

Regeneration status and species diversity of major tree species under scientific forest management in Kapilbastu district, Nepal

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In Nepal, scientific forest management has been practiced as an effective forest management technique to utilize forest resources sustainable. However, the program has faced many controversies such as intentional logging of only high-valued timber species like *Shorea robusta*. In addition, few believe this program is severely affecting the regeneration productivity and species diversity in the natural forests. In order to address these issues, we examined the regeneration condition and plant species diversity in the stands where scientific forest management operations were carried out. The data related to regeneration status and species diversity were collected using a systematic random sampling of the selected stands. Our results showed good regeneration conditions (Seedling >5000, Sapling >2000) in all the studied stands. The tree species community was dominated by *S. robusta* (Sal) followed by *Schleichera oleosa* (Kusum) and *Casia fistula* (Rajbriksha). The value of diversity indices of different species varied significantly between felling series. The highest diversity was found in the second year felling series with the Simpsons Index of dominance value 0.6934 and the lowest species diversity was in the first year felling series with a value of 0.8448. It can be recommended that the regeneration felling practice has helped in promoting the regeneration condition and growth.

Keywords: Regeneration, scientific forest management, *Shorea robusta*, silvicultural treatment.

Nepal consists of a total of 5.96 million ha i. e. 40.36% forest area (DFRS, 2015). There was no robust management of productive forests in the past due to the centralized institution structure of forest management in Nepal (Paudyal, 2007). The management was based on the annual allowable cut principle in which a single selection silvicultural system was applied for harvesting. Recently, the government of Nepal has started promoting Scientific Forest Management (SciFM) describing “an application of a appropriate silvicultural system and forest management principles through design of systematic compartments of fixed rotation age”. This highlights the use of shelterwood silviculture system with very high intensity logging, leaving

only 15–30 mature mother trees per ha to address inactive forest management, suboptimal forest production, and forest health degradation (Bhattarai *et al.*, 2018; Poudel, 2018). At present, it has been implemented by 285 Community Forest User Groups (CFUGs) across Nepal (Baral & Dhakal, 2018). Since its pilot implementation in Tilourakot Collaborative Forest, SciFM now has been expanded to 30 collaborative forests, 285 community forests and seven government block forests (Baral & Dhakal, 2018). As of 2020, around 121,852 ha of forests are currently being managed scientifically using SciFM principles both within collaborative forests and community forests in 52 districts of the nation (Bhandari & Lamichhane, 2020). The regeneration and

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community-level species richness of both seedlings and saplings increases under active forest management (Subedi *et al.*, 2018). The forest management activities benefit the forest with improved regeneration (Malik & Bhatt, 2015), greater species diversity and richness (Poudyal *et al.*, 2020), and ultimately leading to sustainability (Pokharel *et al.*, 2015) if followed in prescribed way. In forest management, regeneration study not only depicts the current status but also hints about the possible changes in forest composition in the future (Malik & Bhatt, 2016). Also, species is one of the major analytical characteristics of the plant community (Malik *et al.*, 2014). Knowledge of species composition and diversity of tree species is of utmost importance not only to understand the structure of a forest community but also for planning and implementation of conservation strategy of the community (Malik & Bhatt, 2015). Assessment of forest community composition and structure is very helpful in understanding the status of tree populations, regeneration, and diversity for conservation purposes (Mishra *et al.*, 2013). The species richness and diversity of trees are fundamental to total forest biodiversity because trees provide resources and habitat for almost all other forest species (Malik, 2014).

The forests of lowland Nepal are prone to many calamities like fire, grazing, and flood. The most

affected plant communities by these calamities are regenerations and young trees. Enough knowledge and study in forest characteristics of different tree species is essential to guarantee forest's natural regeneration (Mousavi *et al.*, 2011). Several researchers (Hull *et al.*, 2010; Sunam *et al.*, 2013; Baral *et al.*, 2018; Basnyat *et al.*, 2018a; Basnyat *et al.*, 2018b) define SciFM as a tool having complex mechanism which promotes centralization of forest disfavoring forest users in Nepal. It is also explained as the name of active utilization implemented without considering institutional aspects (Paudel *et al.*, 2018). The government has announced to discontinue SciFM practice in June 2019 stating the excessive logging of only high-valued tree species like *Shorea robusta* which results in lowering and declining the plant diversity and regeneration status, respectively. The long-term effects of SciFM on plant species and regeneration conditions are not studied well. Most of the studies are concerned with livelihood impact on SciFM. There has been significant increment in the regeneration per hectares after implementing the SciFM program in this study area that makes it as an ideal location to assess the success or failure of SciFM program. Therefore, this study was carried out to assess the regeneration status and plant species diversity of major tree species after felling of the stands in SciFM.

Materials and methods

Study area

The study was carried out in the Shringighat Community Forest (CF) which is located in Badganga Municipality of Kapilbastu district in the western Terai region of Nepal in 2019 (Figure 1). The Shringighat CF covers an area of 499.26 ha, and is located between 27°44'13.2"–27°45'14.1"N latitudes and 83°11'27.8"–83°11'57.5"E longitudes. The elevation of the study area ranges from 190 m to 200 m above the mean sea level. This forest is dominated by Sal (*S. robusta*)

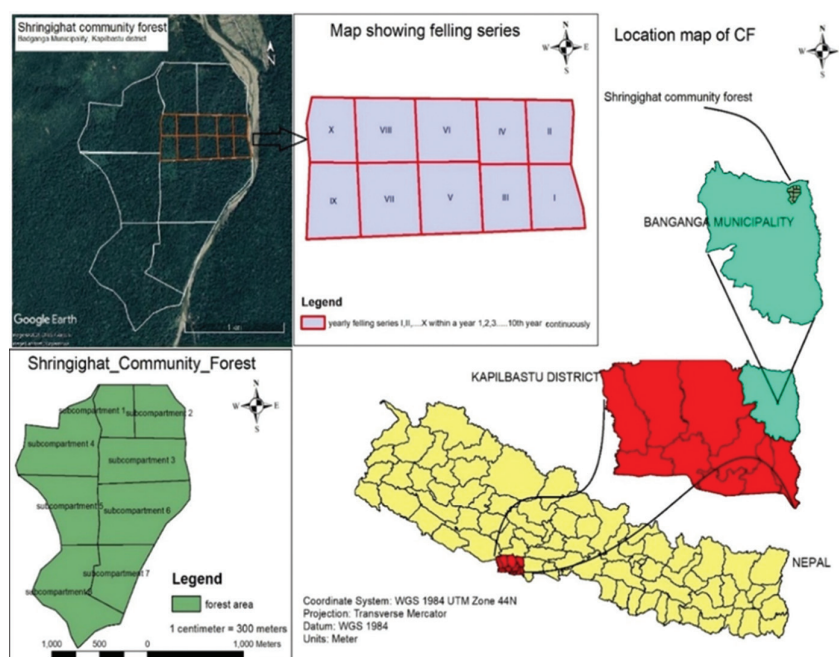


Figure 1: Map showing the location of the study area

associated with Asna (*Terminalia alata*), Karma (*Adina cordifolia*), Kusum (*Schleichera oleosa*), Satisal (*Dalbergia latifolia*), Rohini (*Mallotus philippensis*), Kutmero (*Litsea polyantha*), Bel (*Aegle marmelos*), etc. The major soil types found here are clayey loam, alluvium, and rocky types of soil. The forest is managed under an Irregular Shelterwood Silvicultural System. Altogether, 2,480 households are benefited from this Community Forest.

Data Collection

The data was collected using a systematic random sampling method. The vegetation sampling data were collected from a total of 40 concentric circular sample plots (CCSPs) of 10 m radius spaced at 50 m (Figure 2, Aryal *et al.*, 2017). Further, the data on the plant species diversity were also collected from each of sample plot. The sample plots were overlaid on the map using the fishnet tool in ArcGIS 10.4.1, and the GPS coordinates of the plots were extracted. Each plot was located in the field with the help of Garmin GPS device. The total number of sample plots was determined in accordance with the total felling area, and resource inventory was carried out with a sampling intensity of 1% as per the Community Forest Inventory Guidelines 2061 (DOF, 2004).

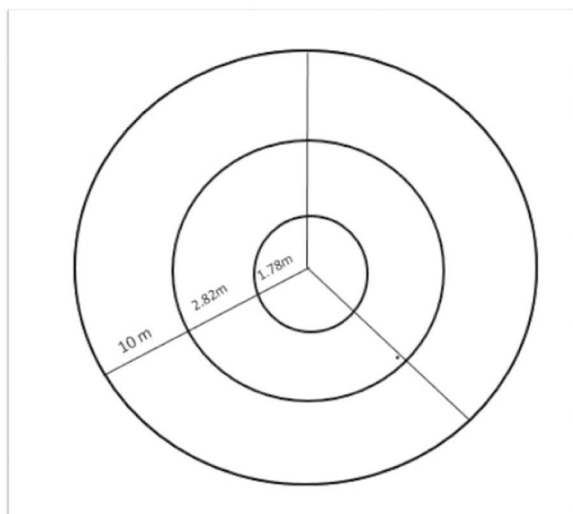


Figure 2: A concentric circular sample plot

The number of tree species (≥ 10 cm DBH) were counted in the main plot of 10 m radius. To gather data on regeneration, individual plants were

categorized into seedlings (height < 1.3 m), and saplings (height > 1.3 m and < 10 cm DBH). The study was conducted in those periodic blocks where regeneration felling operation was carried out, and the areas were mapped out using ArcGIS 10.4.1. The seedlings and saplings within 1.78m and 2.82m radii in each CCSP (Subedi *et al.*, 2010) were counted and noted. The density per hectare of each species was calculated to determine their regeneration status in the managed coup. Table 1 shows the area and the total number of sample plots in different felling series.

Table 1: No. of sample plots vs. Area of different felling series

Felling Series	Area (ha)	No. of sample plots
First-year	3.43	15
Second-year	3.82	15
Third-year	2.86	14
Fourth-year	3.76	16
Total	13.87	60

Data analysis

ArcGIS 10.4.1 Software was used for the proximity of establishing sample plots and map preparation. The data were processed and analyzed using MS Excel. The number of seedlings and saplings of *S. robusta* and other species per hectare were calculated, and their status and forest condition were analyzed as per the CF Inventory Guidelines 2061 (DOF, 2004). The density of each species per hectare was calculated using the formula:

$$\text{Species density per hectare} = \frac{\text{Total no. of seedlings and saplings}}{\text{Area of sample plot}} \times 10000$$

The condition of different felling series were assessed on the basis of the total number of seedlings and saplings of different tree species per hectare found in the respective felling series. As per the CF Inventory Guidelines 2061 (DOF, 2004), the condition of the forest is 'good' if the numbers of seedlings and saplings exceed 5,000 and 2,000 per hectare. Similarly, the condition of the forest is 'medium' if the numbers of seedlings and saplings occur between 2,000–5,000 and 800–2,000 per hectare; and 'poor' if the numbers

of seedlings and saplings occur below 2,000 and 800 per hectare, respectively (Table 2).

Table 2: Condition of forest based on regeneration status

Plant Type	No. per hectare		
Seedling	>5,000	2,000–5,000	<2,000
Sapling	>2,000	800–2,000	<800
Condition of Forest	Good	Medium	Poor

Source: CF Inventory Guidelines, 2061 (DOF, 2004).

Plant diversity

Species diversity refers to the frequency and variety of species within a geographical area (Malik *et al.*, 2014). It is the combination of species richness and species evenness. Species richness is the total number of species per sampling unit, and this makes no use of relative abundances. Species evenness is the distribution of individuals among the species. Species diversity can be expressed in a single number which can be used to assess the diversity of any population in which each member belongs to unique species. The plant diversity was measured using the following diversity indices:

- a) The concentration of dominance was measured using the Simpson’s Index which is mathematically expressed as–

$$\text{Simpson's Index of Dominance (D)} = \sum_{i=1}^S (pi)^2 \dots\dots\dots (i)$$

Where 'S' is the total number of species, 'pi' is the proportion of all individuals that belong to species 'i' in the sample. The value of 'D' ranges between 0 and 1. The value near zero corresponds to higher diversity or heterogeneous community while the value near one relates to a more homogeneous community.

- b) The Simpson Index of Diversity is calculated by subtracting Simpson’s Index of Dominance from 1, i. e.

$$\text{Simpson Index of Diversity} = 1 - D \dots\dots\dots (ii)$$

where, 'D' is the Simpson Index of Dominance the value of which also ranges between 0 and 1; the greater the value, the more the sample diversity.

- c) Shannon–Wiener Diversity Index (Shannon, 1948) was used for the calculation of species diversity. Mathematically, it is expressed as:

$$\text{Shannon-Wiener Diversity Index (H)} = - \sum_{i=1}^S (Pi) (\ln Pi) \dots\dots\dots (iii)$$

where, 'S' is the total number of species in the sample, 'Pi' is the proportion of all individuals that are of species 'i'. The Shannon Index increases as both the richness and the evenness of the community increase.

- d) Species richness index (d) indicates the mean number of species per sample (Margalef, 1958), and is expressed as:

$$d = \frac{S-1}{\ln N} \dots\dots\dots (iv)$$

where 'd' is the species richness index, S is the number of species and N is the number of individuals of all species.

- e) Equitability or evenness index (e) refers to the degree of the relative dominance of each species in that area. Mathematically, it is expressed as:

$$e = \frac{H}{\ln S} \dots\dots\dots (v)$$

where 'e' is the evenness, 'H' is the Shannon–Wiener’s Diversity Index and 'S' is the number of species. The value of e ranges from 0 (not even) to 1 (completely even).

Results

Regeneration status

The quantitative structures of regeneration of different tree species in the different felling series were studied based on the count of their seedlings and saplings in the sample plots. Table 1 depicts the area and the total number of sample plots in different felling series while Table 3 shows the number of seedlings and saplings of different species in the sample plots of different felling

Table 3: Total count of regenerations of different species in the sample plots

Species	Felling Series							
	1 st yr. Felling Series		2 nd yr. Felling Series		3 rd yr. Felling Series		4 th yr. Felling Series	
	No. of Seedlings	No. of Saplings	No. of Seedlings	No. of Saplings	No. of Seedlings	No. of Saplings	No. of Seedlings	No. of Saplings
<i>S. robusta</i>	150	230	239	289	185	260	381	275
<i>S. oleosa</i>	10	0	9	0	11	0	5	1
<i>C. fistula</i>	5	0	0	0	7	0	2	2
<i>D. latifolia</i>	0	3	8	0	2	0	0	0
<i>T. alata</i>	0	0	8	10	0	0	0	3
<i>A. cordifolia</i>	0	0	6	0	23	0	1	0
Others	16	0	70	11	16	6	62	0
Total	181	233	332	310	244	266	451	281

Source: Field Inventory, 2019.

series counted during the inventory process. The regeneration count of *S. robusta* was found to be the highest among all the other species present in all the felling series.

The numbers of seedlings and saplings of different species per hectare were determined based on

their regeneration counting in the sample plots. *S. robusta* had the highest number of seedlings and saplings per ha in all the felling series as compared to those of all the other tree species. The regeneration status of different species are highlighted in Figures 3–6 with respect to their felling series.

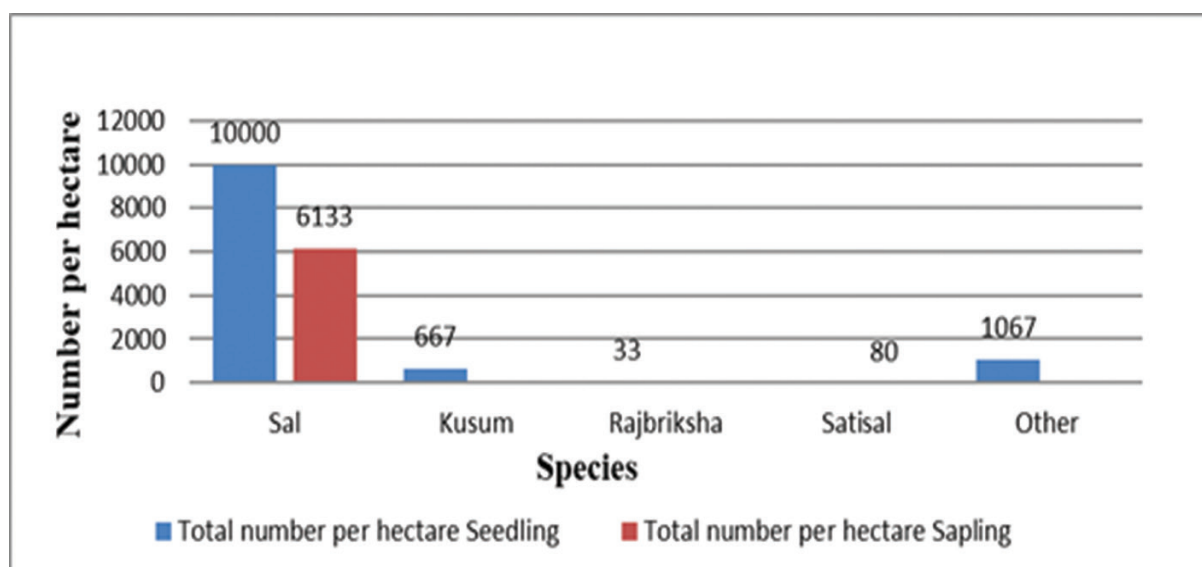


Figure 3: Regeneration status of seedlings and saplings of different. spp. in the 1st Yr. Felling Series

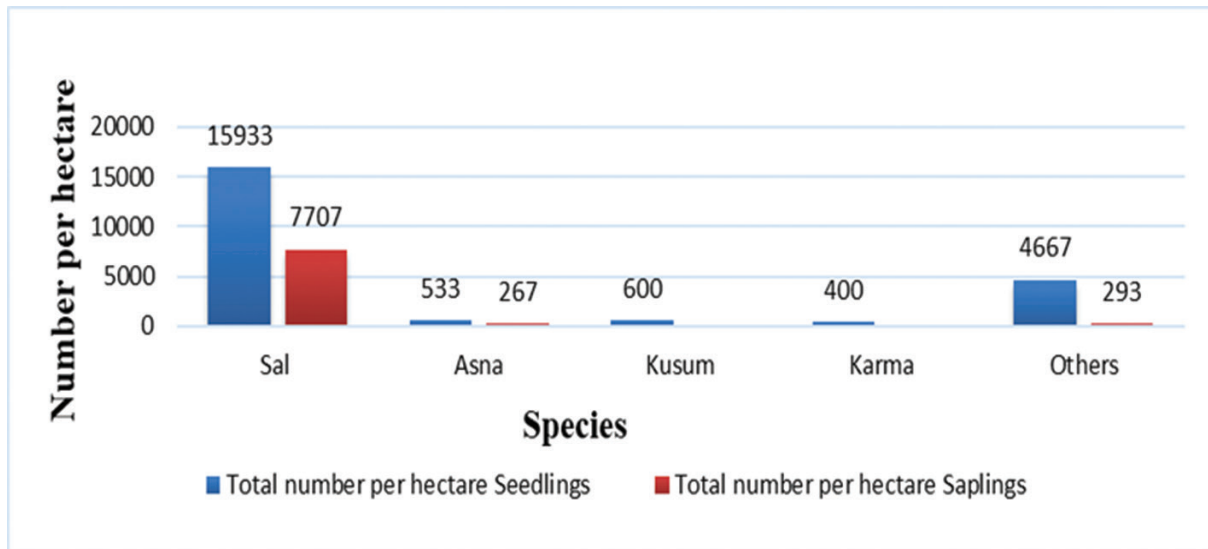


Figure. 4: Regeneration status of seedlings and saplings of different spp. in 2nd Yr. Felling Series

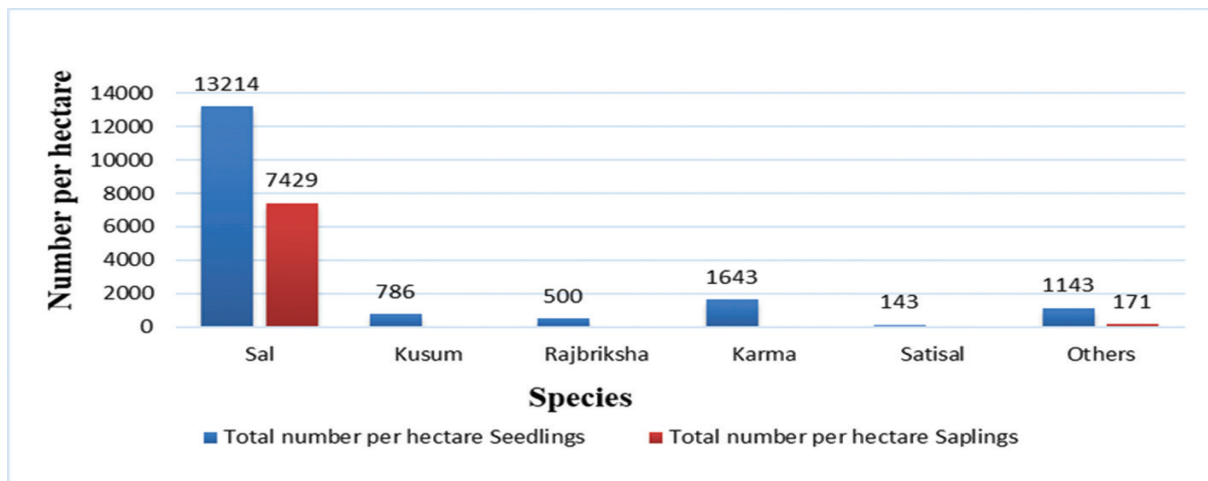


Figure 5: Regeneration status of seedlings and saplings of different spp. in the 3rd Yr. Felling Series

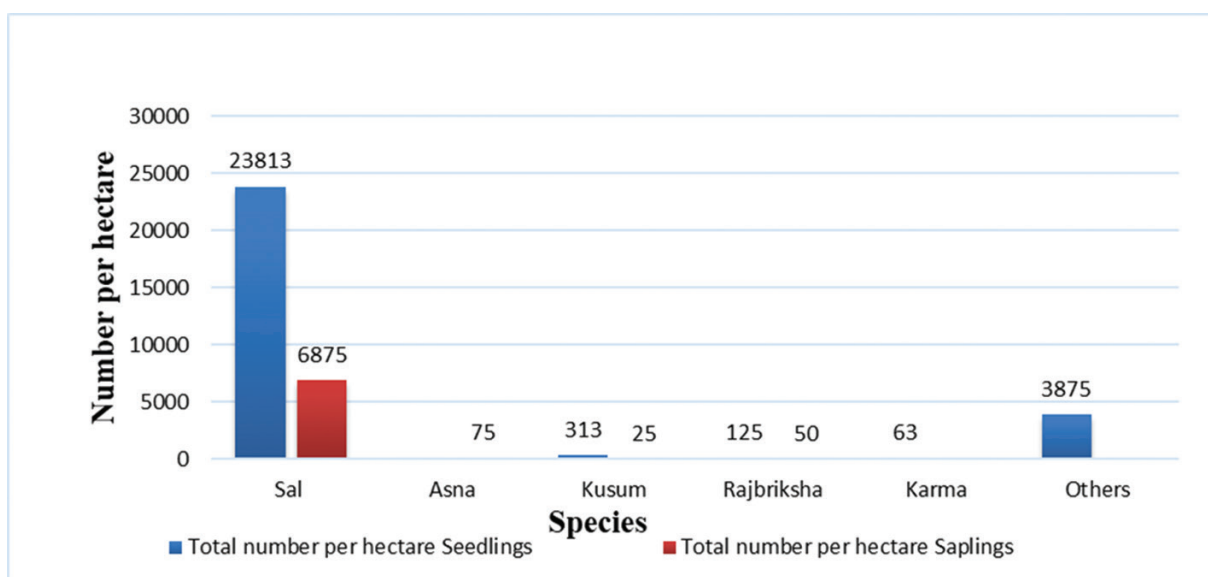


Figure 6: Regeneration status of seedlings and saplings of different spp. in the 4th Yr. Felling Series

Regeneration status of different felling series

Table 6 below depicts the regeneration status of different felling series.

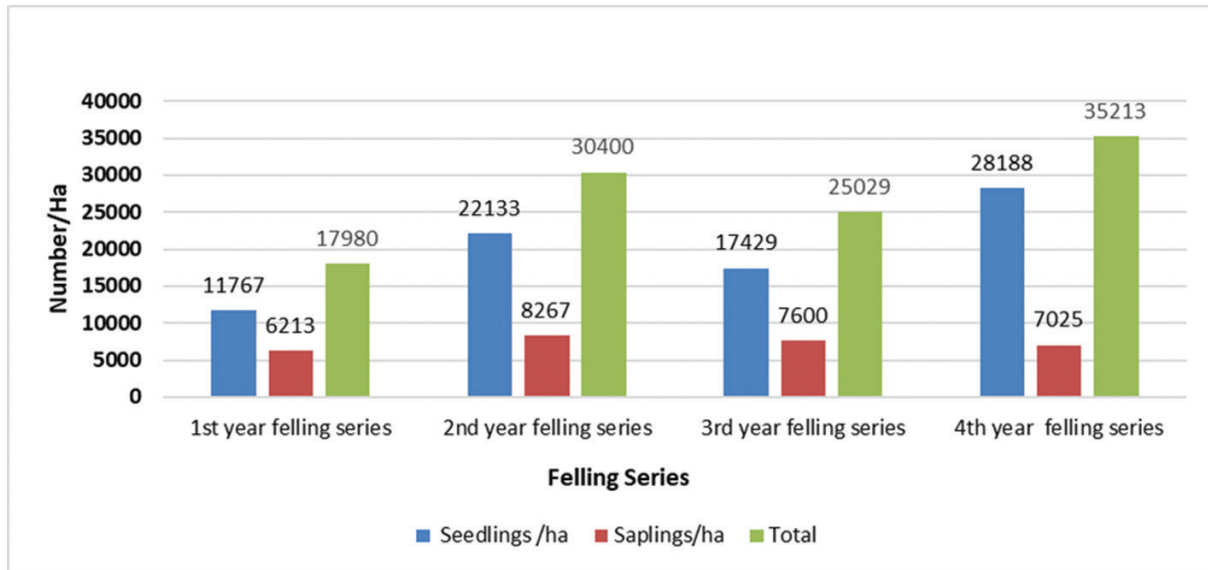


Figure 7: Regeneration status of different felling series

The total number of seedlings (28,188/ha) and saplings (7,025/ha) combined per ha was found to be the highest (35,213) in the 4th Year Felling Series. In this Felling Series, *S. robusta* possessed the highest number of seedlings (15,933) and saplings (6,875) per ha while *A. cordifolia* had the least (only 63 seedlings per ha, Figure 6).

The 2nd Year Felling Series had the second highest number of seedlings (22,133/ha) and saplings (8,267/ha) combined (30,400) per ha. In this Felling Series, the highest number of seedlings (23,813) and saplings (7,707) per ha were belonged to *S. robusta* while *A. cordifolia* consisted of the least (just 400 seedlings per ha, Figure 4).

Similarly, the third highest number of seedlings (17,429/ha) and saplings (7,600/ha) combined (25,029) per ha was noticed in the 3rd Year Felling Series. This Felling Series also possessed *S. robusta* as the dominant species with 13,214 seedlings per ha and 7,429 saplings per ha; *D. latifolia* consisted of merely 143 seedlings per ha (Figure 5).

The 1st Year Felling Series consisted of the least number of seedlings (11,767/ha) and saplings (6,213/ha) combined (17,980/ha) per ha. *S. robusta* possessed the highest number of seedlings

(10,000/ha) and saplings (6,113/ha) whereas *C. fistula* occupied the least (just 33 seedlings per ha, Figure 3).

Figure 7 shows the summary of regeneration status in different felling series.

As per the CF Inventory Guidelines 2061, the regeneration status of all the felling series were found to be in good condition with the number of seedlings and saplings exceeding 5,000 and 2,000 per ha, respectively.

Diversity of plant species

Table 4 shows a different scenario of the plant diversity indices. Comparing the diversity indices among the four felling series, the value of the Simpson's Index (0.6934) in the 2nd Year Felling Series was more near to '0' which indicated that it was more diverse as compared to the other felling series. Also, the value of the Shannon Weiner Index (0.6255) was higher in the 2nd Year Felling Series in comparison with those of the other felling series which also supported the result of the Simpson Index. In the case of the species evenness, the value was found to be greater (0.3869) in the 2nd Year Felling Series which depicted that the species were more evenly distributed in this series as compared to the other felling series.

Table 4: Plant diversity indices in different felling series

Felling Series	No. of species	Simpson's Index of Dominance (D)	Shannon Wiener Index (H)	Simpson's Index of Diversity (1-D)	Species Richness Index (d)	Evenness Index (e)
1 st Year	6	0. 8448	0. 3833	0. 1552	0. 8298	0. 2139
2 nd Year	6	0. 6934	0. 6255	0. 3066	0. 7734	0. 3869
3 rd Year	7	0. 7663	0. 5072	0. 2337	0. 9624	0. 2606
4 th Year	7	0. 8104	0. 4071	0. 1896	0. 9097	0. 2092

Source: Field Inventory, 2019.

Similarly, the species richness index was greater (0. 9624) in the 3rdYear Felling Series which possessed total of seven species. The 4th Year Felling Series also consisted of seven species, but had a comparatively lower value of the species richness index (0. 9097) which could be due to the difference in the abundance of the species in those two felling series. However, if the values of all the plant diversity indices were analysed independently without comparing one felling series with another, then we could relate that there was no suitable plant diversity maintained in all the felling series as the dominance of a single species (*S. robusta*) was found to be more in all felling areas. It can be noticed from Figures 3, 4, 5 & 6 and Table 3 that there is a homogeneous type of regeneration in all the felling series.

Discussion

Natural regeneration of plant species is crucial to the sustainable management of tropical forests (Medjibe *et al.*, 2014). Therefore, knowledge about the plant regeneration procedure and dynamics is essential to plan and implement the management activities in the forest (Mwavu & Witkowski, 2009; Puhlick *et al.*, 2012; Yang *et al.*, 2014). This study revealed the number of regenerating species and plant diversity in the Shringihat CF. The study found that executing SciFMin community forests safeguards the promising forest health in terms of substantial regeneration of demanded species, *S. robusta* in the lowland region of Nepal. In all the felling series, *S. robusta* was found to be the dominant species, which is similar to the findings of the Terai forest inventory during 2010–2012 (DFRS, 2015). The same results were reported by Giri *et al.* (1999); Paudyal (2013); Acharya *et al.*

(2009); Sapkota *et al.* (2009). After *S. robusta*, the dominance of other species was found to be different in the different felling series (see Figure 3, 4, 5 & 6).

The study found higher seedlings and saplings number in this CF; it could be the result of regeneration felling in the Shringihat Community Forest. The numbers of seedlings were found to be 11,767/ha in the 1st Year Felling Series, 22,133/ha in the 2nd Year Felling Series, 17,429/ha in the 3rd Year Felling Series, and 28,188/ha in the 4th Year Felling Series. On an average, there were 19,879 seedlings per ha in all the felling series which corresponds to the results of Awasthi *et al.* (2015) who found 16,555–21,000 seedlings per ha after regeneration felling of *S. robusta* forest under irregular shelterwood system in a similar site of Rupandehi district. Similarly, there were 6,213 saplings per ha in the 1st Year Felling Series, 8,267 per ha in the 2nd Year Felling Series, 7,600 per ha in the 3rd Year Felling Series, and 7,025 per ha in the 4th Year Felling Series with *S. robusta* as the dominant species. As per the Community Forest Inventory Guidelines 2061, the status of regeneration (good, satisfactory, poor), the densities of the seedlings and saplings were found to be 'good' in all the four felling series. The difference in regeneration status in the different felling series may be due to the differences in the intensity of grazing, logging, cleaning operations, and the growth of invasive species in the different felling areas. A number of researchers such as Gautam *et al.* (2002); Sakurai *et al.* (2004); Yadav *et al.* (2003) have stated that the prohibition of controlled grazing inside CFs in Nepal is to contribute positive ecological impacts of the CF program, which ultimately increases forest cover, stem density, and natural regeneration. A

study carried out by Buffum *et al.* (2009) also sorted the overall increase in seedling and sapling density to the reduced grazing intensity in a late successional broadleaved community forest in Bhutan. Similarly, the impact of logging on tree regeneration varied with size and disturbance intensity. When the disturbances were immediate in intensity, the diversity of natural regeneration was highest whereas, pioneer tree species proliferated in the more heavily disturbed areas (de Carvalho *et al.*, 2017). A study conducted by Baniya *et al.* (2019) in Pine forest has also recommended that, the regeneration status and normal growing stock can be enhanced if the thinning and felling is carried out annually in different compartments in different CFs. Invasive Tree Species (ITS) might influence natural regeneration by directly limiting the saplings of native species (Hejda *et al.*, 2017). The ITS shed large numbers of seeds below their canopies, and there exists competition for light and soil resources (Kawaletz *et al.*, 2014). Hence, it affects regeneration too.

From long ago, species richness, various diversity indices, stem density and species importance value index has been used to evaluate population dynamics and their diversity in the forest (Gimaret–Carpentier *et al.*, 1998). Different types of forest management practices significantly affect the structure of plant species diversity in forests (de Avila *et al.*, 2015). However, the script of the management objectives also plays a crucial part in determining plant diversity and species richness in the long–term (Cedamon *et al.*, 2017). Species diversity refers to the frequency and variety of species within a geographical area (HMGN/MFSC, 2002). It refers to the species richness and evenness within an area which describes the structure of the plant community. Plant species are directly affected by the harvesting or management practices operated in a stand. This study showed the dominance of single species was higher, i. e. 0. 69 to 0. 84. Subsequently, the diversity index was low in all the four felling series. The Simpson Species Diversity Index was found to be less in all the four felling series. i. e. between 0. 15 to 0. 30. Awasthi *et al.* (2020) also concluded that the silvicultural practices under SciFM decreases plant diversity as the species diversity index was found to have decreased in

all the managed blocks than in the unmanaged ones. The Shannon–Wiener Index was found to be between 0. 38 to 0. 62. As these four felling series can be considered as managed forests, the present values are closely comparable to those reported by Uniyal *et al.* (2010) from Garhwal Himalaya, where it was 0. 7 for the managed forests and 1. 4 for the unmanaged ones. Also, the species richness and species evenness were found to be comparatively low in this study; the species richness was found to be between 0. 77 to 0. 96 while the species evenness was found to be within the range of 0. 20 – 0. 36 which could be due to the harvesting and logging practices in the felling series. Harvesting operations and logging intensity are accounted to be decidedly effectual in shaping species diversity and composition (González–Alday *et al.*, 2008). For example, the higher the harvesting quantity, the lesser the species diversity in SciFM practices (Shima *et al.*, 2018). The cause of lowering species diversity, evenness, and richness in managed blocks is also accounted for the proportionately higher logging intensity in SciFM, where just 15–30 mother trees per hectare are kept during regeneration felling in the forest (Poudyal *et al.*, 2019). The species richness indices in the 1st, 2nd, 3rd and 4th Year Felling Series in this study were found to be 0. 8298, 0. 7734, 0. 9624, and 0. 9097, respectively, indicating less species richness in our study site. A study conducted by Halpern & Spies (1995) and Smith *et al.* (2005) revealed the declining of species richness due to high logging intensity in the sub–tropical forests of Australia. Our findings also indicated positive impacts towards regeneration status in different felling series but with less species diversity. Several researchers such as Carreño–Rocabado *et al.*, 2012; Smith *et al.*, 2005; and Roberts & Gilliam, 1995) have argued that there is less species diversity in intensively managed production forestry than natural forest. The study performed by Sapkota *et al.* (2010) also found the significant decline in the species diversity along the disturbance gradient in *S. robusta* forest in Nepal. The additional management activities like fertilization, grazing, and herbicide application could also affect the species composition and diversity of vegetation in addition to the initial effect of logging and preparation of site. Shima

et al. (2018) concluded that species diversity increased with the decreasing logging intensity in Malaysia suggesting that the active management activities and logging practices in forests would change the species composition with due regards of changes in species mortality and recruitment.

Conclusion

This study conducted a comparative analysis about the regeneration status and species diversity in different felling series of the Shringigh at CF where SciFM was practiced. We found that SciFM resulted in homogeneity of the tree species and increased the number of regeneration of the seedlings and saplings whereas it eventually decreased the species diversity within the felling series. We found that SciFM practices increased the dominance of the intended/high-value species. The silvicultural operations like regeneration felling followed by the post-harvesting operations showed excessive growth in the seedlings and saplings density. Similarly, the regeneration promotion activities like cleaning, weeding, thinning were found suitable for establishing the regeneration of the intended species. Taking this into consideration, the CFUGs, management planners and practitioners should focus on maintaining the species diversity avoiding the excessive dominance of any single species. Hence, this study recommends the concerned authorities to adopt various measures for establishing a heterogeneous plant community under SciFM and control the risk factors that may affect regenerations. However, the reason behind the homogeneity of the species and essential measures to maintain plant species diversity should be further studied.

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