https://doi.org/10.3126/banko.v33i2.58280 Banko Janakari, Vol 33 No. 2, 2023 Pp 24–37

Impact of silvicultural system on regeneration status and species diversity: reflection from far-western lowland, Nepal

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Received: 2, September 2023 Revised: 24, November 2023 Accepted: 4, February 2024 Published: 26, February 2024

Adoption of silvicultural system aims to enhance the regeneration of desired species. Irregular shelterwood system was initiated in *Shorea robusta* dominated forest under different forest management regimes including community forest in lowland forest of Nepal. The present study was conducted in 2023 to compare the regeneration status and species diversity between the two different management practices (scientific forest management and conventional forest management) in Patela Community Forest in far-western lowland of Nepal. A total of 27 quadrat sample plots (each with 4 m^2) were established at a spacing of 50 m x 50 m across the three scientifically managed blocks, each with an area of 2.14 ha. An equal number of sample plots (27) were established within the conventionally managed blocks. Important Value Index, Sorenson's Similarity Indices, and the distribution patterns of each species were calculated in both the management blocks to compare the species diversity. Shapiro-Wilk test was performed to check the normality of regeneration count, and a two-sample t-test was employed to examine the significant differences in the mean count of the plant species. The present study revealed that the conventionally managed forest block has higher species diversity; however, the number of seedlings was significantly high in the scientifically managed forest blocks. The Important Value Index Analysis indicated that *S. robusta* was dominant tree species in both the management blocks followed by *Terminalia tomentosa*; however, there was higher number of *S. robusta* regeneration under the scientifically managed blocks. The study concludes that irregular shelter-wood system is effective for regulating *S. robusta* forests in the western lowlands of Nepal.

Keywords: Important Value Index, silvicultural system, *Shorea robusta*, species diversity, sustainable forest management

One-third of the earth's landmass is covered by forests (WWF, 2023), providing various ecological, social, and economic benefits to humans and other organisms (Paquette & Messier, 2010). The services provided by forest range from protection of water, soil, and biodiversity to betterment of micro-climate and regulation of the carbon cycle (Wardle & Kaoneka, 1999). Nearly 45% (44.74%) of the total area of Nepal is covered by forest (FRTC, 2022). The forest of Nepal is being managed under different management regimes including government managed forest, community forest and other community based forest management regimes (NLC, 2019). Sustainable forest management has been promoted as a way to maintain the ecological integrity of forests while meeting the needs of local communities and supporting economic development (Baral *et al*., 2018).

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Sustainable forest management is an approach that integrates social, ecological, and economic considerations into forest management practices (Teplyakov, 2011; Sheppard *et al.*, 2020). It is an approach that aims to preserve and boost the health and productivity of forest ecosystems in a long-run (Monserud, 2003) while ensuring that the benefits of forest resources are equitably distributed (Wilson & Wang, 1999). Sustainable forest management is grounded on the principles of biodiversity conservation, social & economic development, and ecosystem services (Marchi *et al.*, 2018). Conventionally managed forests, on the other hand, are managed for short-term gains and are often characterized by transformations to other land uses, unsustainable harvesting and logging practices, and reduced biodiversity (Kubsa & Tadesse, 2002). This type of forest management can result in the loss of forest biodiversity, degraded ecosystem services, and reduced resilience to environmental stresses (Siraj *et al.*, 2018).

In the global context, the terms 'Scientific Forest Management' (SciFM) and 'Sustainable Forest Management' have been used interchangeably (Poudel, 2018). The Government of Nepal enacted SciFM through the approval of the SciFM Guidelines in 2012 (MFSC Nepal, 2014) to address various forest-related problems, such as sub-standard forest production, insufficient forest management, and declining forest health (Awasthi *et al.*, 2020). This technique involves utilizing appropriate silvicultural methods and principles of forest management to establish structured compartments with a set rotation age (Awasthi *et al.*, 2020). The predominant silvicultural system under the guidelines was the shelter wood system, which involves high-intensity logging and retention of only 15–30 fully-grown mother trees per hectare (Poudyal *et al.*, 2019). The forest region divided into eight periodic blocks with an 80-year rotation age and 10-year of regeneration interval (Subedi *et al.*, 2018). The irregular shelterwood system was employed in managing the blocks, with distinct operations occurring in each one (Bhusal *et al.*, 2020). For example, regeneration felling, intermediate felling, and final felling are carried out in one periodic block, while thinning and cleaning operations are accomplished in others (Awasthi *et al.*, 2020). The key activities associated with SciFM include selecting and labeling mother trees, harvesting, thinning, fencing, cleaning, weeding, and creating fire-lines among others (Bhusal *et al.*, 2020). Implementation of silvicultural-system-based forest management practices was officially started in 2012; however, the guidelines for the same were approved in 2014 (GoN, 2014). We have used both the terms 'scientifically managed forest' and/or 'sustainably managed forest' adopting the SciFM Guidelines. However, the government of Nepal has abolished the SciFM Guidelines in 2021 (GoN, 2021, Basnyat, 2021) stating that SciFM practices have a negative impact on forests (GoN, 2021; Adhikari *et al.*, 2023). Nevertheless, the decision is still debatable among the concerned stakeholders in Nepal. Thus, this study aims to compare the regeneration status and diversity in the scientifically/sustainably managed forest blocks with those in the conventionally managed forest blocks within a community forest in Kailali district situated in the far-western lowland of Nepal by understanding the ecological impact of scientific forest management practices on forest regeneration and biodiversity. The following hypotheses were assumed:

H_1: Regeneration counts both in the conventionally managed and sustainably managed forest blocks were normally distributed; and

H_2: There was a significant difference in the mean count of the plant species between the conventionally managed forest blocks and the sustainably managed forest blocks.

The findings of the research have been expected to be useful for policymakers, forest managers, and local communities in designing and implementing sustainable forest management practices that support both ecological and socio-economic objectives.

Materials and methods

Study area

The study was conducted in the Patela Community Forest (CF) located between 28^0 41' 57.92" – 28^0 42' 19.41" N latitudes and between 80^0 38' 39.55"

– 80^0 39' 30.21" E longitudes (Figure 1) within Kailali district of Far-western Nepal. The PCF covers an area of 171.44 ha, and is bounded by Patela Village on the east, Debariya CF on the west, Samaiji CF on the north, and Beli-Milan CF on the south. The dominant plant species were Sal (*Shorea robusta*) followed by Asna (*Terminalia tomentosa*), Karma (*Adina cordifolia*), and Jamun (*Syzygium cumini*). The Patela CF was handed over to 98 households in 2009, and scientific forest management was started in this CF in 2017 following the irregular shelterwood silvicultural system. The total forest area had been divided into 8 periodic blocks/sub-compartments, each with an area of 21.43 ha and with eighty-year rotation period and ten-year regeneration period; eighty-year rotation period has been proposed and practiced for *S. robusta* dominated forest in Nepal (Poudel, 2018). Each sub-compartment (SC) was further divided into 10 annual felling coupes, and regeneration fellings were carried out in those felling coupes.

Treatment area

Among the eight sub-compartments, felling operation was implemented in the sub-compartment 7 (SC7). Before abolishment of the Guidelines, regeneration fellings were carried out in three annual felling coupes (each with an area of 2.14 ha) within the SC7 in the three successive years- 2018, 2019 and 2020. The areas under regeneration felling were set aside as 'sustainably managed blocks' while the remaining blocks were considered as 'conventionally managed blocks'. As conventionally managed block, the sub-compartment 6 (SC6) was also further divided into 10 annual coupes (each with an area of 2.14 ha) so as to compare their regeneration status with those in the scientifically managed blocks. Three annual coupes were considered as conventionally managed blocks for this research purpose. The adjoining blocks were taken for both the sustainably managed blocks and the conventionally managed blocks in order to minimize the other locality factors (area, elevation, and soil type) affecting regeneration. The selected sub-compartments and felling coupes are highlighted in Figure 1.

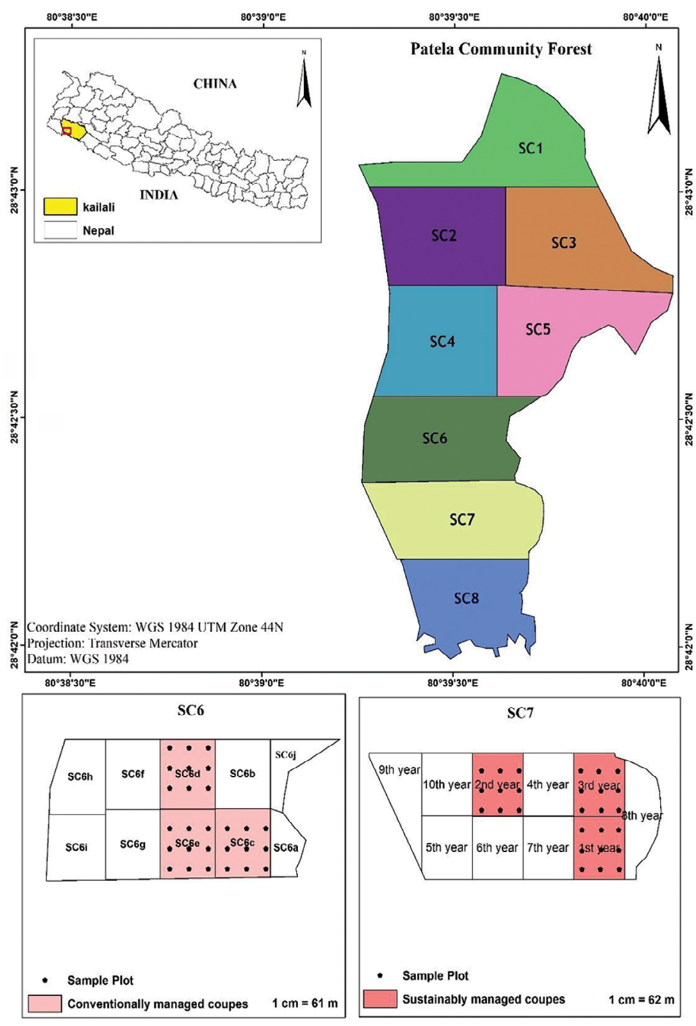

Figure 1: Map showing the location of the study area (Patela CF) along with the sub-compartments (8) and annual felling coupes (10) in Kailali district, Far-western Nepal

Data collection

Vegetation survey was conducted in February–March, 2023 following the quadrat methods as described by Mishra (1968); Shrestha (1996); Cunningham (2001); and Shrestha *et al*. (2007). Systematic random sampling was conducted in SC7 by laying down 27 square quadrats (sample plots), each of 4m^2 size (Figure 2) at a spacing of 50m x 50 m in three sustainably managed blocks where regeneration felling was carried out. Similarly, 27 quadrat sample plots (each with 4 m^2 area) were laid out at a spacing of 50 m 50 m in SC6 for collecting data. Vegetation sampling was conducted within a total of 54 sample plots (27 in sustainably managed blocks and 27 in conventionally managed blocks) by laying down the quadrat of 2 m X 2 m (4 m^2) in each sample plot as suggested by Kharel *et al*. (2021); the seedlings and saplings of all the live tree species within the quadrats were counted and recorded.

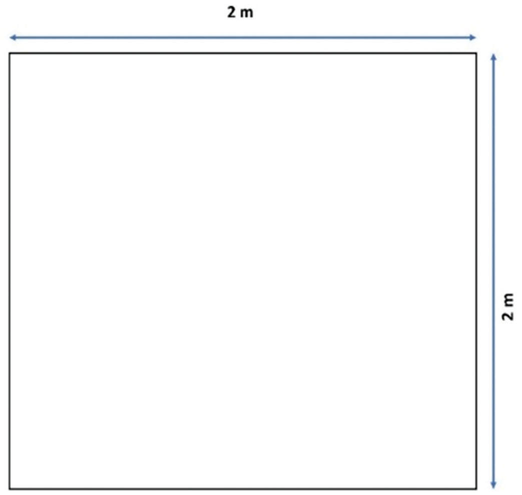

Figure 2: A square quadrat for vegetation sampling

Data analysis

The study examined the composition of plant communities in both the managed and unmanaged blocks. Structural analysis of the regeneration data both in the disturbed and undisturbed blocks was analyzed by calculating the Important Value Index (IVI), considering the relative values of density, frequency, and abundance to present the comprehensive overview of the species dynamics following the methods of Shukla & Chandal (2000) and Zobel *et al*. (1987).

- Frequency (%) = $\frac{\textit{Number of plots in which a species occured}}{\textit{Total number of plots}} \times 100$ (Eq. 1)
- Relative Frequency (RF, %) = $\frac{\textit{Frequency of a species}}{\textit{Total frequency of all species}} \times 100$ (Eq. 2)
- Density (stem/ha) = $\frac{\textit{Total number of individuals of a species in all plots}}{\textit{Total number of plots} \times \textit{area of a plot}} \times 100$ (Eq. 3)
- Relative Density (RD, %) = $\frac{\textit{Density of a species}}{\textit{Total density of all species}} \times 100$ (Eq. 4)
- Abundance = $\frac{(\textit{Total number of individuals of a species})}{\textit{Total number of plots in which the species occured}} \times 100$ (Eq. 5)
- Relative Abundance (RA, %) = $\frac{\textit{Abundance of a species}}{\textit{Total abundance of all species}} \times 100$ (Eq. 6)
- Important Value Index (IVI) = $RF + RD + RA$ (Eq. 7)

Plant species diversities

Species diversity pertains to the occurrence and diversity of species within a specific geographic region, combinely representing species richness and evenness (Malik *et al*., 2014). The following eight diversity and richness indices were analyzed to get a comprehensive understanding of regeneration diversity in both the sustainably managed and conventionally managed forest blocks:

1. The statistical measure of the number of species and evenness in a particular area was calculated using the Species Diversity Index (S_{DI}) (Odum & Barrett, 1971) which is expressed as:

   S_{DI} = S/N (1), (Eq. 8)

   Where, S is the total number of species and N is the total number of individuals of all the species; the higher value of species diversity index indicates the healthier ecosystem (Magurran *et al*., 2010).

2. The average of species count per sample plot was assessed using the Species Richness Index (R) (Margalef, 1958) which is expressed as:

   R = (S – 1) / Ln (N), (Eq. 9)

   Where, S is the total number of species and N is the total number of individuals of all species; it represents the total number of species within a defined region (Moore, 2013).

3. The species diversity in the forest stand was assessed using the Shannon-Weiner Diversity Index (H) (Michael, 1984) which is expressed as:

   $H = -\sum p_i \text{ X } \mathrm{Ln}\, p_i$, (Eq. 10)

   Where, p_i is the number of individuals of one species divided by the total number of individuals in the samples; the higher value of H indicates the greater species richness and evenness (DeJong, 1975); its value ranges from 0 to H_{max} (Shannon, 1948).

4. The maximum value of the species diversity was assessed using the Shannon's Maximum Diversity Index (H_{max}) (Kent, 2011) which is expressed as:

   H_{max} = Ln (S), (Eq. 11)

   Where, S is the total number of species; it depends upon species richness (Shannon, 1948).

5. The proximity of species in the forest was assessed using the Shannon's Equitability Index (E_H) (Kent, 2011) which is expressed as:

   $E_H = H / H_{max}$, (Eq. 12)

   Where, H is the Shannon-Weiner Diversity Index and H_{max} is the Shannon's Maximum Diversity Index.

6. The concentration of relative dominance expressed by each species was assessed sing the Species Evenness Index (E) (Pielou, 1966) which is expressed as:

   E = H/ Log (S), (Eq. 13)

   Where, H is the Shannon-Weiner Diversity Index and S is the total number of species.

7. The degree of diversity was assessed using the Simpson Diversity Index (D) (Magurran, 1988) which is expressed as:

$D = \sum P_i X P_i$, (Eq. 14)

   Where, P_i is the number of individuals of one species divided by the total number of individuals in the samples; the Simpson index decreases as biodiversity increases (Rahman *et al*., 2011).

8. The Dominance of Simpson Index (D) (Magurran, 1988) which is expressed as:

   D' = 1 – D, (Eq. 15)

   Where, D is the Simpson Diversity Index.

Similarity of species

The similarity of the species between the conventionally managed and sustainably managed forest blocks was assessed by using the Sorenson's Similarity Index (C_S) (Zhou *et al*., 2014) which is expressed as:

$C_S = \frac{(2j)}{a+b}$,
(Eq. 16)

Where, *j* is the total number of common species found in both the forest blocks, *a* is the total number of species found in the conventionally managed forest blocks, and *b* is the total number of species found in the sustainably managed forest blocks.

Distribution pattern

The ratio of the abundance (A) to frequency (F) was calculated for each plant species in the two separate forest blocks, and their distribution was considered to be regular, random, and contagious (i.e. occurring in clusters) if A/F <0.025, A/F = 0.025-0.05 and A/F >0.05 respectively (Whitford, 1949; Khatri *et al*., 2021; Khadka *et al*., 2023).

Statistical analysis

R version 4.0.3 (R Core Team, 2023) was used for performing all the statistical analysis using "stats" package at 5% level of significance. For checking the normality, Shapiro-Wilk Test (Shapiro & Wilk, 1965) was used. The null hypothesis (H_0) was accepted when the calculated p-value > 0.05 (Shapiro & Wilk, 1965). After obtaining the normal distribution of data from the Shapiro-Wilk Test, a 'two-sample test' was used to check the significant difference in the mean count of plant species between conventionally managed forests and sustainably managed forests.

Results

Regeneration status

A total of 10 and 13 regenerating plant species were recorded in the sustainably and conventionally managed forest blocks, respectively (Table 1).

The regeneration statuses of the conventionally managed and sustainably managed forests are highlighted in Table 2. The regeneration was found to be 35,741 per ha in the conventionally managed forest blocks while it was 59,537 per ha in the sustainably managed forest blocks.

Table 1. Regeneration status of conventionally and sustainably managed forest blocks

S. N.	Species	Regeneration per hectare	
		Conventionally managed blocks	**Sustainably managed blocks**
1.	*A. cordifolia*	370	556
2.	*Ficus religiosa*	93	-
3.	*Lagerstroemia parviflora*	93	741
4.	*Litsea monopetala*	648	1,389
5.	*Madhuca longifolia*	93	93
6.	*Mallotus philippensis*	1,204	-
7.	*Psidium guajava*	-	93
8.	*Scheichera oleosa*	833	741
9.	*Semecarpus anacardium*	93	-
10.	*S. robusta*	27,593	48,056
11.	*S. cumini*	1,852	463
12.	*Terminalia bellirica*	185	1481
13.	*T. tomentosa*	2,500	5,926
14.	*Trewia nudiflora*	185	-
	Total	**35,742**	**59,539**

Important Value Index (IVI)

In the case of the conventionally managed forest blocks, *S. robusta, T. tomentosa*, and *S. cumini* were found to be the most significant species based on the Importance Value Index (IVI) (Table 2), indicating their overall importance in this ecosystem. *S. robusta* particularly leads in multiple aspects, having the highest relative frequency (RF), relative density (RD), and relative abundance (RA) among the surveyed species. Conversely, the species like *F. religiosa, L. parviflora*, *S. anacardium*, and *M. longifolia* appeared as less frequent, with lower density and abundance as compared to the dominant species in these forest blocks.

On the other hand in the case of the sustainably managed forest blocks, *S. robusta* possessed the highest IVI with the highest RF, RD and RA, making it the most dominant plant species (see Annexes I and II). After *S. robusta*, *T. tomentosa* had the highest IVI of 43.67 (Table 2), making it the second most abundant plant species. *P. guajava* and *M. longifolia* were found to be the plants with the least IVI.

Table 2: Important Value Indices of tree species in conventionally and sustainably managed forest blocks

S. N.	Species	Conventionally managed forest blocks				Sustainably managed forest blocks			
		RF (%)	**RD (%)**	**RA (%)**	**IVI**	**RF (%)**	**RD (%)**	**RA (%)**	**IVI**
1.	*A. cordifolia*	3.90	1.04	4.65	9.58	5.48	0.93	2.96	9.37
2.	*F. religiosa*	1.30	0.26	3.49	5.04	0.00	0.00	0.00	0.00
3.	*L. parviflora*	1.30	0.26	3.49	5.04	6.85	1.24	3.16	11.25
4.	*L. monopetala*	6.49	1.81	4.88	13.19	9.59	2.33	4.23	16.15
5.	*M. longifolia*	1.30	0.26	3.49	5.04	1.37	0.16	1.97	3.50
6.	*M. philippensis*	10.39	3.37	5.67	19.42	-	-	-	-
7.	*P. guajava*	-	-	-	-	1.37	0.16	1.97	3.50
8.	*S. oleosa*	9.09	2.33	4.48	15.91	2.74	1.24	7.89	11.88
9.	*S. anacardium*	1.30	0.26	3.49	5.04	-	-	-	-
10.	*S. robusta*	29.87	77.20	45.18	152.30	36.99	80.72	37.94	155.64
11.	*S. cumini*	12.99	5.18	6.97	25.14	6.85	0.78	1.97	9.60
12.	*T. bellirica*	2.60	0.52	3.49	6.60	1.37	2.49	31.58	35.44
13.	*T. tomentosa*	16.88	6.99	7.24	31.12	27.40	9.95	6.32	43.67
14.	*T. nudiflora*	2.60	0.52	3.49	6.60	-	-	-	-

Plant species diversity indices

The plant diversity indices in the conventionally and sustainably managed forest blocks are highlighted in Table 3 below:

Table 3: Biological indices in conventionally and sustainably managed forest blocks

Forest blocks	Diversity indices							
	H	H_{max}	E_H	SDI	R	E	D	D'
Conventionally managed	0.98	2.56	0.38	0.03	1.68	0.88	0.61	0.39
Sustainably managed	0.78	2.20	0.36	0.01	1.24	0.82	0.67	0.33

Note: H = Shannon-Winner Diversity Index; $\mathbf{H_{max}}$ = Shannon's Maximum Diversity Index; $\mathbf{E_H}$ = Shannon's Equitability Index; **SDI** = Species Diversity Index; **R** = Species Richness Index; **E** = Species Evenness Index; **D** = Simpson Diversity Index; and **D'** = Dominance of Simpson Diversity Index.

The study evaluated the biological diversity in the conventionally and sustainably managed forest blocks through a comprehensive analysis of key diversity indices. In the conventionally managed forest blocks, the Shannon-Winner Diversity Index (H) was observed to be significantly higher (0.98), indicating a greater overall diversity in terms of both species abundance and evenness as compared to that (0.78) in the sustainably managed ones. A slightly higher value (2.56) of the Shannon's Maximum Diversity Index in the conventionally managed forest blocks as compared to that (2.20) in the sustainably managed ones also supported the result.

Moreover, the diversity indices provided insights into the distribution and dominance of the species within the two forest blocks. The Dominance of Simpson Index (D') is notably lower (0.33) in the sustainably managed forest blocks as compared to that (0.39) in the conventionally managed ones, indicating a more equitable distribution of species in the former. Additionally, the Species Richness Index (R=1.68) revealed that the conventionally managed forest blocks had a higher count of different species as compared to that (1.24) in the sustainably managed ones. These findings contribute valuable insights into the nuanced dynamics of biological diversity in conventionally and sustainably managed ecosystems, informing our understanding of their ecological health and management strategies.

The value of Sorenson's Coefficient was found to be 0.782, which indicated that there were 78% common and 22% different tree species in the sustainably and conventionally managed forest blocks

Distribution pattern

All the tree species in both the conventionally and sustainably managed forest blocks showed contagious distribution.

Statistical analysis

1. Shapiro-Wilk Test

The results of the Shapiro-Wilk Test are depicted in Table 4 below:

Table 4: Shapiro-Wilk Test of normality in the conventionally and sustainably managed forest blocks

Statistical parameter	Forest blocks	
	Conventionally managed	**Sustainably managed**
W	0.96875	0.95694
P-value	0.569	0.314

Since the p-values for both the conventionally and sustainably managed forest blocks were greater than 0.05, the number of regenerations was normally distributed. Furthermore for visual inspection of normality, histograms were plotted for each forest type, indicating a normal distribution.

2. Two-sample t-test

The two-sample t-test (Snedecor & Cochran, 1989) was used to determine if the population means of the two sustainably and conventionally managed forest blocks were equal or not. The results are presented in Table 5 below:

Table 5: Two sample t-test in sustainably and conventionally managed forest blocks

Test	Forest blocks	Mean	SD	t-value	df	p-value	95% CI
Two-sample t-test	Sustainably managed	23.93	25.83	–3.61	52	0.0006788	[–15.15, –4.33]
	Conventionally managed	14.19	13.12				

Since the calculated p-value < 0.05, the assumed hypothesis (H_2) is accepted which considered a significant difference in the mean counts between the two forest blocks. These results suggested that the management practices had a significant impact on the counts of the selected tree species

Discussion

Based on the findings of our study, the level of regeneration was observed to be significantly greater in the sustainably managed forest blocks as compared to the conventionally managed ones. This difference in regeneration can be attributed to the implementation of an irregular shelterwood system as a management intervention. These results suggest that sustainable forest management practices can have a positive impact on forest regeneration and may be an effective approach for ensuring long-term forest health and productivity. Studies done by Khanal & Adhikari (2018), Kharel *et al*. (2021) and Khatri *et al*. (2021) found that the sustainably managed blocks exhibited a higher regeneration status as compared to the unmanaged blocks. This finding aligns with the results of our own study, indicating a congruence between our study and their studies. Many studies from different parts of Nepal have shown an increase in the number of regeneration of selected species (e.g. *S. robusta*) by applying shelterwood system (Awasthi *et al*., 2015; Cedamon *et al*., 2018; Khanal & Adhikari, 2018; Aryal *et al*., 2021)

The Important Value Index (IVI) is an important tool for assessing the ecological significance of plant species in a given ecosystem, and it indicates the dominance of a species (Siraj & Zhang, 2018). The results of our study indicated that *S. robusta* was the most dominant plant species in both the forest blocks, with the highest IVI values of 152.30 and 155.64 in the conventionally and sustainably managed forest blocks, respectively. After the implementation of scientific forest management, the number, frequency, density and abundance of the species were found to have increased in the case of *S. robusta*, which are similar to the results obtained by Shrestha *et al*. (2019) and Kharel *et al*. (2021). After *S. robusta, T. tomentosa* was found to be the next dominant tree species in both the forest blocks, with the Important Value Indices of 43.67 in the sustainably managed forest blocks and 31.12 in the conventionally managed ones. The increased plant density indicates the more number of plant species per area. The sustainably managed forest blocks possessed the higher value of density per ha for each plant species than that of the conventionally managed ones. Similar type of result was observed by Barzin *et al*. (2018), with more plant density in managed forest.

A significant role is played by forest management activity to create a variation among different biological indicators (Torras *et al*., 2012). The results of our study showed that there was higher biological diversity in the conventionally managed forest blocks than in the sustainably managed ones. The irregular shelterwood system has negative effect on plant diversity, showing an increase in the concentration of the dominance of *S. robusta* (Gotame *et al*., 2020). Our study showed the lower Shannon-Weiner Diversity Index (0.78) in the sustainably managed forest blocks than in the conventionally managed ones (0.98), affecting both the species richness and evenness, which are similar to the results obtained by Awasthi *et al*. (2015) and Ranabhat *et al*. (2016). This might be due to regular cleaning, weeding and other anthropogenic disturbances in the sustainably managed forest blocks as has been claimed by Khatri *et al*. (2021). Similarly, the Shannon's Maximum Diversity Index was found to be higher (2.56) in the conventionally managed forest as compared to that (2.20) in the scientifically managed ones. A study conducted by Luna-Bautista *et al*. (2015) also reported the higher plant diversity in the unmanaged forests where diversity in managed forest is lost due to the effect of logging and cleaning. Our results indicated that the conventionally managed forests blocks had a higher Species Richness Index (1.68) as compared to the sustainably managed ones (1.24); specifically, we recorded a total of 13 and 10 plant species in the conventionally and sustainably managed forests, respectively. Similar results were obtained by Friedel *et al.* (2006), with more plant species in the unmanaged forest than in the managed one. We attribute this difference to the initial effect of the irregular shelterwood system, where the cleaning and weeding of undesired plant species in sustainably managed forests reduce the richness index.

The findings of our study were also consistent with the results of the previous studies conducted by Awasthi *et al.* (2015), Kharel *et al.* (2021), and Khadka *et al.* (2023). A review done by Paillet *et al.* (2010) in Europe and Shrestha *et al*, (2019) in Tilaurakot collaborative forest found that the Species Richness Index was higher in the unmanaged forests than that in the managed ones. A study done by Nouri *et al.* (2015) in Iran observed that the species evenness were higher in the unmanaged forest than that in the managed one, which coincides with the results of our study. The species diversity, richness, and evenness in a sustainably managed forest are comparatively lower because of human activities such as logging, harvesting, and removal of unwanted vegetation, and anthropogenic disturbances (Khadka *et al.*, 2023). Similarly, Smith *et al.* (2005) suggests that species richness is lower at initial phase of shelterwood system due to regeneration felling and post-harvest activities but after a long run it will be more than unmanaged natural stand. Our findings reveal the value of Sorenson's Coefficient as 0.78 which is very close to the value (0.75) obtained by Khatri *et al.* (2021) in their study. It shows that the proportion of species decreases after the implication of irregular shelterwood system (Monarrez-Gonzalez *et al.*, 2020). A similar type of study done by Khadka *et al.* (2023) revealed that regenerating plant species exhibit a contagious distribution in managed forests, while the majority of species in unmanaged forests also display a similar contagious distribution pattern. The contagious distribution is considered to be most common in pattern in nature (Odum, 1971). Khatri *et al.* (2021) also found that all of the plant species showed contagious distribution in both the managed and unmanaged forests, which coincides with our findings. It means the regenerating plant species generally grow in clusters near seed trees. On the contrary, Chowdhury *et al.* (2019) claimed that the lower value of the Simpson Diversity Index indicated the better species diversity in some forest areas. In our study, the Simpson Diversity Index was found to be slightly low (0.61) in the conventionally managed forest blocks than that (0.67) in the sustainably managed ones, which indicated that the conventionally managed forest blocks had higher plant diversity as compared to that in the sustainably managed ones; these results were similar to those obtained by Monarrez-Gonzalez *et al.* (2020) in Mexico. Likewise, the lower value of the Species Evenness Index (0.82) in the sustainably managed forest blocks as compared to that (0.88) in the unmanaged ones also supported the results, which were similar to those obtained by Mohammadnezhad-Kiasari *et al.* (2023).

Conclusion

The irregular shelterwood system applied in the Patela Community Forest resulted in the higher number of species diversity in the conventionally managed forest blocks than in the sustainably managed ones. However, the number of seedlings of desired species including *S. robusta* was found to be significantly higher in the scientifically management forest blocks. The significant disparity in regeneration count, between these two forest blocks, highlights the favorable impact on the forests that are managed for timber production in future. While the conventionally managed forest blocks exhibited greater plant diversity, the sustainably managed ones displayed a more concentrated distribution of regeneration. Our study concludes that irregular shelterwood system is effective in enhancing the regeneration of desired species. Furthermore, scientific forest management plays a crucial role in transforming conventionally managed forests into sustainable and high productive forest by retaining the regeneration of desired as well as productive tree species and removing the unwanted as well as unproductive ones.

Author Contribution Statement

Prakash Ojha : Author's contribution: develop the research tools, field data collection, data analysis, draft preparation, review and editing. Keshav Raj Acharya: Author's contribution: support for conception of the idea, Analysis of the data, revision of the research findings, and input during the writing of the research paper. Aliza Subedi : Author's contribution: Review and editing. Siddhartha Regmi: Author's contribution: Review and editing.

Data Availability

The data used in this study are accessible upon request to the corresponding author.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgments

The authors are grateful to the WWF-GEF supported Integrated Landscape Management to Secure Nepal's Protected Areas and Critical Corridors (ILaM) Project for providing us financial support to carry out this research/study. We are thankful to all the anonymous reviewers and editors for their constructive comments and suggestions in finalizing this article.

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Annex I: Abundance to frequency ratios of tree species in sustainably managed forest blocks

S. N.	Scientific name	Local name/ Common name	Frequency	Abundance	A/F
1.	*Adina cordifolia*	Karma	14.81	150.00	10.13
2.	*Psidium guajava*	Amba	3.70	100.00	27.00
3.	*Lagerstroemia parviflora*	Bot dhaiyanro	18.52	160.00	8.64
4.	*Litsea monopetala*	Kutmiro	25.93	214.29	8.27
5.	*Madhuca longifolia*	Mahuwa	3.70	100.00	27.00
6.	*Scheichera oleosa*	Kusum	7.41	400.00	54.00
7.	*Shorea robusta*	Sal	100.00	1922.22	19.22
8.	*Syzygium cumini*	Jamun	18.52	100.00	5.40
9.	*Terminalia bellirica*	Barro	3.70	1600.00	432.00
10.	*T. tomentosa*	Asna	74.07	320.00	4.32

Annex II: Abundance to frequency ratios of tree species in conventionally managed forest blocks

S. N.	Scientific name	Local name/ Common name	Frequency	Abundance	A/F
1.	*A. cordifolia*	Karma	11.11	133.33	12.00
2.	*Ficus religiosa*	Pipal	3.70	100.00	27.00
3.	*L. parviflora*	Bot dhaiyanro	3.70	100.00	27.00
4.	*L. monopetala*	Kutmiro	18.52	140.00	7.56
5.	*M. longifolia*	Mahuwa	3.70	100.00	27.00
6.	*Mallotus philippensis*	Sindure	29.63	162.50	5.48
7.	*S. oleosa*	Kusum	25.93	128.57	4.96
8.	*Semecarpus anacardium*	Bhalayo	3.70	100.00	27.00
9.	*S. robusta*	Sal	85.19	1295.65	15.21
10.	*S. cumini*	Jamun	37.04	200.00	5.40
11.	*T. bellirica*	Barro	7.41	100.00	13.50
12.	*T. tomentosa*	Asna	48.15	207.69	4.31
13.	*Trewia nudiflora*	Bhellar	7.41	100.00	13.50