INTERNATIONAL JOURNAL OF ENVIRONMENT
Volume-12, Issue-1, 2023 ISSN 2091-2854
Received: 19 October 2022 *Revised: 26 December 2022* *Accepted: 7 January 2023*

CONTROLLED BURNING AND ITS EFFECTS ON *SHOREA ROBUSTA* (SAL) REGENERATION IN DHANSAR BLOCK FOREST, RAUTAHAT

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Abstract

Fire is used as a management tool to administer a wide range of ecosystems worldwide. Forest fires in *Shorea robusta* (Sal-dominated) forests take the form of ground fires and mostly affect regeneration. We investigated the effect of forest fire on Sal regeneration in 42 sample plots, of which 21 were subjected to controlled burning. The results showed that species richness decreased from fire-unaffected (19) to fire-affected (10). The total density of Sal seedlings in the fire-affected sites was 3829 seedlings ha^{-1}, while in the fire-unaffected sites were 1779 seedlings ha^{-1} representing an increased species dominance of Sal species in the post-fire condition. The total density of Sal saplings in the fire-affected sites was 343 seedlings ha^{-1}, while in the fire-unaffected sites was 571 seedlings ha^{-1}. A significant difference with a large effect size (Cohen's d=0.97) was observed in the seedling regeneration of Sal, while no significant difference was observed in the sapling regeneration of Sal in the post-fire condition. The increment of Sal seedlings may be due to the fire-hardy silvicultural characteristics of *Shorea robusta* and the decline of Sal saplings may be due to stem mortality in the small diameter classes. We conclude that fire is a beneficial tool for seedling regeneration but not for plant establishment. Future research studies regarding the impact of fire intensities, soil moisture, biological disturbances, temperature, light intensity, etc. on regeneration are recommended.

Keywords: Disturbance, Diversity, Dominance, Post-fire, Wildfire

DOI: https://doi.org/10.3126/ije.v12i1.52442

Introduction

Fire is one of the most significant eco-events that can have varied ecological effects (Keane et al., 2002; Whelan, 1995). Forest fire has influenced the Earth's surface for more than 350 million years, and human societies have coexisted with it since its origin (Doerr and Santín, 2016). Forest fire is one of the main contributors to forest degradation around the world (FAO, 2020), and several countries have suffered a significant loss in the primary productivity of forests (Weisse and Goldman, 2020). Forest fires destroy timber and non-timber forest products, reduce biological diversity, and degrade soil, inducing soil erosion, and risks of floods and landslides (Parajuli et al., 2015). Fire is ubiquitous as it may play an important role in the management of landscapes (Verma et al., 2017).

Natural regeneration is an indicator of forest ecosystem health (Tyagi et al., 2011). A healthy regeneration of species maintains species diversity and density in any ecosystem (Bargali et al., 2022). Plant communities are strongly affected by forest fires (Danthu et al., 2003), which influence regeneration potential and plant mortality (De Luis et al., 2005). Fire plays an important role in the removal of competition from surviving species. In addition to suppressing certain species, forest fires also encourage other species, leading to changes in vegetation structure (Walters et al., 2004). Fire-tolerant plant species generally increased in abundance at the expense of those killed by fire (fire-sensitive plants) due to a considerable reduction in competition and possibly due to alternations in other conditions (Gallagher et al., 2022). Regeneration of post-fire trees depends on a variety of factors, from climate suitability to the characteristics of the microsite (Wooten et al., 2022). A successful reestablishment post-fire may be influenced by seed source, climate, competition or facilitation, and micro-climates (Stevens-Rumann and Morgan, 2019).

There are regular occurrences of forest fires during the long and intense dry season, which have serious impacts both on ecosystem degradation, and the deterioration of vulnerable social and economic conditions, especially in fragile Himalayan ecosystems in Nepal (Wang et al., 2021). However, no systematic collection of fire impacts on wildlife, medicinal plants, health, weather and climate from brown clouds have been studied in Nepal. This scenario is also similar in South Asia as a whole (Lelieveld et al., 2019). Regeneration, dominance, and diversity of woody species are connected to the overall disturbance regime, including intensity, frequency, and scale (Zhu et al., 2007). A forest fire reduces the floral production, alters regeneration rates, and threatens endemic and endangered species (Bargali et al., 2022). A forest fire has a significant impact on species composition, structure, and diversity in tropical forests (Kittur et al., 2014). It is crucial to understand how vegetation responds to fire to gain insight into changes in fuel availability, landscape flammability, and wildlife habitat (Belcher, 2013). The environmental impacts of fire have drawn the interest of researchers in recent years (Martin et al., 2002). Considering the changing fire regime, forests are expected to take a longer time to recover, affecting on regeneration and species composition (Verma et al., 2017).

Commonly, forest fires occur every year in Nepal, particularly in the forests of the Terai and Churia hills. Community forests and leasehold forests are less affected as compared to protected forests and government-managed forests in Nepal (Acharya, 2008). An average of 200,000 hectares of forests are burned during the fire season from November to May in Nepal (Bajracharya, 2002; NDRRMA, 2022). Nepal witnessed severe wildfire incidents from September 2019 to September 2020 (Figure 1). The forest fire occurrences are increasing as a consequence of regional warming and extended dry spells (Sharma and Goldammer, 2011), growing aridity, and hydrological changes (NCVST, 2009), nevertheless, the national capability to deal with these wildfires is insufficient in Nepal.

Shorea robusta-dominated natural deciduous broadleaved forests are the major forests of the Terai region of Nepal (Sharma, 1996a; Sapkota et al., 2009). It can yield a large number of seedlings in a good seed year, but only a minority of them survive and establish (Chapagain et al., 2021). The effects of fire on vegetation, soil properties, and biomass have been studied across the globe over the last few decades (Verma and Jayakumar, 2012). The impact of disturbance regimes on *S. robusta* regeneration has been researched (Belbase et al., 2020; Gautam et al., 2016; Gautam and Mandal, 2018; Bhuyan et al., 2003). Limited research has focused on the factors affecting tropical forests and no studies have focused on the post-fire regeneration of *S. robusta* in Nepal. Hence, this study aimed to understand the post-fire effects on the regeneration density of *S. robusta* compared to the recorded other plant species in the Dhansar block forest representing the Terai region of Nepal as a case study. Investigating the post-fire changes in the Sal regeneration helps in the forest management planning in the tropical Sal forests in Nepal.

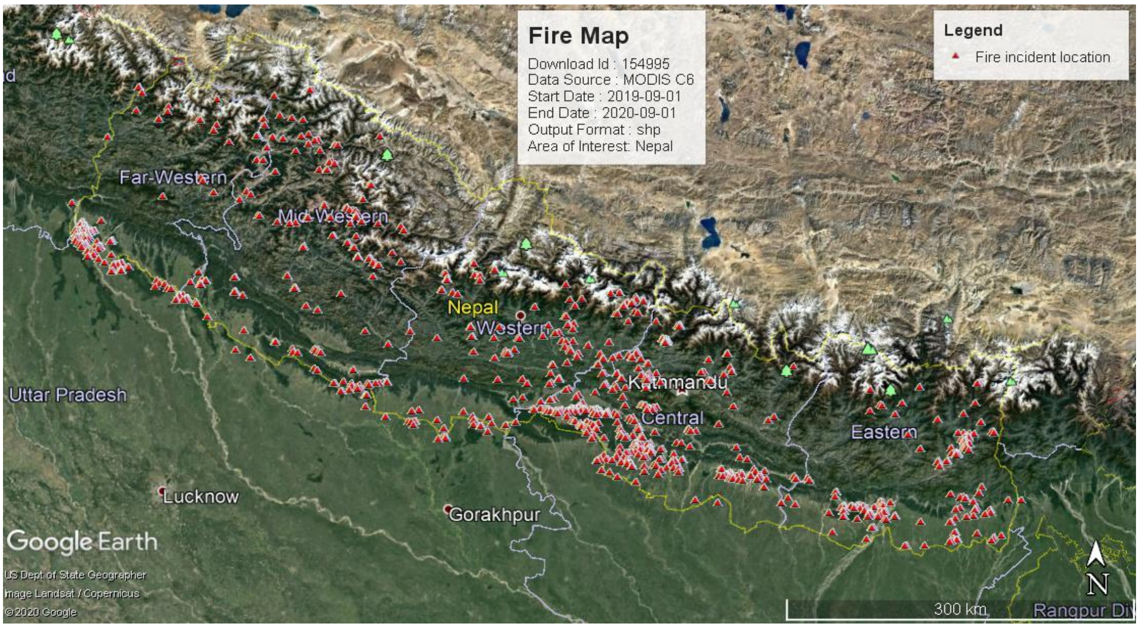

Figure 1: MODISC6 Image of Nepal from 2019 September to 2020 September.

Material and methods

Study area

The research site was Dhansar block forest, Rautahat district, Nepal, which is situated in the north-west part of Rautahat district, Nepal (latitude: 27008’59’’ to 27012’05’’ N, longitude: 85014’28’’ to 85016’30’’ E, and elevation: 155 m to 180 m MSL). The whole forest area is 1050 ha (excluding the river bank of the Dhansar river), which is divided into three compartments and 24 sub-compartments. An irregular shelterwood system was applied, which is an intensive silvicultural system for the management of forests for production purposes. *Shorea robusta*, *Terminalia alata*, *Adina cordifolia*, etc., are the main floral species, and *Asparagus racemosus*, *Terminalia chebula*, *Terminalia bellirica*, etc. are the main NTFPs of the forest. Poaching is the main cause of the wildfires that spread through this block forest. Fire line construction, leaf litter collection, and burning before the fire season are the main activities to control the fire listed in the management scheme in the Dhansar block forest. The Dhansar block forest of Rautahat district was selected with due consideration that the forest is frequently affected due to high human disturbances owing to the disturbed forest.

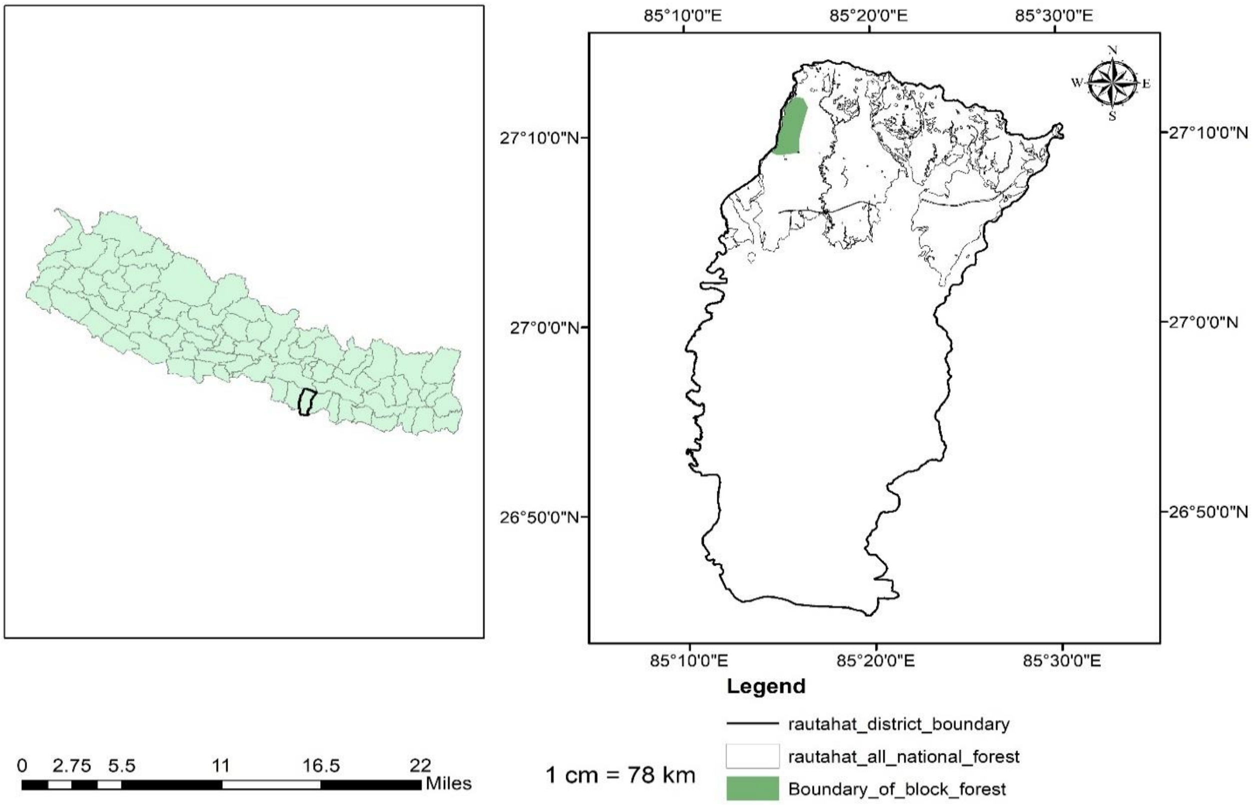

Figure 2: Study area map of the Dhansar block forest.

Data collection

Experimental design

This study was conducted in 2020 within 3 months (April-August) research duration in the Dhansar block forest. The controlled burning (low-intensity fire) was set in 3 ha of the forest during April. The measurements were taken after 3 months in August. The total sampling area of the whole forest was 6 ha and divided into two strata i.e. fire affected and unaffected. A total of 42 sampling plots (21 for fire affected and 21 for unaffected areas) were assessed. Stratified random sampling was used to lay out the sample plots in each stratum. For seedlings, 1*1 m subplots were laid on one corner of the 5*5 m plot, whereas saplings were measured in the 5*5 m plot size. The number of regeneration (seedlings and saplings) of all the recorded species during sampling was considered. The seedlings were considered as heights between 30 cm to 100 cm. The saplings were considered a height of more than 100 cm and DBH up to 9.9 cm (Government of Nepal/MFSC, 2004).

Data analysis

The analyses were made on the basis of *Shorea robusta* and other species found in the field survey (Table 1). Species other than *S. robusta* were considered other species. Regeneration density (No/ha) under fire-affected and fire-unaffected sites was calculated, analyzed, and investigated for making statistical inferences using IBM SPSS Statistics 23. A two-tailed t-test with a 5 % level of significance (p) was used to test the significant difference between two independent sample means (fire affected and fire unaffected) of variation in regeneration (seedling and sapling). The null hypothesis for the study was that i) there is no significant variation in post-fire conditions due to fire on the regeneration of *S. robusta* and other species, whereas the alternate hypothesis was that there is a significant variation in post-fire conditions due to fire on regeneration.

Results

Effect of controlled burning on regeneration

The pattern of forest fires on species regeneration and diversity revealed a decrease in species richness in the fire-affected sites (10) than in the fire-unaffected sites (19) (Table 1).

Table 1: Regeneration of species during fire affected and fire unaffected condition

Species	Fire affected	Fire unaffected
Shorea robusta Gaertn.	+	+
Lagerstroemia parviflora Roxb.	+	+
Albizia chinensis (Osbeck) Merr.	+	+
Terminalia bellirica (Gaertn.) Roxb.	+	+
Toona ciliata M. Roem.	-	+
Terminalia chebula Retz.	+	+
Bixa orellana L.	+	+
Lagerstroemia indica L.	+	+
Cleistocalyx operculatus (Roxb.) Merr. & L.M. Perry	+	+
Hydrangea aspera D. Don	+	+
Holarrhena pubescens Wall. ex G. Don	+	+
Carthamus tinctorius L.	-	+
Murraya koenigii (L.) Spreng.	-	+
Bridelia retusa (L.) A. Juss.	-	+
Dysoxylum gobara (Buch.-Ham.) Merr.	-	+
Cassia fistula L.	-	+
Cornus oblonga Wall.	-	+
Sapium insigne (Royle) Benth. & Hook. f.	-	+
Schima wallichii (DC.) Korth.	-	+

+ indicates the presence of the species whereas – indicates the absence of the species

The density of seedlings (number/ha) of the *Shorea robusta* was higher in the fire-affected site (3829) than in the fire-unaffected site (1771). Similarly, other species' seedlings' density was higher in the unaffected site (2514) than in the fire-affected site (2000) (Figure 3).

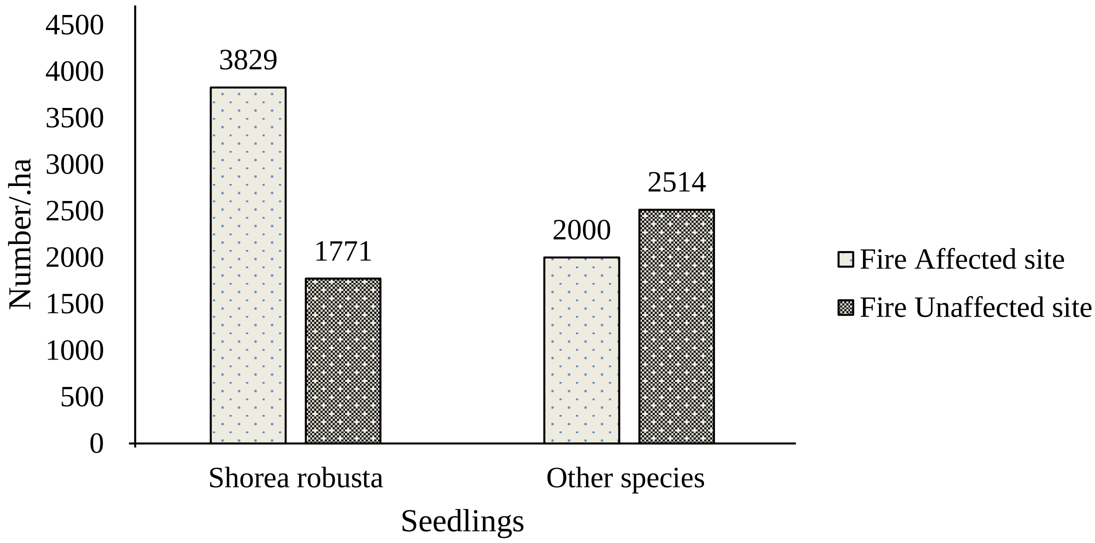

Figure 3: Seedling density under fire-affected and fire-unaffected sites

The density of saplings (number/ha) of the *S. robusta* were higher in the fire-unaffected site (571) than in the fire-affected sites. Similarly, saplings of other species were also higher in the fire-unaffected site (629) than in the fire-affected site (229) (Figure 4).

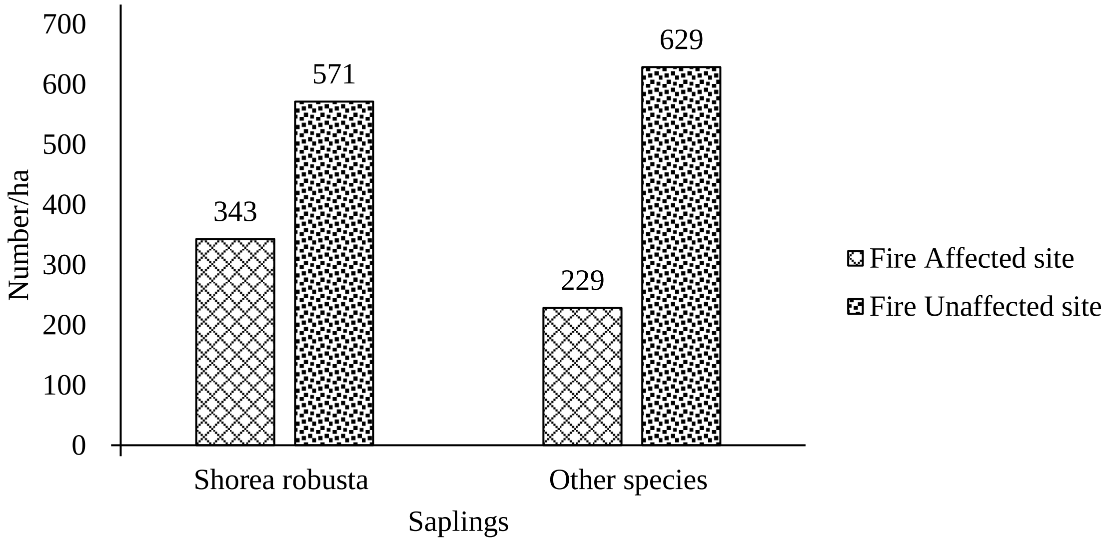

Figure 4: Sapling density under fire-affected and fire-unaffected sites

The results revealed a significant mean difference in *S. robusta* seedlings with t=3.166, p=0.003. Findings showed that fire-affected sites were found 2.16 times higher on *S. robusta* seedlings (M=9.57, SD=5.60) compared to the fire-unaffected sites (M=4.43, SD=4.89). The value of Cohen's d was 0.97 (> 0.8) which indicates a large effect size (Table 2).

Table 2: Mean comparison of fire-affected and fire-unaffected sites in *S. robusta* seedlings

	Fire affected		Fire unaffected				
Variables	*M*	*SD*	*M*	*SD*	t	p	Cohen's d
S. robusta seedlings	9.57	5.60	4.43	4.89	3.166	0.003	0.97

The results revealed a non-significant mean difference in the other species' seedlings with t= -1.416, p=0.165. Findings showed that fire-unaffected sites were found higher in the rest species' seedlings (M=6.29, SD=2.77) compared to the fire-affected sites (M=5, SD=3.098). The value of Cohen's d was 0.43 (<0.5) which indicates a small effect size (Table 3).

Table 3: Mean comparison of fire-affected and fire-unaffected sites in other species seedlings

	Fire affected		Fire unaffected				
Variables	*M*	*SD*	*M*	*SD*	t	p	Cohen's d
Other species seedlings	5	3.098	6.29	2.77	-1.416	0.165	0.43

The results revealed a non-significant mean difference in the *S. robusta* saplings with t= -0.710, p=0.482. Findings showed that fire-unaffected sites were found higher in the *S. robusta* saplings (M=1.43, SD=3.58) compared to the fire-affected sites (M=0.86, SD=0.85). The value of Cohen's d was 0.21 (<0.5) which indicates a small effect size (Table 4).

Table 4: Mean comparison of fire-affected and fire-unaffected sites in *S. robusta* saplings

	Fire affected		Fire unaffected				
Variables	*M*	*SD*	*M*	*SD*	t	p	Cohen's d
S. robusta saplings	0.86	0.85	1.43	3.58	-0.710	0.482	0.21

The results revealed a non-significant mean difference in the saplings of other species with t= -1.42, p=0.163. Findings showed that fire-unaffected sites were found higher in the rest species saplings (M=1.57, SD=3.18) compared to the fire-affected sites (M=0.57, SD=0.50). The value of Cohen's d was 0.43 (<0.5) which indicates a small effect size (Table 5).

Table 5: Mean comparison of fire-affected and fire-unaffected sites in other species saplings

	Fire affected		Fire unaffected				
Variables	*M*	*SD*	*M*	*SD*	t	p	Cohen's d
Other species saplings	0.57	0.50	1.57	3.18	-1.42	0.163	0.43

Discussion

Tropical forests used to experience very few fires, leaving plenty of time for regeneration (Slik et al., 2008). Nevertheless, tropical forest fires have increased in frequency and on a larger scale in the last few decades than in the past (Dickson et al., 2006; Stephens et al., 2015). The extent of the damage depends upon the frequency and intensity of fires, forest types, the availability of fuel, and local climatic factors.

Results showed that species richness decreased and species dominance of certain fire-resistant species i.e. density of *Shorea robusta* species increased in the post-fire condition which aligns with the study (Bargali et al., 2022; Kittur et al., 2014; Verma et al., 2017). The increased species density of *S. robusta* may be due to fire-resistant characteristics (Gautam and Devoe, 2006). The decrease in species richness in post-fire conditions may be due to the proliferation of root sprouts (Saha and Howe, 2003). Gautam et al. (2016) found a negative relationship between disturbance and regeneration (both seedlings and saplings), while Sapkota et al. (2009) concluded that moderate disturbances promote regeneration.

The seedling density of *Shorea robusta* was found significantly higher in the fire-affected sites which are supported by the previous research of Gould et al. (2002) and Mondal and Sukumar (2015). Forest fires in *S. robusta* forests take the form of ground fires and mostly affect the regeneration and the ground flora which normally recovers during the monsoons (Kovacic, 1998). *S. robusta* was a successful survivor after the fire and became an important component of the post-fire community in Uttaranchal, India (Chandra et al., 2015). The enhanced number of seedlings of *S. robusta* could be caused by increased nutrient availability, reduced pathogen population, and breaking of seed dormancy (Verma et al., 2017). Nevertheless, the seedling density of other species was found lower in the fire-affected sites which is consistent with the findings of (Kittur et al., 2014).

Specifically, in burned areas, seedling establishment and survival may differ from unburned areas (Petrie et al., 2016). Thus, regeneration patterns during the first few years after fire likely affect the trajectory of the ecosystem (Turner et al., 2016). However, the interaction of various potential influencing factors is complex, and climate variables may not adequately explain the germination and survival processes in post-fire environments (Stevens-Rumann and Morgan, 2019).

Fire occurred through natural or manmade factors that reduce vegetation growth and change forest structure (Spanos et al., 2010). Our study found increased Sal seedlings but reduced saplings in the low-intensity controlled burning. However, similar to our results, Keyser et al. (2008) found sites with high burn severity had lower regeneration than those with low to moderate burn severity. In contrast, the highest tree regeneration densities were found in high-severity burn plots by Coop et al. (2010) and Shive et al. (2013). Many have also found that tree regeneration varies with distance from the seed source, but not with burn severity (Coop and Schoettle, 2009).

Forest fire management is an important aspect of sustainable forest management ensuring the health of forest ecosystems, where negative impacts of fire are minimized and positive impacts are maximized. These research findings help to address the issue of the post-fire effect on Sal regeneration for the effective forest management of Sal-dominated forests in the Terai region of Nepal. The research duration was short for the in-depth study so effective factors for variation such as rainfall quantity, soil moisture, biological disturbance, intensity, temperature, canopy, etc., in regeneration pattern are further recommended for future study.

Conclusions

This study examined the post-fire effects of controlled burning in regeneration density. The reduction of species richness and species dominance of *Shorea robusta* in the post-fire conditions induces favorable conditions for regeneration, thereby reducing the survival competition. A significant difference with a large effect size due to post-fire conditions in the seedling regeneration of *S. robusta* indicates fire as a positive catalyst tool for seedling regeneration and seedling production of *S. robusta*. The variation of the sapling regeneration of *S. robusta* and other species was found to be lower in the fire-affected areas, i.e., fire is a beneficial tool for regeneration but not for plant establishment. Hence, fire is not recommended for the sapling establishment period or after the seedling regeneration. This study provides baseline data for the regeneration management of *S. robusta* in the Terai region of Nepal. This study has the limitation of short duration effect, hence, future studies might focus on the long-term studies considering different fire intensities effects on regeneration.

Authorship contribution statement

Conceptualization, B.P.D., and V.T.C.; Methodology, B.B.; S.S.; B.P.D, and V.T.C.; Validation, B.B.; S.S.; B.P.D, and V.T.C.; Formal analysis, B.P.D., and V.T.C.; Data collection, B.P.D.; Writing—original draft, B.P.D.; Writing—review and editing, B.B.; S.S.; B.P.D, and V.T.C. We agree that the published version of the manuscript is accurate and complete.

Conflict of interest statement

No conflict of interest is declared by the authors.

Acknowledgments

We would like to thank Division Forest Office, Rautahat for granting us permission to conduct this study. We would like to acknowledge Mr. Jeetendra Gautam for his supervision. We are thankful to Mr. Gandiv Kafle, Mr. Shiva Kumar Wagle, Mr. Ashok Parajuli and Mr. Kamal Acharya for providing technical guidance to conduct this research. The first author thanks the REDD Implementation Centre, Babarmahal, Kathmandu for providing the financial support for the master level research.

References

Acharya, K. P., 2008. Forest Fire Management Plan. Makawanpur District Forest Office

Amatya, S. M., Shrestha, K. R., Cedamon, E., 2016. Nepal Forestry Handbook. Nepal Foresters Association.

Bajracharya, K.M., 2002. Forest Fire Situation in Nepal. (IFFN No. 26 – January 2002, p. 84-86): https://gfmc.online/iffn/country/np/np_2.html

Bargali, H., Calderon, L. P. P., Sundriyal, R. C. & Bhatt, D., 2022. Impact of forest fire frequency on floristic diversity in the forests of Uttarakhand, western Himalaya. *Trees, Forests and People*, *9*(March), 100300. https://doi.org/10.1016/j.tfp.2022.100300

Belbase, K., Poudel, A. S. & Chhetri, S. G., 2020. Comparison of Forest Stand Condition Between Thinned and Unthinned Blocks Under Collaborative Forest Management of Western Lowlands of Nepal. *Research Square*, 1–14.

Belcher, C. M., 2013. Understanding fire regimes and the ecological effects of fire. *Fire Phenomena and the Earth System: An Interdisciplinary Guide to Fire Science*, 97–124.

Bhuyan, P., Khan, M. L. & Tripathi, R. S., 2003. Tree diversity and population structure in undisturbed and human-impacted stands of tropical wet evergreen forest in. *Biodiversity and Conservation*, *12*, 1753–1773.

Chandra, K., Bhardwaj, A. K., Chandra, K. K. & Kumar Bhardwaj, A., 2015. Incidence of forest fire in India and its effect on terrestrial ecosystem dynamics, nutrient and microbial status of soil. *Researchgate.Net*, *5*(2), 69–78. https://doi.org/10.5923/j.ijaf.20150502.01

Chapagain, U., Chapagain, B. P., Nepal, S. & Manthey, M., 2021. Impact of Disturbances on Species Diversity and Regeneration of Nepalese Sal (Shorea robusta) Forests Managed under Different Management Regimes. *Earth*, *2*(4), 826–844. https://doi.org/10.3390/earth2040049

Coop, J. D. & Schoettle, A. W., 2009. Regeneration of Rocky Mountain bristlecone pine (Pinus aristata) and limber pine (Pinus flexilis) three decades after stand-replacing fires. *Forest Ecology and Management*, 257(3), 893-903.

Coop, J. D., Massatti, R. T. & Schoettle, A. W., 2010. Subalpine vegetation pattern three decades after stand-replacing fire: effects of landscape context and topography on plant community composition, tree regeneration, and diversity. *Journal of Vegetation Science*, 21(3), 472-487.

Dickson, B. G., Prather, J. W., Xu, Y., Hampton, H. M., Aumack, E. N. & Sisk, T. D., 2006. Mapping the probability of large fire occurrence in northern Arizona, USA. *Landscape Ecology*, *21*(5), 747–761. https://doi.org/10.1007/s10980-005-5475-x

Doerr, S. H. & Santín, C., 2016. Global trends in wildfire and its impacts: Perceptions versus realities in a changing world. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *371*(1696). https://doi.org/10.1098/rstb.2015.0345

Gallagher, M. R., Kreye, J. K., Machtinger, E. T., Everland, A., Schmidt, N. & Skowronski, N. S., 2022. Can restoration of fire- dependent ecosystems reduce ticks and tick- borne disease prevalence in the eastern United States?. Ecological Applications, 32(7), e2637.

Gautam, K. H. & Devoe, N. N., 2006. Ecological and anthropogenic niches of sal (Shorea robusta Gaertn. f.) forest and prospects for multiple-product forest management - A review. *Forestry*, *79*(1 SPEC. ISS.), 81–101. https://doi.org/10.1093/forestry/cpi063

Gautam, M. K., Manhas, R. K. & Tripathi, A. K., 2016. Patterns of diversity and regeneration in unmanaged moist deciduous forests in response to disturbance in Shiwalik Himalayas, India. *Journal of Asia-Pacific Biodiversity*, *9*(2), 144–151. https://doi.org/10.1016/j.japb.2016.01.004

Gautam, T. P. & Mandal, T. N., 2018. Effect of disturbance on plant species diversity in moist tropical forest of eastern Nepal. *Our Nature*, *16*(1), 1–7. https://doi.org/10.3126/on.v16i1.21558

Gould, K. A., Fredericksen, T. S., Morales, F., Kennard, D., Putz, F. E., Mostacedo, B. & Toledo, M., 2002. Post-fire tree regeneration in lowland Bolivia: Implications for fire management. *Forest Ecology and Management*, *165*(1–3), 225–234. https://doi.org/10.1016/S0378-1127(01)00620-X

Government of Nepal/MFSC., 2004. CF Inventory Guideline 2004. Ministry of Forest and Soil Conservation, Kathmandu, Nepal.

Keyser, T. L., Lentile, L. B., Smith, F. W. & Shepperd, W. D., 2008. Changes in forest structure after a large, mixed-severity wildfire in ponderosa pine forests of the Black Hills, South Dakota, USA. *Forest Science*, 54(3), 328-338.

Kittur, B., Jhariya, M. K. & Lal, C., 2014. Is the forest fire can affect the regeneration and species diversity. *Ecology, Environment and Conservation*, *20*(3), 989–994.

Lelieveld, J., Klingmüller, K., Pozzer, A., Burnett, R. T., Haines, A. & Ramanathan, V., 2019. Effects of fossil fuel and total anthropogenic emission removal on public health and climate. *Proceedings of the National Academy of Sciences of the United States of America*, *116*(15), 7192–7197. https://doi.org/10.1073/pnas.1819989116

Martin, D., Tomida, M. & Meacham, B., 2002. Environmental impact of FMD. *Veterinary Record*, *150*(11), 327. https://doi.org/10.1186/s40038-016-0014-1

Mondal, N. & Sukumar, R., 2015. Regeneration of juvenile woody plants after fire in a seasonally dry tropical Forest of Southern India. *Biotropica*, *47*(3), 330–338. https://doi.org/10.1111/btp.12219

Parajuli, A., Chand, D. B., Rayamajhi, B. K. & Khanal, R., 2015. Spatial and temporal distribution of forest fires in Nepal Invasion of alien plant species and their impact on different ecosystems of Panchase Area, Nepal View project. *XIV WORLD FORESTRY CONGRESS, September*, 7–11.

Petrie, M. D., Wildeman, A. M., Bradford, J. B., Hubbard, R. M. & Lauenroth, W. K., 2016. A review of precipitation and temperature control on seedling emergence and establishment for ponderosa and lodgepole pine forest regeneration. *Forest Ecology and Management*, *361*, 328–338. https://doi.org/10.1016/j.foreco.2015.11.028

Saha, S. & Howe, H. F., 2003. Species composition and fire in a dry deciduous forest. *Ecology*, *84*(12), 3118–3123. https://doi.org/10.1890/02-3051

Sapkota, I. P., Tigabu, M. & Odén, P. C., 2009. Spatial distribution, advanced regeneration and stand structure of Nepalese Sal (Shorea robusta) forests subject to disturbances of different intensities. *Forest Ecology and Management*, *257*(9), 1966–1975. https://doi.org/10.1016/j.foreco.2009.02.008

Shive, K. L., Sieg, C. H. & Fulé, P. Z., 2013. Pre-wildfire management treatments interact with fire severity to have lasting effects on post-wildfire vegetation response. *Forest Ecology and Management*, 297, 75-83.

Slik, J. W. F., Bernard, C. S., Van Beek, M., Breman, F. C. & Eichhorn, K. A. O., 2008. Tree diversity, composition, forest structure and aboveground biomass dynamics after single and repeated fire in a Bornean rain forest. *Oecologia*, *158*(3), 579–588. https://doi.org/10.1007/s00442-008-1163-2

Spanos, I., Ganatsas, P. & Tsakaldimi, M., 2010. Evaluation of postfire restoration in suburban forest of Thessaloniki, Northern Greece. *Global Nest J*, 12, 390-400.

Stephens, S. L., North, M. P. & Collins, B. M., 2015. *Large Wildfires in Forests: What Can be Done?*

Stevens-Rumann, C. S. & Morgan, P., 2019. Tree regeneration following wildfires in the western US: a review. *Fire Ecology*, *15*(1), 1–17. https://doi.org/10.1186/s42408-019-0032-1

Turner, M. G., Whitby, T. G., Tinker, D. B. & Romme, W. H., 2016. Twenty-four years after the Yellowstone Fires: Are postfire lodgepole pine stands converging in structure and function? *Ecology*, *97*(5), 1260–1273. https://doi.org/10.1890/15-1585.1

Tyagi, J. V., Kumar, R., Srivastava, S. L. & Singh, R. D., 2011. Effect of micro-environmental factors on natural regeneration of Sal (Shorea robusta). *Journal of Forestry Research*, *22*(4), 543–550. https://doi.org/10.1007/s11676-011-0197-1

Verma, S., Singh, D., Mani, S. & Jayakumar, S., 2017. Effect of forest fire on tree diversity and regeneration potential in a tropical dry deciduous forest of Mudumalai Tiger Reserve, Western Ghats, India. *Ecological Processes*, *6*(1), 4–11. https://doi.org/10.1186/s13717-017-0098-0

Wang, S. W., Lim, C. H. & Lee, W. K., 2021. A review of forest fire and policy response for resilient adaptation under changing climate in the Eastern Himalayan region. *Forest Science and Technology*, *17*(4), 180–188. https://doi.org/10.1080/21580103.2021.1979108

Wooten, J. T., Stevens-Rumann, C. S., Schapira, Z. H. & Rocca, M. E., 2022. Microenvironment characteristics and early regeneration after the 2018 Spring Creek Wildfire and post-fire logging in Colorado, USA. *Fire Ecology*, *18*(1). https://doi.org/10.1186/s42408-022-00133-8

Zhu, J., Mao, Z., Hu, L. & Zhang, J., 2007. Plant diversity of secondary forests in response to anthropogenic disturbance levels in montane regions of northeastern China. *Journal of Forest Research*, *12*(6), 403–416. https://doi.org/10.1007/s10310-007-0033-9