scientific purposes and replicate original forest fire patterns to meet the Community Forest Act's criteria. Four regions were chosen and designated as control plots in their natural state, factoring in the extent of forest fires, forest conversion areas, and regions affected by natural forest fires. The plot layout ensures a uniform environmental region, including topographical and plant features, as illustrated in the provided map (Figure 1).

**Fire frequency mapping** The investigation was conducted exclusively in deciduous forests within designated areas. For each fire management classification, including the control (B0) and varying fire frequency categories (B1B3), three 0.1-ha square plots were randomly established. Soil samples were obtained from areas subjected to fire management interventions and left undisturbed (Figure 2, Table 1).

The experimental design involved establishing twelve plots, each  $40 \times 40 \text{ m}^2$ , divided into three plots per area and further into twenty-four subplots of  $10 \times 10 \text{ m}^2$ . Trees with a diameter at chest height (dbh) of 4.5 cm or more were included. Trees with a dbh of less than 4.5 cm but a height of

more than 1.30 m were also studied. Five experimental plots of  $4 \text{ m}^2$  each represented seedlings, vines, and herbaceous plants shorter than 1.30 m. These plots were randomly placed within each large experimental plot, and tree species were identified for analysis. The analysis included several aspects of plant community structure. The metrics, such as frequency value, prominence value, density value, relative frequency, relative prominence, relative density, and plant importance index, were calculated. Additionally, the species similarity index (Xu, 2009), Shannon–Weiner diversity index (Yeom & Kim, 2011), and biomass using allometric equations (Khairil et al., 2011) were assessed (Figure 1).

**Environmental impact assessment** Environmental impacts of forest fires on community forests were assessed in four areas: natural control plot, forest burning area, forest conversion area, and natural forest fire area. The plot was based on consistent environmental criteria, including topographical and vegetation characteristics. Data collection mirrored studies on the ecology of deciduous dipterocarp forests and community forest use, particularly in control plot areas. Data collection was performed post-wildfire, post-harvest, and post-natural forest fire. The impact assessment evaluated changes quantitatively and qualitatively, showing the rate of change due to forest fires.

Data analysis involved comparing differences between research areas using ANOVA and studying variable relationships using Pearson's correlation and canonical correspondence analysis (CCA). CCA is a multivariate statistical method used to explore relationships between ecological community data (such as species composition) and environmental variables (such as fire frequency, soil properties, and vegetation characteristics). By plotting data in a multidimensional space, CCA helps identify patterns and

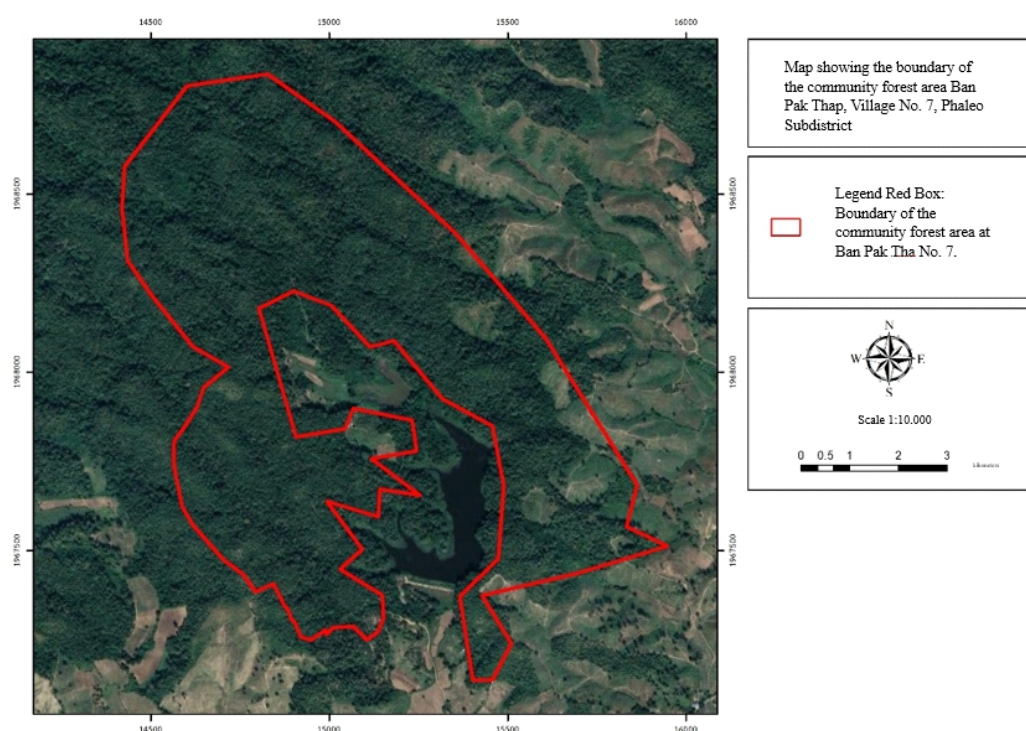


Figure 1 The plot layout ensures a uniform environmental region, including topographical and plant features.

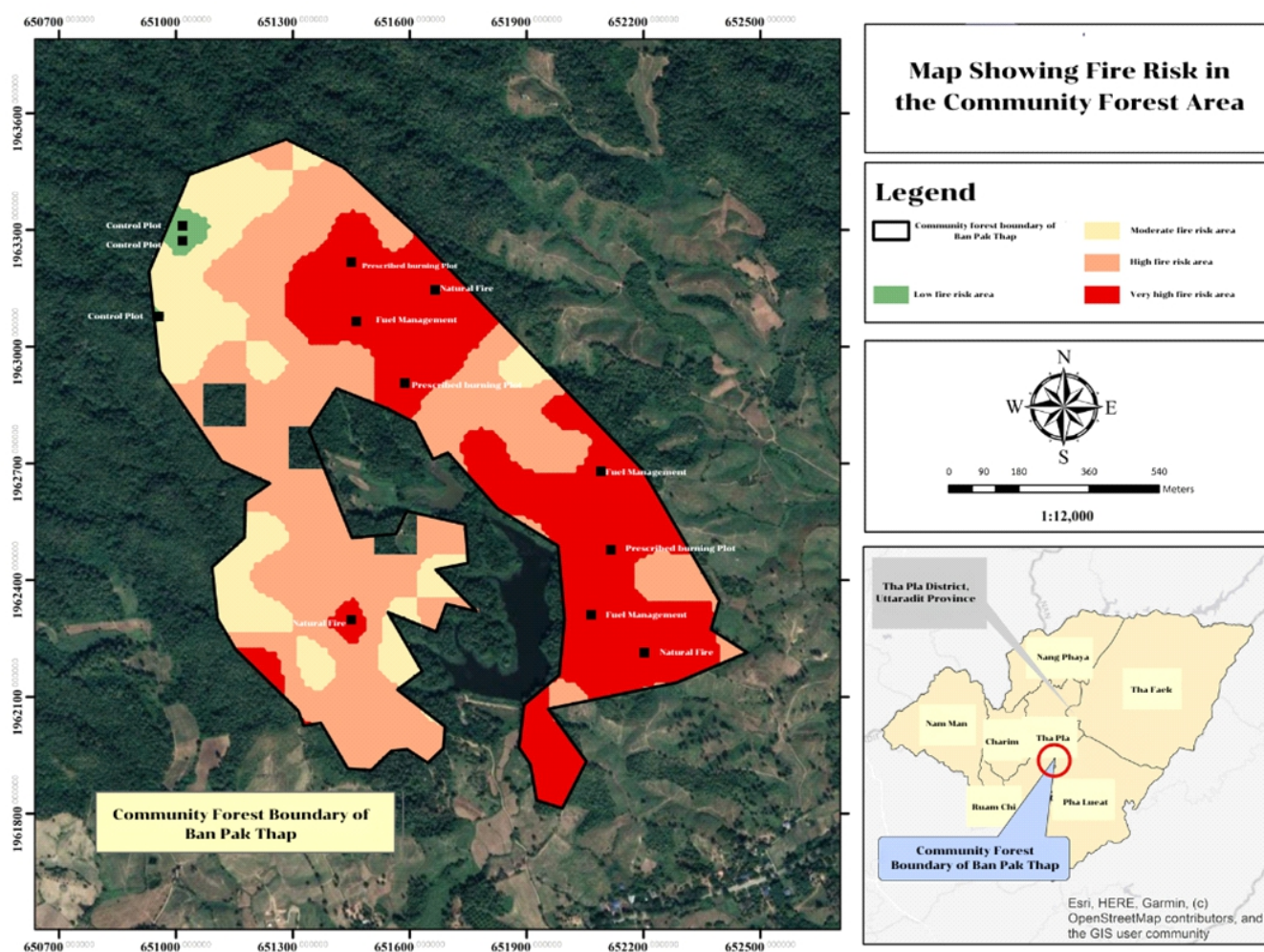


Figure 2 Site class from fire frequency class for study area.

Table 1 Description of study sites and fire classes

Class code	Fire frequency class	Management of forest fire	Number of plots
FC	Control	-	3
FK	Fuel management	Fuel management	3
FB	Prescribed burning	Prescribed burning	3
FF	Natural fire	-	3

correlations that indicate how forest management practices and natural disturbances influence the structure and function of forest ecosystems.

## Results

### Assessing the impact of changes in tree species inventory

**Control plot (FC1FC3)** These plots represent areas that have not undergone any fire intervention. There is a noticeable positive percentage change in both saplings and seedlings, indicating healthy growth under natural conditions. This positive growth is attributed to the absence of disturbances, allowing natural succession and growth processes to occur undisturbed.

**Varying fire frequency categories plot (FB1FB3)** These plots have undergone controlled burns. The graph shows a moderate positive change in both saplings and seedlings, suggesting that prescribed burning can enhance the growth of younger plants by reducing competition and promoting nutrient recycling. This aligns with previous research that highlights the benefits of controlled burns in reducing underbrush competition, releasing nutrients, and creating favorable conditions for younger plant growth (Fernandes & Botelho, 2003).

**Prescribed burning plot (FK1FK3)** These plots involve the removal of combustible materials, such as dry leaves, twigs, and other debris, to reduce fire risk and improve resource

availability. Saplings and seedlings in these plots exhibit a high positive percentage change, indicating that fuel management significantly promotes the growth of younger trees by enhancing access to nutrients and reducing fire hazards (Figure 3).

**Analysis of forest management practices and their impact on tree characteristics**  
*Coverage change* The control plot exhibited a slight positive change (+2.54%), indicating stable growth in undisturbed conditions. The prescribed burning plot also showed a minimal positive change (+0.97%), reflecting the beneficial effects of controlled burns in maintaining vegetation cover. The prescribed burning demonstrated a significant positive change (+11.69%), highlighting the effectiveness of fuel management in enhancing forest cover. In contrast, the natural fire plot experienced a significant negative change (-15.12%), demonstrating the detrimental impact of uncontrolled fires on forest coverage.

*Density change* A similar trend was observed in tree density. The control plot showed a slight positive change (+1.56%), while the prescribed burning plot exhibited a minimal positive change (+0.40%). The prescribed burning plot recorded a slight positive change (+1.57%), indicating increased tree density due to fuel management. However, the natural fire plot experienced a negative change (-9.18%), underscoring the adverse effects of natural fires on tree density.

*Abundance change* Tree abundance showed minimal positive changes in the control plot (+1.17%) and the

prescribed burning plot (+3.50%), indicating that prescribed burns can enhance tree abundance. The prescribed burning plot demonstrated a significant positive change (+12.32%), further supporting the benefits of fuel management in promoting forest regeneration. Conversely, the natural fire plot exhibited a slight positive change (+2.60%), suggesting some resilience in tree abundance despite negative impacts on other metrics.

*Other metrics* When comparing the four experimental plots, the control, prescribed burning, and grab the fuel plots showed no change (0%) in importance change, whereas the natural fire plot slightly decreased (-1.31%); in diversity index change, the control plot remained the same (0%), the prescribed burning plot increased (+1.34%), the grab the fuel plot rose (+2.68%), and the natural fire plot decreased slightly (-1.83%); and with respect to biomass change, the control plot increased (+5.87%), the prescribed burning plot rose slightly (+1.43%), the grab the fuel plot increased (+3.40%), but the natural fire plot declined (-2.06%).

These results provide a comprehensive understanding of how forest management practices influence key forest parameters. Managed plots demonstrate positive changes over time, indicating the benefits of interventions such as prescribed burning and fuel management in promoting forest recovery and resilience (Table 2, Figure 4).

The Pearson's correlation matrix provides insights into the linear relationships between forest parameters. Table 2 summarizes these relationships, highlighting how key forest metrics, such as coverage, density, abundance, and biomass, are interconnected.

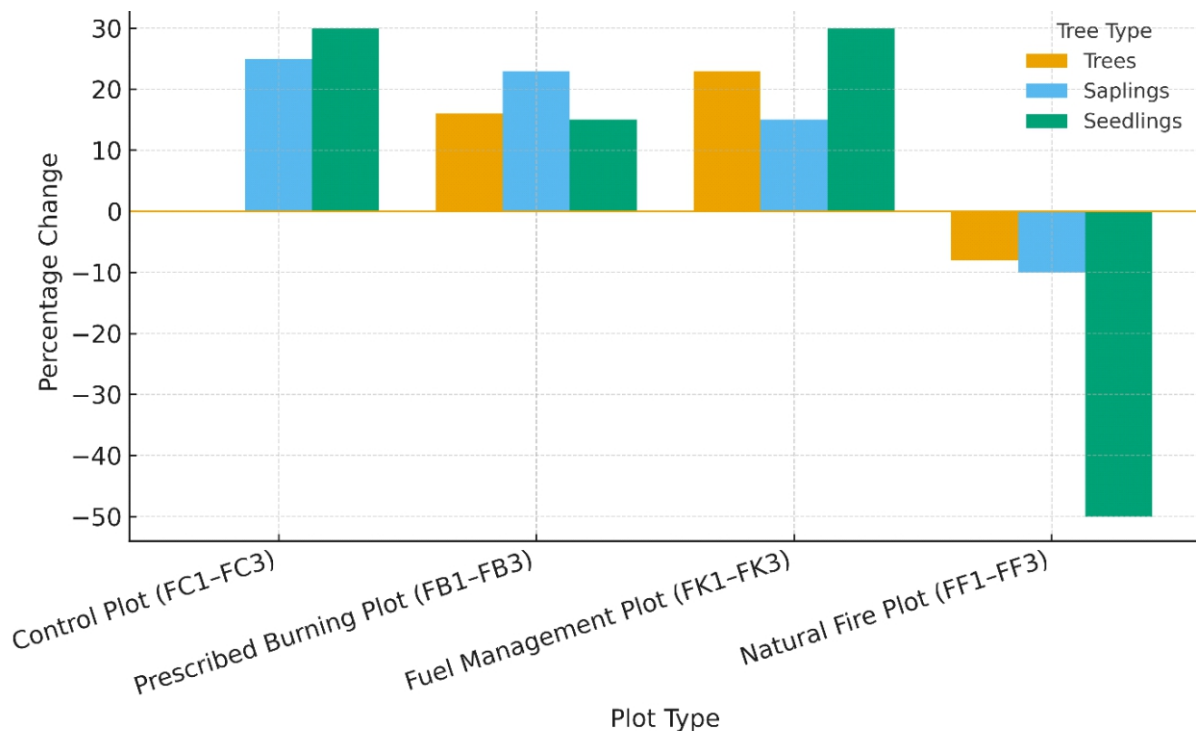


Figure 3 The percentage change in trees is negative, indicating a decline in mature trees due to fire damage.

Table 2 Summary of vegetation metrics across different plot types and time periods

Plot type	Time period	Coverage (%)	Density (trees m <sup>-2</sup> )	Abundance (trees plot <sup>-1</sup> )	Importance (%)	Shannon-Weiner diversity index	Biomass (kg ha <sup>-1</sup> )
Control plot (FC1–FC3)	Time 1	1,180	2.55	170	38.25	1.55	65,483.21
	Time 2	1,210	2.59	172	38.25	1.55	69,331.89
% Change		+2.54	+1.17	0	0	+5.87	+5.87
Prescribed burning plot (FB1–FB3)	Time 1	1,025	2.47	171	34.28	1.48	64,251
	Time 2	1,035	2.48	177	34.28	1.48	65,118
% Change		+0.97	+3.50	0	0	+1.34	+1.34
Prescribed burning plot (FK1–FK3)	Time 1	1,112	2.32	138	36.28	1.57	58,621
	Time 2	1,242	2.34	156	36.28	1.57	60,494
% Change		+11.69	+12.32	0	0	+2.68	+2.68
Natural fire plot (FF1–FF3)	Time 1	1,164	2.07	133	34.23	1.52	54,118
	Time 2	988	1.88	125	35.12	1.50	53,126
% Change		-15.12	-6.02	+2.60	-1.31	-1.83	-1.83

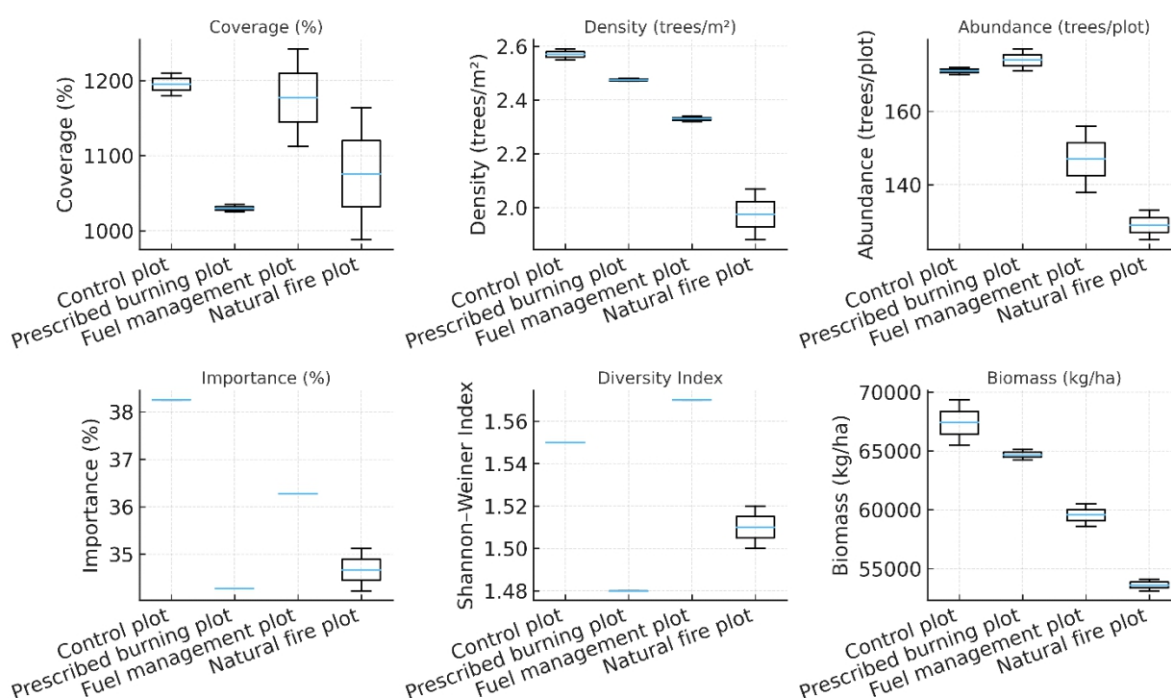


Figure 4 The box plots for each parameter across the different plot types.

**Key findings** Coverage shows a strong positive correlation with density (0.97), abundance (0.88), and biomass (0.97), but it is negatively correlated with importance (-0.69) and the Shannon-Weiner diversity index (-0.67). Density also strongly correlates with coverage (0.97) and biomass (0.94), yet shows negative relationships with importance (-0.60) and the Shannon-Weiner diversity index (-0.63). Abundance is positively associated with coverage (0.88) and biomass

(0.78) but negatively linked to importance (-0.60) and the Shannon-Weiner diversity index (-0.62). In contrast, importance has a strong positive correlation with the Shannon-Weiner diversity index (0.91), while negatively correlating with coverage (-0.69), density (-0.60), abundance (-0.60), and biomass (-0.62). Lastly, the Shannon-Weiner diversity index is negatively associated with coverage (-0.67), density (-0.63), and biomass (-0.65), but shows a

positive relationship with importance (0.91). These correlations indicate that forest management practices influence specific ecological parameters, which are interdependent and play a significant role in forest structure and function (Figure 5).

CCA was performed to explore relationships between ecological community data (plot types) and environmental variables (forest parameters). The CCA plot shows the distribution of plot types along the canonical components, illustrating how forest parameters influence each plot type. Control plot is positioned on the negative side of both CCA components, indicating distinct forest parameter characteristics compared to other plot types. Prescribed burning plot is clustered around the center, suggesting moderate influence by the forest parameters, with conditions somewhat intermediate between natural conditions and other management practices. Prescribed burning plot is positioned towards the positive side of CCA component 1, indicating distinct forest parameter characteristics strongly influenced by fuel management practices. Natural fire plot is positioned towards the positive side of CCA component 2, showing significant impacts of natural fire on the forest parameters (Figure 6).

This analysis reveals the significant impacts of different management practices and natural disturbances on forest parameters over time. Most parameters, such as coverage, density, abundance, and biomass, tend to increase over time

in managed plots, indicating recovery or regrowth. In contrast, the natural fire plot often shows decreases in these parameters, highlighting the significant impact of natural fires.

The stability of importance and diversity indices in managed plots suggests that management practices help maintain ecological balance. The Pearson's correlation analysis reveals strong linear relationships between various forest parameters, highlighting how different forest characteristics influence each other. The CCA plot provides a visual representation of how different plot types are influenced by these forest parameters, showing distinct patterns for each management practice or natural condition. These findings underscore the importance of adaptive forest management strategies that consider the relationships between forest parameters and management practices to promote sustainable forest ecosystems. Effective management strategies should aim to balance resource extraction and conservation to maintain forest health and diversity.

**Regression plots for forest parameters** No significant differences were observed between time 1 and time 2 for most parameters, as indicated by the non-significant *t*-statistic and *p*-value results. This suggests that the measured parameters, such as coverage, density, and abundance, remained consistent over time in these plots. However, the Shannon-Weiner diversity index showed a statistically significant

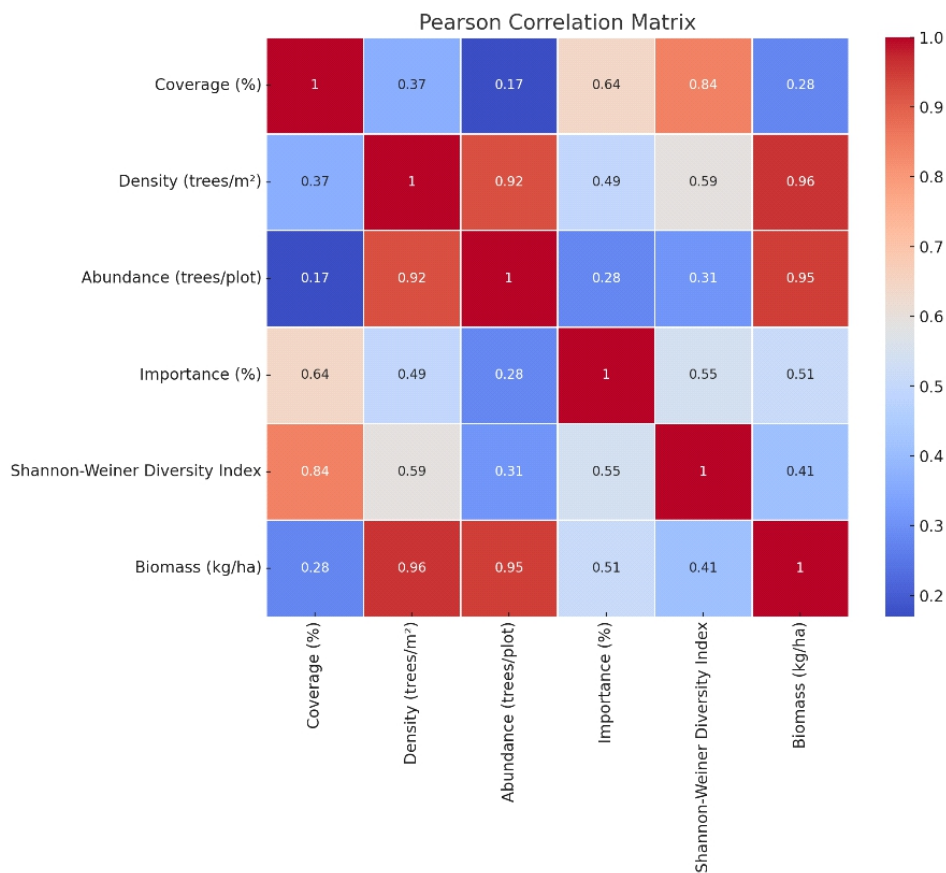


Figure 5 The heatmap above shows the Pearson's correlation matrix for the forest parameters.

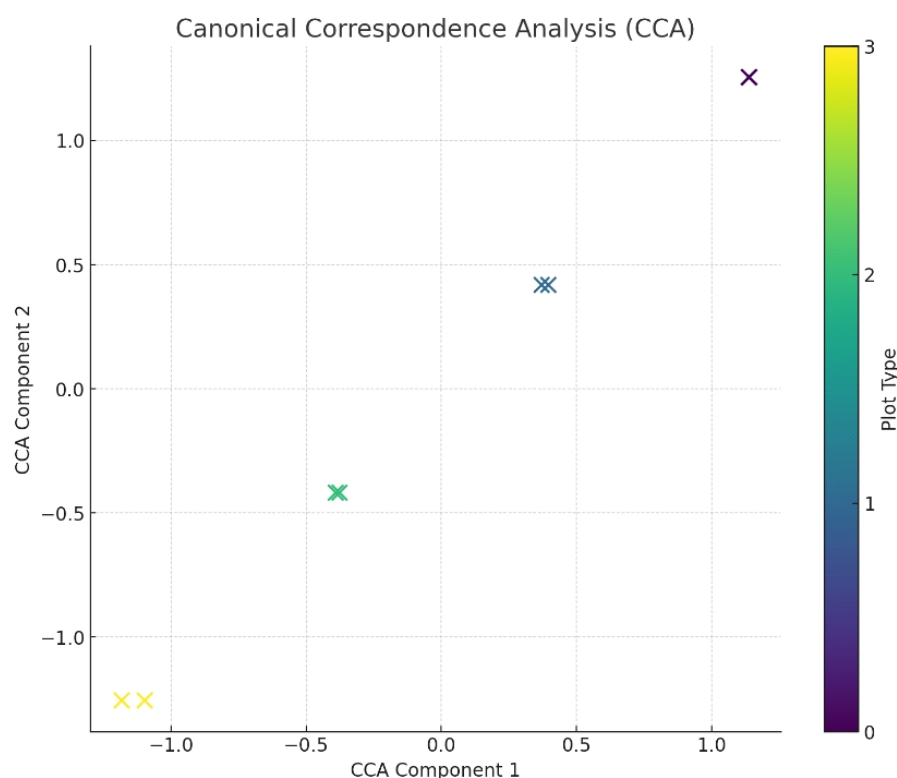


Figure 6 The CCA plot above shows the relationships between the different plot types.

decrease ( $p$ -value  $< 0.05$ ), indicating that natural fires have a measurable negative impact on biodiversity.

Significant variations were noted across the plots for the parameters of density (trees  $m^{-2}$ ), abundance (trees  $plot^{-1}$ ), importance (%), diversity index, and biomass ( $kg\ ha^{-1}$ ) ( $p$ -value  $< 0.05$ ). This suggests that the type of plot (i.e., the fire management strategy applied) significantly influences these forest characteristics. For percentage of coverage, no notable variations were found, indicating that coverage remained relatively uniform regardless of the type of plot or fire management strategy.

**Interpretation of forest type and relationships** While forest type (i.e., the plot type) itself is not a direct numerical value, it serves as a categorical variable that groups data for comparison based on the management strategy applied. Using regression analysis, it is possible to infer how different plot types impact forest parameters. For instance, the differences in density and biomass across the plots reveal the effectiveness of management practices such as prescribed burning and fuel removal in promoting forest recovery.

This analysis provides a detailed understanding of how various management strategies influence forest parameters over time. The results underscore the importance of adaptive practices like prescribed burning and fuel management to enhance forest resilience, while highlighting the potential adverse impacts of natural fires on biodiversity and ecological balance (Figure 7).

**Coverage (%) vs plot type** The regression analysis reveals a slight negative trend in coverage as the intensity of forest management or disturbance increases. This suggests that

more intensive practices, such as prescribed burning or fuel removal, or natural disturbances like wildfires, tend to reduce the percentage of area covered by vegetation. This reduction in coverage could result from factors such as increased tree removal or the clearing of vegetation caused by fires.

**Density (trees  $m^{-2}$ ) vs plot type** A negative trend is observed in tree density across different plot types. As the level of disturbance or management intensity increases, there is a noticeable decrease in the number of trees per square meter. This indicates that intensive forest management practices or natural disturbances are associated with lower tree densities. The reduction in tree density might result from selective logging, thinning practices, or damage caused by natural fires.

**Abundance (trees  $plot^{-1}$ ) vs plot type** The analysis shows a negative trend in tree abundance with increasing disturbance or management intensity. The number of trees per plot decreases as the plot moves from undisturbed (control) to plots with more intensive management practices or natural disturbances. This suggests that higher levels of intervention or disturbance can negatively affect tree abundance.

**Importance (%) vs plot type** There is a negative trend in the importance of tree species as the level of disturbance or management intensity increases. Importance, which reflects the ecological or management significance of tree species, declines under more intensive management practices or natural disturbances. This decrease may result from the removal of key species during harvesting operations or

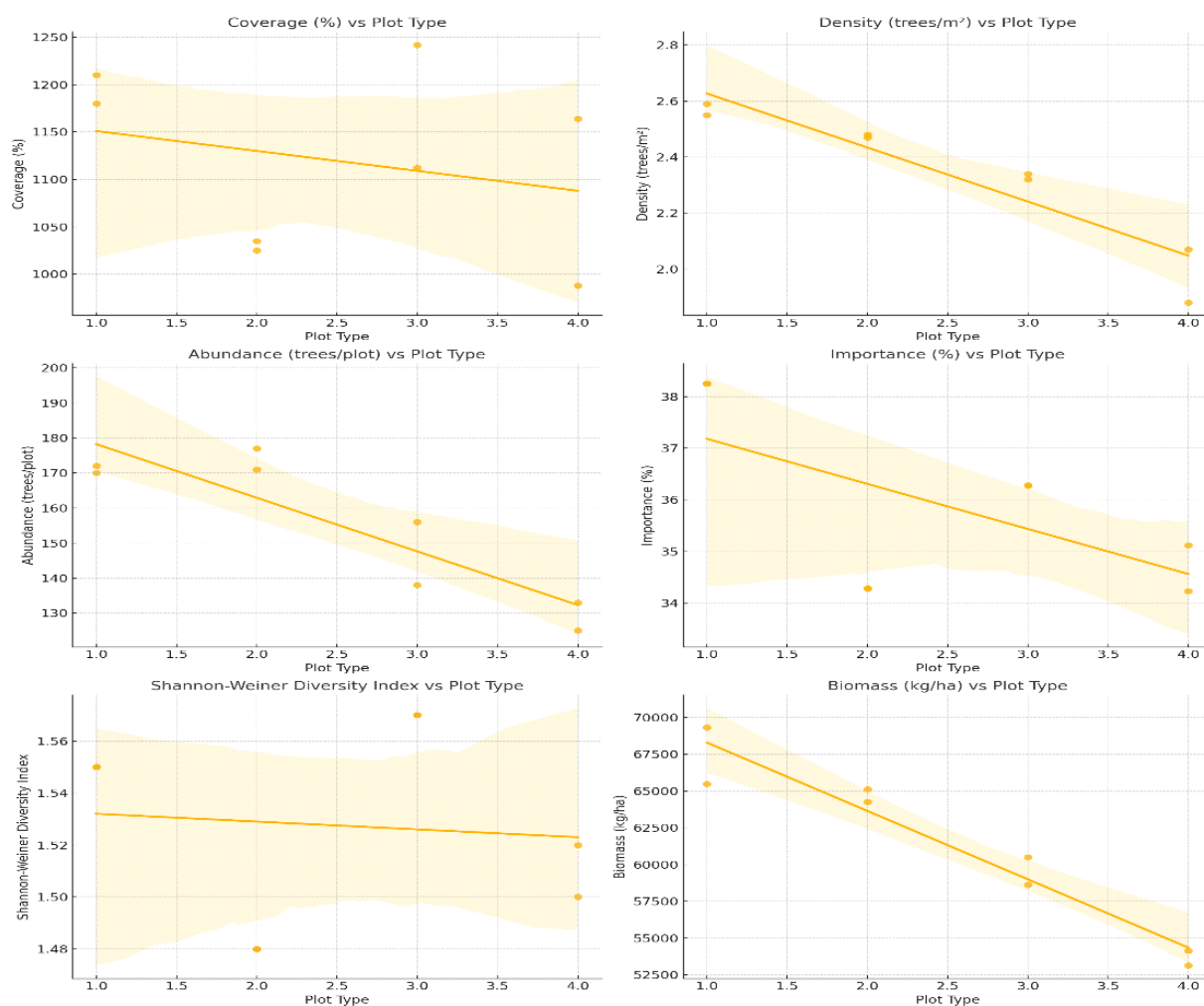


Figure 7 The regression plots above show the relationships between different plot types.

changes in forest composition due to fire, which affects species distribution and dominance.

*Shannon-Weiner diversity index vs plot type* The regression plot indicates a slight negative trend in the Shannon-Weiner diversity index as management intensity or disturbance level increases. This index, which measures species diversity, tends to decline under more intensive management practices or natural disturbances. The reduction in diversity could be attributed to the selective removal of certain species, the impact of fire on less resilient species, or changes in habitat conditions that favor fewer species.

*Biomass (kg ha<sup>-1</sup>) vs plot type* A noticeable negative trend is observed in biomass across different management or disturbance levels. Biomass, which represents the total mass of living trees per hectare, decreases significantly in areas subjected to more intensive management practices or natural disturbances. This decline suggests that factors like increased tree harvesting, reduced tree density, and the effects of fire contribute to lower overall biomass.

The regression analysis of forest parameters across different plot types provides valuable insights into the impacts of forest management practices and natural

disturbances on forest structure and composition. Higher plot type values, representing more intensive management or natural fire conditions, are generally associated with decreases in coverage, density, abundance, importance, diversity, and biomass. These findings highlight the importance of considering the ecological effects of forest management and natural disturbances to ensure sustainable forest ecosystems. Effective management strategies should aim to balance resource extraction and conservation to maintain forest health and diversity.

**Analysis of trend changes over time** This analysis examines the trend changes over time for various forest parameters across different plot types. The parameters analyzed include coverage, density, abundance, importance, the Shannon-Weiner diversity index, and biomass. The data spans two distinct time periods. **Time 1:** Represents the baseline measurements taken before any fire management interventions or natural disturbances occurred; and **Time 2:** Represents measurements taken after the interventions (e.g., prescribed burning, fuel management) or the natural fire events had taken place.

The plot types analyzed include the control plot, prescribed burning plot, prescribed burning plot, and natural

fire plot (Figure 8). By comparing changes between these two time periods, the study evaluates how management practices and natural disturbances influence forest parameters over time.

**Coverage (%) over time** Coverage showed an overall increase from Time 1 to Time 2 across most plot types. In the control plot, coverage increased from 1180% to 1210%, representing a +2.54% change. Similarly, the prescribed burning plot experienced a slight increase from 1025% to 1035%, a +0.97% change. The prescribed burning plot saw a significant rise from 1112% to 1242%, a +11.69% change. However, the natural fire plot exhibited a substantial decrease in coverage, dropping from 1164% to 988%, a -15.12% change. This suggests that while most managed plots demonstrated recovery or growth in vegetation cover, the natural fire plot was significantly affected by natural disturbances, leading to a reduction in coverage.

**Density (trees m<sup>-2</sup>) over time** Density trends also varied across plot types. The control plot's density increased slightly from 2.55 to 2.59 trees m<sup>-2</sup>, a +1.56% change. The prescribed burning plot showed a marginal increase from 2.47 to 2.48 trees m<sup>-2</sup>, a +0.40% change. The prescribed burning plot's density rose from 2.32 to 2.34 trees m<sup>-2</sup>, a +1.57% change. In contrast, the natural fire plot experienced a notable decrease in density, from 2.07 to 1.88 trees m<sup>-2</sup>, a -9.18% change. This indicates that tree density generally improved or remained stable in managed plots, while natural fire disturbances significantly reduced tree density.

**Abundance (trees plot<sup>-1</sup>) over time** Abundance trends

indicated mixed results. In the control plot, tree abundance increased slightly from 170 to 172 trees plot<sup>-1</sup>, a +1.17% change. The prescribed burning plot saw an increase from 171 to 177 trees plot<sup>-1</sup>, a +3.50% change. The prescribed burning plot exhibited a significant rise in tree abundance from 138 to 156 trees plot<sup>-1</sup>, a +12.32% change. Conversely, the natural fire plot showed a decrease from 133 to 125 trees plot<sup>-1</sup>, a -6.02% change. These trends suggest that tree abundance generally improved in managed plots, whereas natural fire disturbances negatively impacted tree numbers.

**Importance (%) over time** The importance of tree species remained relatively stable across most plot types. In the control plot and the prescribed burning plot, there was no change, remaining at 38.25% and 34.28%, respectively. The prescribed burning plot also showed no change, maintaining at 36.28%. However, the natural fire plot experienced a slight increase in importance from 34.23% to 35.12%, a +2.60% change. This stability in importance suggests that management practices help maintain the ecological or management significance of tree species, while natural fire disturbances might alter species composition, slightly increasing the importance of certain species.

**Shannon-Weiner diversity index over time** Diversity trends, as measured by the Shannon-Weiner diversity index, showed stability in most plots but a slight decrease in the natural fire plot. In the control plot, the diversity index remained unchanged at 1.55. The prescribed burning plot also showed no change, remaining at 1.48. The prescribed burning plot maintained its diversity index at 1.57. The natural fire plot, however, saw a slight decrease from 1.52 to 1.50, a -1.31%

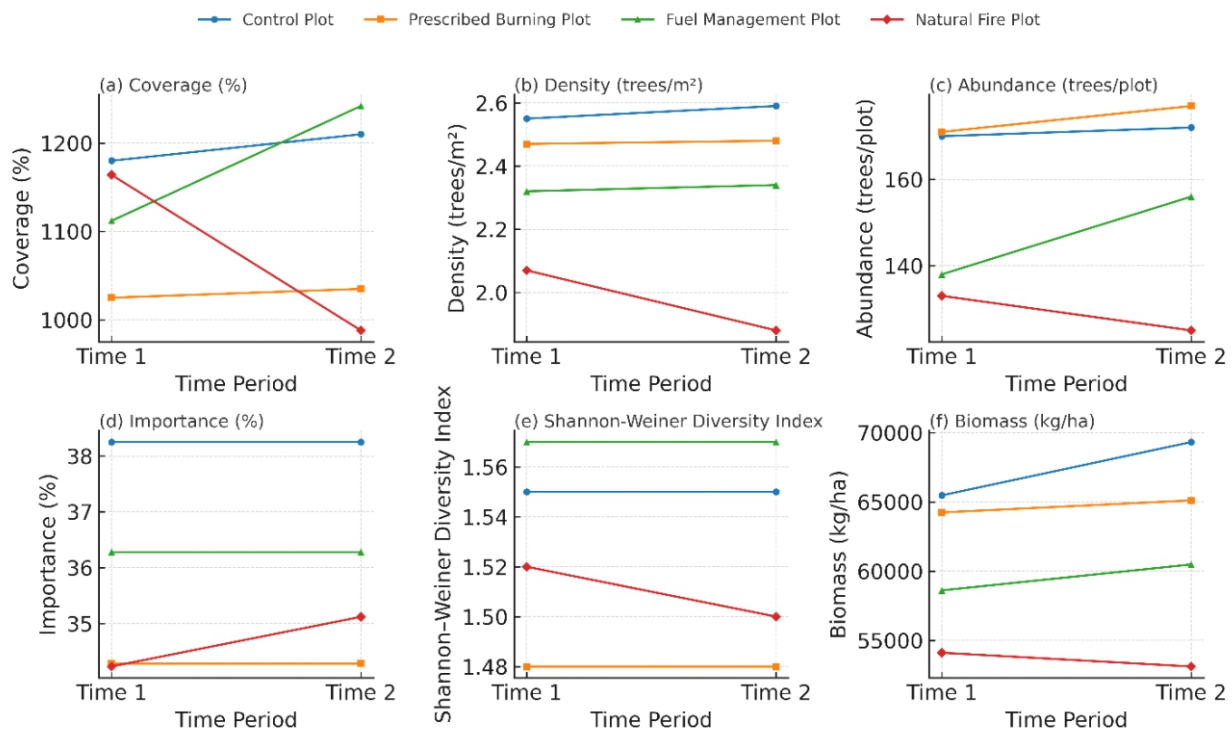


Figure 8 The line plots above illustrate the trend changes over time for various forest parameters across different plot types.

change. This suggests that diversity remained stable under managed conditions but was slightly reduced by natural fire disturbances, potentially due to species loss.

*Biomass (kg ha<sup>-1</sup>) over time* Biomass trends varied, with most plot types showing an increase, except for the natural fire plot. In the control plot, biomass increased from 65,483.21 to 69,331.89 kg ha<sup>-1</sup>, a +5.87% change. The prescribed burning plot saw a slight increase from 64,251 to 65,118 kg ha<sup>-1</sup>, a +1.34% change. The prescribed burning plot's bio-mass rose from 58,621 to 60,494 kg ha<sup>-1</sup>, a +3.18% change. However, the natural fire plot experienced a decrease in biomass from 54,118 to 53,126 kg ha<sup>-1</sup>, a -1.83% change. These trends suggest that biomass generally recovered or grew under managed conditions, while natural fire disturbances led to a reduction in biomass.

The analysis of trend changes over time reveals how different forest parameters respond to various management practices and natural disturbances. Most parameters, such as coverage, density, abundance, and biomass, tend to increase over time in managed plots, indicating recovery or regrowth. In contrast, the natural fire plot often shows decreases in these parameters, highlighting the significant impact of natural fires. The stability of importance and diversity indices in managed plots suggests that management practices help maintain ecological balance. These findings underscore the importance of adaptive forest management strategies that account for both recovery and disturbance impacts to promote sustainable forest ecosystems.

## Discussion

Fuel management plays a critical role in shaping forest ecosystems by balancing the objectives of fire risk reduction and ecological sustainability. Research has consistently demonstrated that reducing forest fuel loads can significantly mitigate the intensity and severity of wildfires while also influencing other ecological processes. For instance, a study by Mitchell et al. (2009) explored the interplay between fuel reduction treatments, fire severity, and carbon storage in the U.S. Pacific Northwest. The findings revealed that while fuel management effectively reduced fire severity, it often resulted in a decrease in overall carbon storage due to the removal of biomass. This trade-off highlights the complexity of fuel management practices and their long-term ecological consequences (Mitchell et al., 2009). Similarly, Santana et al. (2012) investigated the long-term effects of mechanical fuel management on bird communities in Mediterranean cork oak forests. The study revealed that bird species richness and abundance were significantly affected by fuel management, with early-successional species benefiting from the practice while others, such as frugivores and shrub foragers, experienced declines. The researchers emphasized the importance of creating diverse forest mosaics to support a wide range of species with differing ecological needs while reducing fire hazards (Santana et al., 2012). Further, Bouget et al. (2012) provided a comprehensive review of the impacts of fuelwood harvesting on biodiversity in European forests. Their findings indicated that large-scale fuelwood extraction altered habitat conditions by reducing deadwood availability, a critical substrate for saproxylic organisms. The study

emphasized that such practices, if left unchecked, could compromise forest biodiversity, underscoring the need for carefully designed management strategies that maintain ecological balance (Bouget et al., 2012). In terms of ecosystem services, Elliot et al. (2010) synthesized the cumulative watershed effects of fuel treatments in the western United States, identifying significant interactions between fuel reduction practices and watershed health. The study highlighted that while fuel treatments can enhance the resilience of forested landscapes to fire, they must be implemented with consideration for their broader environmental impacts, including soil stability and hydrology (Elliot et al., 2010). Lastly, Ranius et al. (2018) reviewed the effects of logging residue extraction on biodiversity and ecosystem services. Their synthesis revealed that while logging residues can serve as a source of bioenergy, their removal often disrupts ecological functions such as nutrient cycling and habitat provision for species reliant on deadwood. The study advocates for adaptive management strategies that balance biomass extraction with the preservation of ecosystem integrity (Ranius et al., 2018). Together, these studies illustrate the intricate trade-offs involved in fuel management practices. While they are essential for mitigating wildfire risks, their broader ecological implications must be carefully managed to ensure the long-term sustainability of forest ecosystems.

Uncontrolled forest fires have significant and far-reaching impacts on forest ecosystems, disrupting ecological balance and hindering regeneration processes. Studies have shown that such fires lead to a drastic reduction in tree density, plant biomass, and species diversity, fundamentally altering forest structure. For example, Mangle (2022) found that large-scale forest fires can disrupt ecosystem dynamics, leading to long-term consequences for vegetation recovery and biodiversity. Similarly, Tekalign (2016) emphasized the immediate destruction of wildlife habitats and the alteration of forage quality, resulting in shifts in ecosystem functionality.

These fires not only affect the vegetation but also have profound effects on soil properties, as highlighted by Certini (2005). High-severity fires result in the loss of soil organic matter and nutrients, alongside increased erosion and changes in microbial communities, which collectively hinder soil fertility and plant regrowth. In tropical regions, as Syaufina and Nuruddin (2011) pointed out, repeated fires can suppress native species and promote the proliferation of fire-adaptive species, thereby permanently altering successional pathways and ecosystem composition.

Uncontrolled fires not only cause immediate destruction but also set the stage for future vulnerabilities. As Cochrane (2001) explained, fires increase the likelihood of subsequent events by reducing vegetation cover and altering microclimatic conditions, further jeopardizing forest recovery. This cyclical nature of fire damage emphasizes the importance of integrating sustainable fire management practices to mitigate long-term ecological degradation and support the resilience of forest ecosystems.

These studies collectively highlight the multi-dimensional impacts of uncontrolled fires, from ecological disruptions to economic consequences, underscoring the

urgent need for comprehensive management strategies to safeguard forest ecosystems and the services they provide.

Prescribed burning has shown moderate positive impacts on forest regeneration and biodiversity, as evidenced by several studies. Below is a synthesized academic description based on research findings:

Prescribed burning, a controlled use of fire under predefined conditions, plays a pivotal role in forest management by reducing fuel loads, recycling nutrients, and promoting the establishment of fire-adapted plant species. Research highlights its dual benefits: ecological restoration and wildfire risk mitigation. For instance, Eales et al. (2018) conducted a systematic review that demonstrated prescribed burning increases vascular plant richness and diversity in temperate and boreal forests, although its effects vary based on forest type and environmental conditions.

In tropical highland forests, prescribed burning has been found to enhance tree biodiversity and soil carbon storage compared to wildfire sites, supporting ecosystem resilience. López-Cruz et al. (2022) observed that areas exposed to prescribed burns retained higher Shannon diversity indices and healthier soil carbon stocks compared to areas affected by wildfires.

However, the impact of prescribed burns is context-dependent. For example, in mixed-oak forests, Hutchinson et al. (2012) found that while repeated prescribed fires reduced midstory tree density and shifted species composition toward more fire-tolerant species like oaks and hickories, achieving long-term oak regeneration often requires complementary interventions such as canopy thinning.

Despite these advantages, prescribed burning can lead to challenges. Reduced lichen diversity and shifts in microbial communities are among the trade-offs identified in Fennoscandian boreal forests (Hämäläinen et al., 2014). Moreover, high-frequency burns can negatively impact regeneration, particularly in species less adapted to fire, as observed in Mediterranean forests (Hämäläinen et al., 2014).

The long-term efficacy of prescribed burning lies in its integration with broader management strategies. Boer et al. (2009) demonstrated its success in mitigating unplanned fires and enhancing fire resilience in Australian eucalypt forests when combined with targeted fuel management. However, adaptive planning and monitoring are critical to balance its benefits with potential ecological costs.

Prescribed burning, while not without limitations, remains a valuable tool in forest ecosystem management, aiding in biodiversity conservation and resilience building when implemented alongside other ecological interventions.

In conclusion, this study demonstrates that fire management strategies such as fuel removal and prescribed burning play a crucial role in mitigating fire risks, enhancing forest regeneration, and supporting ecosystem health. However, the findings also highlight the ecological trade-offs associated with these practices, particularly in terms of species diversity. Future fire management policies should prioritize strategies that balance resource conservation, biodiversity preservation, and climate resilience to ensure the sustainability of forest ecosystems.

## Conclusion

This study demonstrates that adaptive fire management

strategies, particularly prescribed burning and fuel break creation, significantly influence forest structure, species regeneration, and ecological recovery in tropical community forests. The findings highlight that controlled interventions can promote structural diversity and species resilience, offering a viable approach for balancing forest conservation with local fire-use practices. These insights contribute to the broader understanding of community-based forest fire governance and support the development of ecologically informed fire policies in Southeast Asia.

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