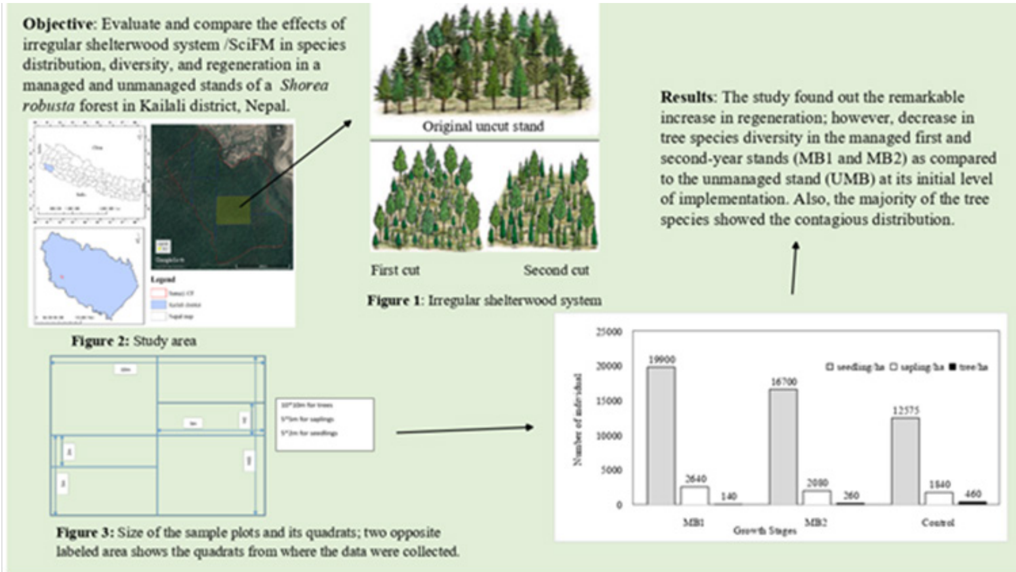
RESEARCH ARTICLE

Effect of irregular shelterwood system-based scientific forest management on tree species distribution, diversity and regeneration in *Shorea robusta* (Sal) forest of Kailali district, Nepal

P. Khadka, K. Ayer and M. S. Miya*



Highlights

- *Shorea robusta* is the dominant species in forests in Terai region of Nepal.
- Unmanaged blocks have a high diversity of species than managed blocks.
- The majority of the tree species showed a contagious distribution.
- Irregular shelterwood system-based scientific forest management supports the better regeneration of Sal species.

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Effect of irregular shelterwood system-based scientific forest management on tree species distribution, diversity, and regeneration in *Shorea robusta* (Sal) forest of Kailali district, Nepal

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Abstract: In Nepal, there had been an attempt to shift forest management practices (from conservation-oriented to productive forest) *via* Scientific Forest Management (SciFM) approach; applying an irregular shelterwood system. However, SciFM faced conflicting arguments regarding logging, regeneration capacity, and species diversity. Thus, this study investigated the effects of irregular shelterwood system-based scientific forest management on tree species distribution, diversity, and the regeneration of a *Shorea robusta* dominated forest in the Kailali district, Nepal. The quadrat method based on simple random sampling was used for vegetation sampling with a total of 20 quadrats for unmanaged blocks and ten quadrats for managed blocks. In each quadrat, the diameter at breast height (DBH) and height of the trees and saplings were measured, while the number of seedlings was counted. Importance Value Index, Diversity indices, Jaccard's Index, and total regeneration were calculated to compare the dominance, diversity, similarities of species between the blocks, and regeneration status, respectively. *Shorea robusta* was the most dominant species in managed and unmanaged blocks. Higher species diversity, evenness, and richness were found in unmanaged blocks. However, species dominance, seedling density, and sapling density were higher in managed blocks. The majority of the tree species showed a contagious distribution. There were significant differences in diversity and regeneration status between managed and unmanaged blocks. Therefore, this study supports the implementation of an irregular shelterwood system for the improved regeneration status of valuable species like *Shorea robusta* to manage the forest sustainably for the future.

Keywords: Dominance; Sapling; Seedling; Silviculture; *Shorea robusta*

INTRODUCTION

Scientific forest management (SciFM) has been practiced in tropical forests; by applying various silvicultural systems that developed between 1900 and 1960 (Dawkins and Philip, 1998). It aims to ensure a regular supply of forest products by establishing a stable forest stand. Tropical countries are practicing SciFM to fulfill socio-economic and environmental goals, although the implications of SciFM are still under debate (Abrams *et al*., 2005). The Government of Nepal endorsed SciFM in participatory forest management in 2014 (MFSC, 2014); however, now, the Government has discontinued its implementation due to conflicting arguments: intentional logging of only high–valued timber species like *Shorea robusta*. SciFM in Nepal aimed to promote the sustainable yield of forest products replacing the over-matured stocks with flourishing regeneration status and increasing revenue for the nation (Awasthi *et al*., 2015; Khanal and Adhikari, 2018; Subedi *et al*., 2018). The SciFM was primarily focused on *Shorea robusta* (Sal) forests, applying an irregular shelterwood system (Awasthi *et al*., 2020). This system offers the flexibility of generating spatial and vertical heterogeneity in stands by successive cutting with a long or indefinite regeneration period (Matthews, 1991).

SciFM follows the implementation of operations (thinning, cleaning, regeneration felling, and other post-harvest operations) under selected silvicultural systems to steer stand dynamics, patterns and growth of regeneration, species diversity, and total forest productivity (Sapkota *et al*., 2009; Mandal and Joshi, 2014; Dieler *et al*., 2017). The fundamental feature of SciFM is ensuring the production and productivity of forests and the renewal of forest stands (MFSC, 2014). Despite its rising popularity in participatory forest management, researchers, forest dwellers, and politicians have questioned SciFM for its technological, social, and biological difficulties and long-term uncertainty (Basnyat *et al*., 2018; Rutt and Wagner, 2019; Poudyal *et al*., 2020). The active interventions and disturbances in forest ecosystems affect species composition, structure, interactions, and diversity (McRae *et al*., 2001; Demarais *et al*., 2017; Sierota *et al*., 2019). Moreover, the climatic and physiographic zones, together with management intervention, alter the regeneration dynamics and species composition in the forests (Figueroa-Rangel and Olvera-Vargas, 2000; Nguyen and Baker, 2016).

In SciFM, intensive management is executed, and regeneration is monitored to see if the goals of sustainable forest management are achieved or not, or if the forest's productive capacity and biological richness have been preserved or not (Kushwaha and Nandy, 2012; Duguid and Ashton, 2013; Nguyen and Baker, 2016). While, some scholars argue that SciFM sustains species diversity (Putz *et al*., 2008; Putz and Romero, 2015; Poudyal *et al*., 2019), it has been criticized by others due to the potential risk for the loss of plant species diversity because of its active management intervention causing habitat alteration in one way or other (Gibson et al., 2011; Shima et al., 2018).

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Moreover, high logging intensity during regeneration felling is assumed to be a risk for failure in regeneration establishment (Dieler *et al*., 2017).

Shorea robusta (Family: Dipterocarpaceae) is a large, 18-32 m tall, with a girth of 1.5-2 m, semi-deciduous, and gregarious tree (Pandey and Shukla, 2001; Orwa *et al*., 2009). It shares 15.27% of forest coverage in Nepal (DFRS, 2014). The regeneration of *Shorea robusta* is challenging due to climatic variability and anthropogenic disturbances (Nguyen and Baker, 2016; Sapkota *et al*., 2019). Most of the mixed Sal forests in the Terai districts of Nepal are typically old, overgrown, diseased, and hollow on the inside (Aryal *et al*., 2016; Shrestha *et al*., 2019). In Nepal, due to the protection-oriented forest management rather than intensive forest management, the seedlings, saplings, and poles do not get proper attention during management intervention. The conventional protection-oriented forest management practices in participatory forestry are inclined to the 4 Ds trees (dead, diseased, decayed, and damaged), which don't maintain the forest stand dynamics and regeneration. The investigation of the possible effects of different kinds of silvicultural systems on regeneration and tree diversity is crucial to predict the future trends in species composition and stand structure for efficient forest management (Awasthi *et al*., 2015). SciFM practice has quite a short history in Nepal: it has been discarded from implementation; very few studies have been carried out, and the information is still minimal about its effect on species diversity and regeneration. Thus, this research aims to evaluate and compare the effects of irregular shelterwood system-based scientific forest management in the regeneration, species distribution, and diversity in managed and unmanaged forest stands of a community forest in the Kailali district, Nepal. The results could serve as baseline information for the future implementation of sustainable forest management strategies in Nepal.

MATERIALS AND METHODS

Study area

The study was conducted in the Samaiji Community Forest (Latitude: 28°43'26.97"N and Longitude: 80°39'6.05"E) of Kailali district, Nepal, in March and April of 2021 (Figure 1). The forest occupies an area of 215.83 ha, and the study was focused on the sub-compartment (SC5) (Area: 26.98 ha). The forest is boarded by the Khutiya River (East), the Jali community forest (West), the Mankiya community forest (North), and a path to Pathhari (South). The elevation of the study area ranges from 160 m to 190 m.s.l. The forest type is the natural *Shorea robusta* (Sal) forest, managed under the irregular shelterwood system. The whole forest is considered a compartment and divided into eight sub-compartments for its management under a 10-year regeneration period and an 80-year rotation period. An operational plan (of 10-year) was created to execute a silvicultural system in one of the sub-compartments (SC5), where regeneration status was poor and dominated by old-growth trees. A yield regulation method based on area control was adopted for the management: SC5 was further divided into ten annual felling areas (AFAs) to carry out regeneration felling activities annually for the next ten years. In SC5, regeneration felling activities were practiced in its two AFAs in 2018/19 and 2019/20. These two AFAs were assigned managed blocks (MB), while the rest of the eight AFAs within the SC5 were taken unmanaged blocks (UMB) up to the date of our field study. The identification assigned for AFAs is MB1 (the treatment year 2018/19), MB2 (the treatment year 2019/20), and the other AFAs within SC5 as UMB. The area of SC5 was fenced to reduce the effects of grazing and human disturbances.

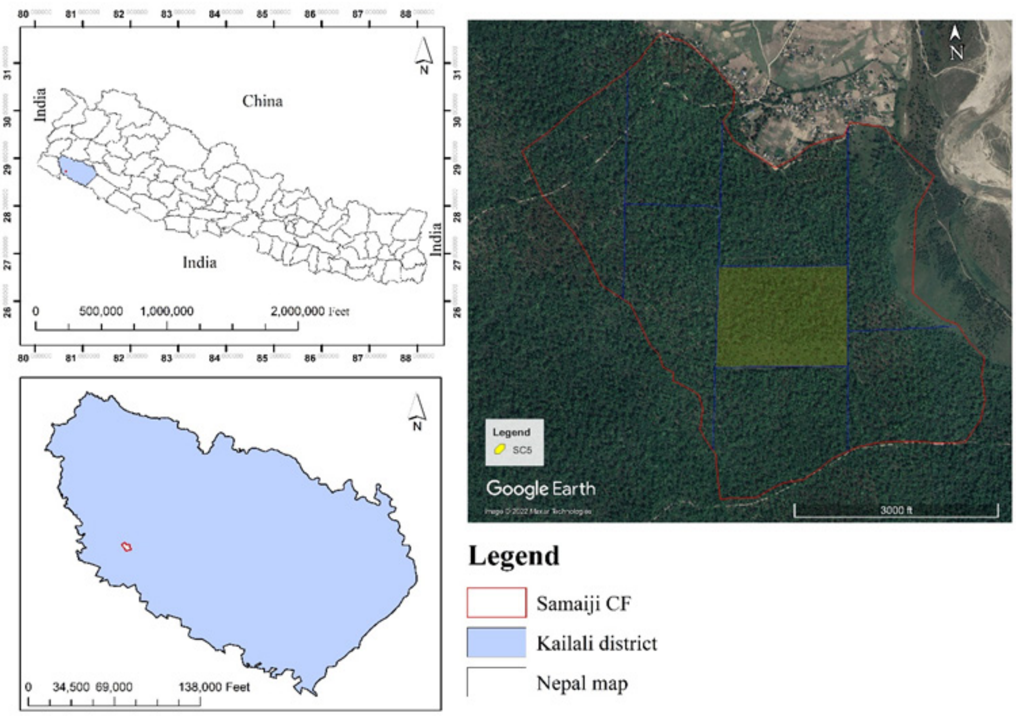

Figure 1: Map of the study area showing Samaiji Community Forest in Kailali district, Nepal.

Data collection

For the data collection, we followed the inventory guidelines of the Government of Nepal (DOF, 2004). Individual tree species were divided into three growth stages based on diameter at breast height (DBH): tree (DBH >10cm), sapling (DBH < 10cm and height > 1.3 m), and seedling (height < 1.3 m). The vegetation sampling was conducted using the quadrat methods (Behera and Misra, 2006; Awasthi *et al*., 2020). We used simple random sampling to select sample plots using Arc. GIS 10.5, with sampling intensities of 0.1% for unmanaged and 0.2% for managed blocks. Altogether 20 quadrats for unmanaged blocks and ten quadrats for managed blocks were studied. The quadrats of 10m × 10m were laid out to sample trees (Figure 2). Each quadrat was split into four equal sub-quadrats from the center, each 5m × 5m, and two opposite sub-quadrats of 5m × 5m for saplings and 5m × 2m for seedlings were studied (Mishra, 1968; Awasthi *et al*., 2015; Khatri *et al*., 2021). Abney's level was used to measure the height. While to measure DBH, diameter tape (for trees) and vernier caliper (for saplings) were used in each sampling unit.

Data analysis

MS Excel (version 2010) and SPSS software (version 20) were used to analyze the data. The Importance Value Index (IVI) was estimated using the density, basal area, and frequency of each species (Ellenberg and Mueller-Dombois, 1974; Khatri *et al*., 2021). Shannon-Wiener diversity index, Simpsons' index, Margelef's richness index, and Pielou evenness (e) or equitability were calculated for the diversity of the species. Jaccard's Index was calculated to compare the similarities and diversity between the blocks.

IVI= Relative Frequency + Relative Basal Area + Relative Density Eq 1

Relative Frequency

$$(RF, \%) = \frac{\text{Frequency of individual species}}{\text{Sum of the frequencies for all species}} \times 100 \quad \text{Eq 2}$$

Relative Density

$$(RD, \%) = \frac{\text{Density of individual species}}{\text{The total density of all species}} \times 100 \quad \text{Eq 3}$$

$$\text{Relative Basal area} = \frac{\text{Basal area of individual species}}{\text{Total basal area of all species}} \times 100 \quad \text{Eq 4}$$

$$\text{Shannon-Wiener Index (H)} = -\sum_{i=1}^{s} (p_i)(\ln p_i) \quad \text{Eq 5}$$

$$\text{Simpson's Index of Dominance (C)} = \sum_{i=1}^{s} (p_i)^2 \quad \text{Eq 6}$$

$$\text{Margalef's Species Richness Index (S)} = \frac{(s-1)}{\ln N} \quad \text{Eq 7}$$

$$\text{Equitability or Evenness Index (e)} = \frac{H}{\ln S} \quad \text{Eq 8}$$

$$\text{Jaccard's Similarity Index (JI)} = \frac{c}{a+b+c} \quad \text{Eq 9}$$

Where, s = number of species, N = total number of individuals of species, pi = proportion of all individuals that are of species 'i', a = number of species common to (shared by) quadrats, b = number of species unique to the first quadrat, and c = number of species unique to the second quadrat.

To study the distribution pattern, the ratio of abundance to frequency (A/F) was contemplated as regular (if A/F < 0.025), random (if A/F = 0.025 – 0.05), and contagious (if A/F > 0.05) (Whitford, 1949; Awasthi *et al*., 2015; Khatri *et al*., 2021). Furthermore, the regeneration status: seedling and sapling, of managed and unmanaged blocks were compared to each other to investigate differences in regeneration status under different treatments. One-way ANOVA was performed to inspect significant differences in these variables among different treatment blocks. Means that showed differences were compared using a post hoc LSD test with a 5% level of significance.

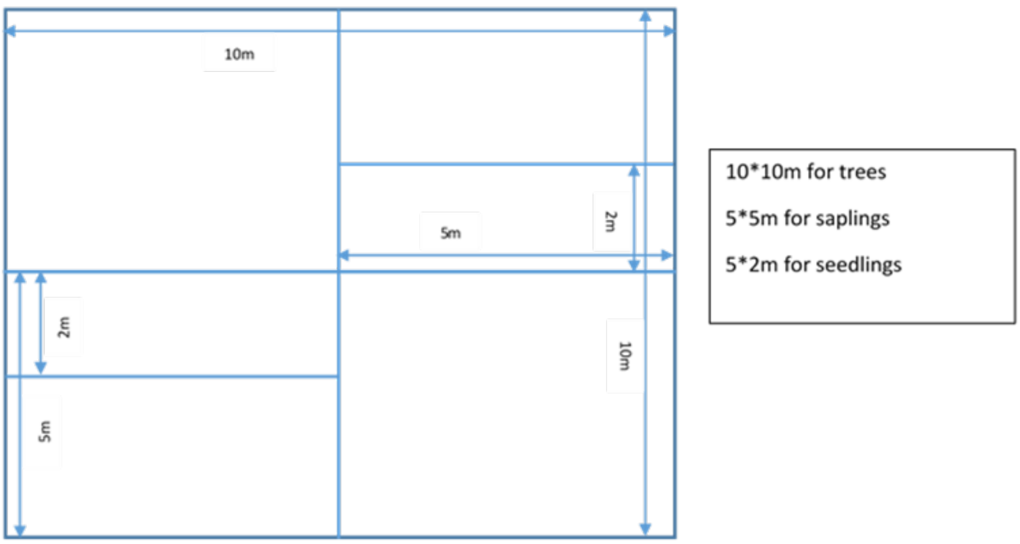

Figure 2: Size of the sample plots and its quadrats; two opposite labeled areas show the quadrats from where the data were collected.

RESULTS

Block-wise composition of tree species

Shorea robusta has the highest IVI of 146.00, 123.75, and 125.92 in Blocks MB1, MB2, and UMB respectively. *Terminalia tomentosa* has the second-highest IVI in MB1 (38.69) and MB2 (31.68), while *Mallotus philippensis* has the second-highest IVI (28.15) in the UMB (Figure 3).

Distribution pattern of tree species

The distribution pattern of tree species varied according to the treatment types. In MB1, the saplings of all species showed a contagious distribution. In MB2, one out of three species showed random distribution in managed treatment units, and in the UMB, eight out of 12 species showed contagious distribution (Appendix 1).

In MB1, the seedlings of all species showed contagious distribution. In MB2, two out of 11 species showed random distribution in managed treatment units, and in the UMB, 18 out of 21 species showed contagious distribution (Appendix 1).

Tree species diversity

Tables 1 shows different scenarios of the tree diversity indices. Comparing the diversity indices among the three blocks, the value of the Shannon-Wiener diversity index (H1=1.23 and H2=1.14) was higher in the unmanaged block which indicated that it was more diverse compared to the other blocks. Also, the species evenness index was greater (e1=1.03 and e2=0.71) in the unmanaged block which depicted that the species were more evenly distributed in this block compared to the managed blocks. Similarly, the species richness index was greater (S1=1.27, S2=1.30) in the unmanaged block than in the managed block. We observed that the newly harvested forest block (MB2) has a higher Shannon-Wiener index than MB1. However, Simpson's index of concentration dominance (C) was significantly higher in managed block MB1 (C1=0.75, C2=0.61) and MB2 (C1=0.71, C2=0.53) than that of the UMB (C1=0.30 and C2=0.40). The mean value of H, C, S, and e varied significantly between the managed blocks and unmanaged blocks at a 0.05 level of significance. These showed low diversity in tree species in managed blocks than unmanaged blocks due to the initial effect of the intervention. In the study area, a higher similarity (60%) was found in the species between managed blocks (MB1 and MB2). In contrast, high dissimilarity (42.85%) was noticed between MB1 and UMB (Table 2).

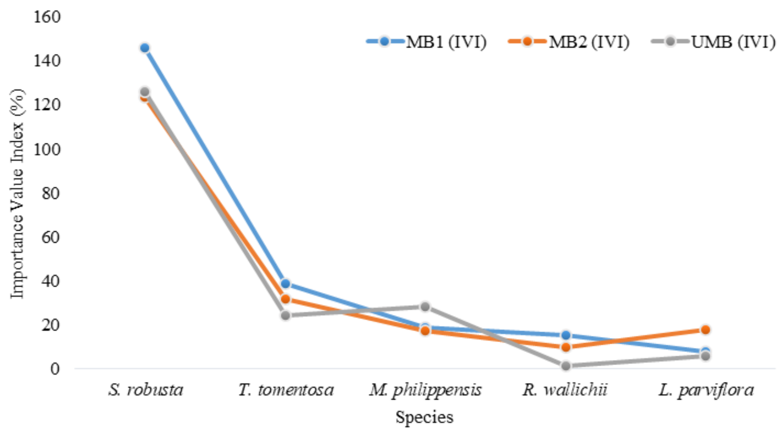

Figure 3: Dominance diversity curves in managed and unmanaged blocks.

Table 1: Mean of plant species diversity, dominance, evenness, and richness indices at sapling layer (Sp) and seedling layer (Sd) in managed block (MB) and unmanaged block (UMB)

Blocks	No. of plots	Sp	Sd	Sp	Sd	Sp	Sd	Sp	Sd
		H1	H2	C1	C2	e1	e2	S1	S2
MB1	5	0.65	0.68	0.75	0.61	0.82	0.53	0.74	0.72
MB2	5	0.68	0.84	0.71	0.53	0.98	0.59	1.21	0.97
UMB	20	1.23	1.14	0.30	0.40	1.03	0.71	1.27	1.30

Table 2: Jaccard's Similarity Index (JI) (%) between managed blocks (MB) and unmanaged blocks (UMB)

Study area	JI (%)
MB1 with MB2	60.00
MB2 with UMB	50.00
MB1 with UMB	42.85

Regeneration status

The study showed higher seedling and sapling densities in the managed blocks than in unmanaged blocks. MB1 has 19,900 seedlings/ha, followed by MB2 with 16,700 seedlings/ha, and UMB with 12,575 seedlings/ha. Similarly, MB1 has 2,640 saplings/ha, followed by MB2 (2,080 saplings/ha) and UMB (1,840 saplings/ha). At the 0.05 level of significance, the mean seedling and sapling densities per hectare differed considerably between managed and unmanaged blocks, demonstrating the importance of an irregular shelterwood system in encouraging regeneration. However, tree density was higher in UMB (460 trees/ha) than in the managed areas (MB1 = 140 trees/ha and MB2 = 260 trees/ha) (Figure 4).

Comparison of regeneration of *S. robusta* with other species

S. robusta seedlings density was higher in the managed blocks (MB1 = 13,100/ha and MB2 = 9,500/ha) but lower in the unmanaged area (UMB = 6,250/ha). Similarly, its saplings density was higher in the managed area (MB1 = 2,240/ha and MB2 = 1,600/ha) and lower in the unmanaged region (UMB = 1,200/ha) (Figure 5). While compared to other species, the seedling density of *S. robusta* was higher in the managed blocks, while it seems almost similar in the unmanaged block.

DISCUSSION

This study revealed the effects of irregular shelterwood system in the regeneration status, tree species distribution, and diversity in the Samaiji CF. In all the blocks*, S. robusta* was the dominant species. While *T. tomentosa* was the co-dominant species in the managed blocks, *M. philippensis* was the co-dominant species in the unmanaged area. The Terai Forest Inventory report of DFRS (2014) stated *S. robusta* as an important species, followed by *T. tomentosa*. Odum (1971) has highlighted contagious distribution patterns as the most common patterns in nature. Most seedlings were modified to grow closer to the mother plants due to the infectious pattern of species dispersion, which was observed in all of the species in MB1. This study resonates with the previous studies conducted by Awasthi *et al*. (2015) in Nepal and Rol *et al*. (2013) in a disturbed rainforest in Cameroon.

The study showed a lower value of the Shannon-Wiener diversity index in managed blocks compared to unmanaged blocks. A higher Simpson's index of dominance in the managed block might be attributable to lesser species diversity since *S. robusta* was the dominant species in the managed stands. Lower species diversity, richness, and evenness in the managed blocks may be due to harvesting and logging practices, clean-up of unwanted vegetation, and other anthropogenic disturbances. The lower diversity

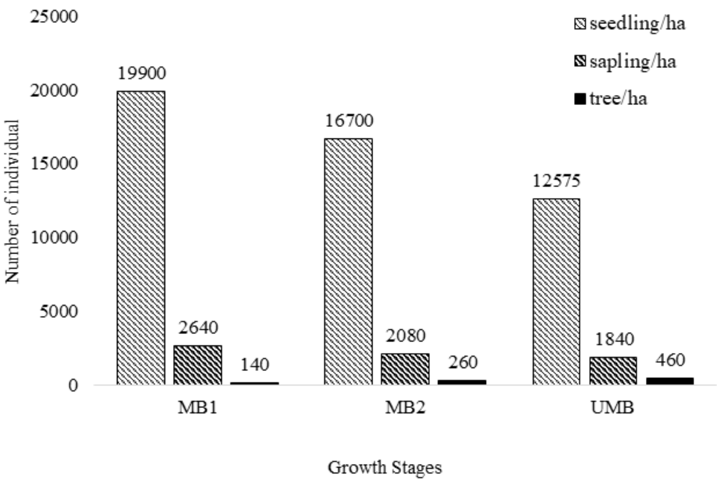

Figure 4: Seedling, sapling, and tree density in the managed and unmanaged blocks.

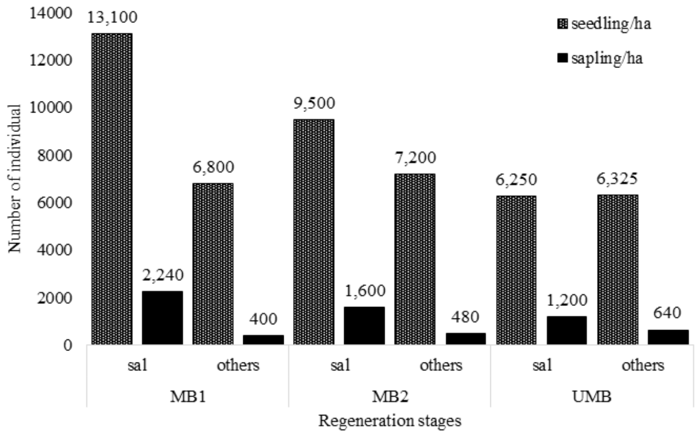

Figure 5: Regeneration status of *Shorea robusta* in contrast to other species in managed and un-managed blocks.

in MB1 against the newly harvested block (MB2) may be due to the post-harvesting operation carried out in MB1. Harvesting operations and logging intensity shape species composition and diversity (González–Alday *et al.,* 2008). In SciFM, only 15–30 mother trees per hectare are retained during regeneration felling (Poudyal *et al*., 2019; Awasthi *et al*., 2020). The results of the study showed similar findings to the study of Awasthi *et al*. (2015). Kharel *et al*. (2021) and Khatri *et al*. (2021) have also reported lower species diversity in the managed block than in the unmanaged block in their study in Nepal. In the Loveh forest in Iran, Mohammadi *et al*. (2008) found a low value of Shannon-Wiener Index in the wild stand compared to the managed stands with the shelterwood system. Awasthi *et al*. (2020) also found a significant decline in plant diversity but an increase in the concentration of dominance in managed forest blocks. The study performed by Sapkota *et al*. (2010) also found a significant decline in the species diversity in the *S. robusta* forest in Nepal. While Ayer *et al*. (2022) reported higher species diversity in scientifically managed forests than in conventionally managed forests in the Kanchancpur district, Nepal. In an irregular shelterwood system, the regeneration felling and post-harvesting operations decrease species diversity in the managed stands at its initial stage; however, it will increase in the long run than in the natural stands (Smith *et al*., 2005).

The present study found that managed areas had higher seedling and sapling densities, perhaps owing to regeneration felling, than the unmanaged region, which had no regeneration felling. The higher regeneration in the managed area could be because of the open canopy, less competition, fencing, and protection from fire and grazing. Canopy openings and the creation of gaps in the forest have a notable effect on regeneration (Zhu *et al*., 2014; Awasthi *et al*., 2020). Suoheimo (1999) reported 50,000–100,000 seedlings/ha after the regeneration felling of Sal forests as a result of a uniform shelterwood system. Our findings match the findings of Awasthi *et al*. (2015), Khanal and Adhikari (2018), Kharel *et al*. (2021), and Khatri *et al*. (2021). The presence of an acceptable quantity of understory regeneration defines the forest's health and vitality (Awasthi *et al*., 2015). A study from Timilsina *et al*. (2007) reported higher seedling density but a lower sapling density from central Nepal. Napit (2015) also found a similar scenario. In addition, DFRS (2014) forest resource assessment showed a similar result, which reported a low established saplings although seedlings density of Sal was high in those stands.

The seedling and sapling density of *S. robusta* were higher in the managed area, while it was low in the unmanaged area compared to other species. A lower number of saplings than seedlings might be due to damages that occurred during regeneration felling in the blocks. Several studies from different places in Nepal showed a high density of Sal seedlings after one year of regeneration felling in natural stands (Awasthi *et al*., 2015; Cedamon *et al*., 2016; Khanal and Adhikari, 2018; Aryal *et al*., 2021). *S. robusta* is a high-light-demanding species (Jackson, 1994) and requires total overhead light from the earliest stages of growth (Champion and Seth, 1968). For light-demanding species, canopy gaps facilitate seedling germination by allowing solar radiation to penetrate the forest floor (Awasthi *et al*., 2020). Opening the canopy in the forest stands not only aids in regeneration but also assists the growth of understory seedlings and saplings (Troup, 1986). Fencing and fire line construction in SC5 reduced the effects of repeated fire, intensive grazing, and indiscriminate harvesting of trees.

The present study did not consider rainfall, temperature, soil, and geology of the area, as well as herbs and shrubs species, thus recommended incorporating all these factors in future studies.

CONCLUSION

The intervention of Scientific Forest Management, by applying an irregular shelterwood system, positively affected the natural regeneration of the Sal forest, although it decreased the species diversity of the stand. The seedling and sapling densities were higher in the managed blocks compared to the natural blocks. Also, the dominance of Sal was higher in managed blocks. The majority of the tree species showed a contagious distribution. This study recommends the application of such type of forest management for the productive and protective function of the forest. Besides, further studies should be carried out to investigate its long-term effects on plant species diversity.

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DECLARATION OF CONFLICT OF INTEREST

The author declares no competing interests.

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Appendix 1 Distribution pattern of species in sapling and seedling layers

Blocks	Species name	Sapling layer		Seedling layer	
		A/F	Distribution pattern	A/F	Distribution pattern
MB1	*Anogeissus latifolius*	-	-	0.07	Contagious
	Madhuca longifolia	-	-	0.07	Contagious
	Magnolia pterocarpa	-	-	0.06	Contagious
	Mallotus philippensis	-	-	0.09	Contagious
	Schleichera oleosa	-	-	0.07	Contagious
	Shorea robusta	0.06	Contagious	0.27	Contagious
	Terminalia tomentosa	0.06	Contagious	0.09	Contagious
MB2	*Adina cardifolia*	-	-	0.04	Random
	Albizia sp.	-	-	0.07	Contagious
	Anogeissus latifolius	-	-	0.10	Contagious
	Artocarpus lacucha	-	-	0.06	Contagious
	Ficus lacor	-	-	0.08	Contagious
	Lagerstroemia parviflora	0.04	Random	0.06	Contagious
	Mallotus philippensis	-	-	0.03	Random
	Semecarpus anacardium	-	-	0.06	Contagious
	Shorea robusta	0.10	Contagious	0.20	Contagious
	Syzygium nervosum	-	-	0.06	Contagious
	Terminalia tomentosa	0.09	Contagious	0.07	Contagious
UMB	*Adina cardifolia*	0.15	Contagious	0.04	Random
	Albizia lucidor	0.07	Contagious	0.25	Contagious
	Albizia sp.	-	-	0.04	Random
	Anogeissus latifolius	-	-	0.20	Contagious
	Casearia graveolens	-	-	0.20	Contagious
	Cassia fistula	-	-	0.20	Contagious
	Ficus benghalensis	-	-	0.20	Contagious
	Ficus lacor	-	-	0.20	Contagious
	Lagerstroemia parviflora	0.20	Contagious	-	-
	Litsea monopetala	0.04	Random	0.14	Contagious
	Madhuca longifolia	0.40	Contagious	0.40	Contagious
	Magnolia pterocarpa	0.20	Contagious	0.25	Contagious
	Mallotus philippensis	0.04	Random	0.07	Contagious
	Rhus wallichii	-	-	0.10	Contagious
	Schleichera oleosa	-	-	0.05	Random
	Semecarpus anacardium	0.09	Contagious	0.80	Contagious
	Shorea robusta	0.08	Contagious	0.14	Contagious
	Syzygium cumini	0.04	Random	0.07	Contagious
	Syzygium nervosum	0.03	Random	0.06	Contagious
	Terminalia bellirica	-	-	0.80	Contagious
	Terminalia tomentosa	0.10	Contagious	0.06	Contagious

(Abbreviation used: A/F= abundance/frequency, MB = managed block, and UMB = unmanaged block)