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Impact of Canopy Openings on Regeneration Dynamics in Lowland Sal (*Shorea robusta* Gaertn.) Forests in Nepal

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ABSTRACT

Background and Objective: Canopy opening has a vital role in the regeneration density of plant species as these critically influences the germination and early growth of regeneration, particularly in the regeneration composition of *Shorea robusta* species. This study investigates the influence of canopy openings on regeneration dynamics in Sal (*Shorea robusta*) forests within two community-managed forests in Nepal: Pashupati Community Forest (Makwanpur) and Janakinagar Collaborative Forest (Sarlahi). **Materials and Methods:** Using a stratified sampling approach, 40 plots were surveyed and categorized based on canopy cover (0-50% as open canopy and 51-100% as dense canopy). Regeneration was assessed by counting seedlings and saplings, and statistical analysis (at 5% level of significance) was performed using SPSS. **Results:** The study showed significantly higher regeneration density in open canopy areas compared to dense canopy areas, with Shorea robusta showing strong sensitivity to light availability. A strong negative correlation was found between canopy cover and regeneration density (r = -0.74 and r = -0.87). **Conclusion:** The study concludes that integrating forest silvicultural interventions into community and collaborative forest management practices is essential for sustainable forest regeneration and long-term productivity. It also highlights the need for site-specific silvicultural interventions and further research into long-term ecological and socio-economic factors affecting forest regeneration.

KEYWORDS

Canopy cover, community forest management, forest regeneration, *Shorea robusta*

INTRODUCTION

Forests are dynamic ecosystems where regeneration plays a fundamental role in maintaining structural stability, biodiversity, and productivity[1,2]. Among tropical deciduous forests, the Shorea robusta Gaertn. (commonly known as Sal in Nepal) The forest ecosystem is one of the most dominant and economically significant forest types in the lowlands of Nepal[3,4]. Covering a large portion of the Terai and Siwalik Regions, Sal forests support a wide range of ecosystem services, including timber production, carbon sequestration, biodiversity conservation, and the livelihoods of forest-dependent communities[4,5]. Sustainable regeneration of these forests is critical for maintaining their ecological integrity and ensuring long-term forest productivity.

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Shorea robusta is a light-demanding species, requiring adequate sunlight for seed germination and early seedling growth[3]. Under natural forest conditions, the closed canopy often limits sunlight penetration to the forest floor, hindering seed-based regeneration of Sal communities[6]. Canopy openings, whether natural (due to tree fall, wind throw, or senescence) or anthropogenic (such as selective felling, irregular shelter wood systems, or thinning operations), play a vital role in creating favorable microclimatic conditions for seed-origin regeneration by enhancing light availability, increasing soil temperature, and reducing competition from shade-tolerant understory species communities[6,7].

In Nepal, various silvicultural systems have been applied in Sal forests, especially within community forest management regimes, to promote regeneration and improve forest stand structure communities[5,7]. One such approach is the irregular shelter wood system, which involves the selective removal of mature trees to create canopy gaps[5]. However, the ecological implications of these canopy manipulations are not fully understood, particularly in terms of how they influence the dynamics of seedling and sapling establishment, species composition, and biodiversity patterns. While, increased light due to canopy opening may enhance the growth of target species like Sal, it may also lead to reduced overall species diversity due to competitive exclusion, changes in soil moisture regimes, and increased vulnerability to invasive species gaps[8]. Various studies from Nepal and other parts of the world have highlighted the complex relationship between canopy structure and regeneration success gaps[9-11]. For instance, seedling density of Sal is significantly higher in areas with lower canopy closure, suggesting a positive correlation between canopy openness and seed-based regeneration gaps[4,10]. Conversely, heavily shaded forests tend to support denser growth of coppice-origin regeneration and higher species richness, but with slower growth rates gaps[8]. Given the increasing emphasis on sustainable forest management (SFM) and climate resilience, it is essential to generate empirical evidence on the influence of canopy openings on forest regeneration in Sal-dominated ecosystems gaps[5,7]. This study aims to fill this knowledge gap by assessing the effects of varying degrees of canopy cover on the regeneration dynamics of Shorea robusta in the lowland forests of Nepal. Through this research, we aim to contribute to the development of an ecologically sound forest management plan that balances timber production, biodiversity conservation, and ecosystem service maintenance in Nepal's Sal forests.

MATERIALS AND METHODS

Study area: The study was conducted from March, 2022 to June, 2022 in two community-based forests, namely: Pashupati Community Forest (CF) from Makwanpur District and Janakinagar Collaborative Forest (CFM) from Sarlahi District.

Makwanpur District is located between Latitude 27°29'N and Longitude 85°3'E. Accordingly, Sarlahi district is located between Latitude 26°58'N and Longitude 85°34'E. Both the forests are dominated by *Shorea robusta* with other associates such as *Terminalia alata, Lagerstroemia parviflora* etc.[12,13] Details of the studied forest area presented in Table 1.

Sampling design and data collection: In both forests, the irregular shelter wood system has been applied with regeneration felling for Sal forest management[12]. Stratified sampling method was adopted for data collection, where the area with regeneration felling was carried out as taken as open canopy (i.e.) and the undisturbed area with no regeneration felling was taken as dense canopy (i.e.,) productivity[8]. Individual plants were categorized into seedlings (ht < 1.3 m) and saplings (dbh <10 cm and ht > 1.3 m)

Table 1: Details of the studied FUGs

S.N.	Name of FUGs	Address	Area (hectare)	Date of handover (in BS)
1	Pashupati CF	Manahari-7, Makwanpur	288.22	1993/11/10
2	Janakinagar CFM	Janakinagar-, Sarlahi	1294.27	2017/12/14

FUG: Forest user group, CF: Community forest, CFM: Collaborative forest management, BS: Bikram sambat (Nepali calendar), ha: Hectare

as recommended by the Community Forest Inventory guideline of the Government of Nepal[13]. The quadrants of 5×2m were laid out for seedlings and saplings count. A total of 40 plots (20 from each forest) were taken from two forests. Furthermore, of the total 20 plots, every 10 plots were stratified into two canopy cover classes, namely: 0-50%, and 51-100% productivity. Diameter tape and GPS were used for the measurement of plots. A densitometer was used to determie the canopy coverage.

Data analysis: Data analysis was carried out using Statistical Package for the Social Sciences (SPSS) version 30. Descriptive statistics were used to present graphs and tables, while inferential statistics (at 5% level of significance) were also used to test the relationships between different variables under study.

RESULTS

Conditions of regeneration: Figure 1 presents the comparison of regeneration conditions (measured in terms of seedlings per hectare and saplings per hectare) between two different forest management sites: Pashupati CF and Janakinagar CFM. Janakinagar CFM (9,200 seedlings per hectare) has a higher seedling density compared to Pashupati CF (8,100 seedlings per hectare), indicating possibly better regeneration or more recent disturbance creating favorable conditions for seedling emergence. Similarly, Janakinagar CFM (4,300 saplings per hectare) shows a higher sapling density, although the difference is smaller than that observed in seedlings.

Shorea robusta dominated the regeneration composition in both sites, with a density of 5,900 seedlings per hectare and 3,000 saplings per hectare in Pashupati CF, and 7,600 seedlings per hectare and 3,500 saplings per hectare in Janakinagar CFM. Other regenerating species included *Terminalia alata*, *Lagerstroemia parviflora*, *Syzygium cumini*, *Syzygium operculata* etc.

Influence of canopy opening on regeneration density: Table 2 and 3 show the relationship between canopy cover and regeneration in two forest management sites, Pashupati CF and Janakinagar CFM. Under 0-50% canopy cover, regeneration is highest, with a total of 5,500 seedlings per hectare and 2,450 saplings per hectare in Pashupati CF. In contrast, under 51-100% canopy, the regeneration significantly drops to 2,600 seedlings per hectare and 1,500 saplings per hectare.

A similar pattern is observed in Janakinagar CF, where 0-50% canopy cover supports greater regeneration: 5,800 seedlings per hectare and 2,550 saplings per hectare. Under 51-100% canopy cover, regeneration density reduces to 3,400 seedlings per hectare and 1,750 saplings per hectare, although still higher than Pashupati in both canopy classes. *Shorea robusta* is the dominant regenerating species in both forests, with the highest number of seedlings and saplings found under 0-50% canopy cover.

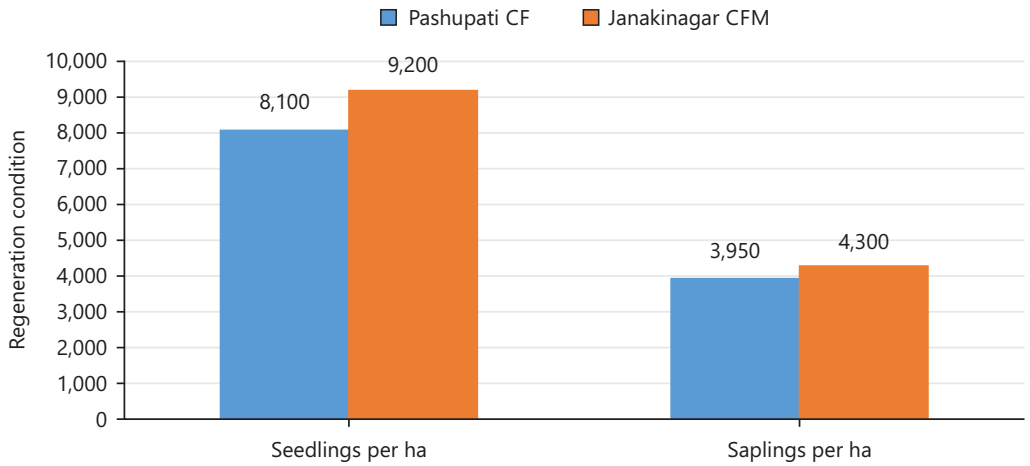

Fig. 1: Forest regeneration status in the studied CF and CFM

Table 2: Canopy coverage and regeneration density per hectare in Pashupati CF

			Regeneration count		Regeneration density (per ha)	
Forest user group	Canopy cover (%)	Species	Seedling	Sapling	Seedling	Sapling
Pashupati CF	0-50	*Shorea robusta*	83	38	4150	1900
		Terminalia alata	8	2	400	100
		Others	19	9	950	450
		Total			5,500	2450
	51-100	*Shorea robust*	35	22	1750	1100
		Terminalia alata	3	1	150	50
		Others	14	7	700	350
		Total			2600	1500

Table 3: Canopy coverage and regeneration density per hectare in Janakinagar CFM

			Regeneration count		Regeneration density (per ha)	
Forest user group	Canopy cover (%)	Species	Seedling	Sapling	Seedling	Sapling
Janakinagar CFM	0-50	*Shorea robusta*	95	44	4750	2200
		Terminalia alata	6	1	300	50
		Others	15	6	750	300
		Total			5800	2550
	51-100	*Shorea robust*	57	26	2850	1300
		Terminalia alata	2	1	100	50
		Others	9	8	450	400
		Total			3400	1750

A strong negative correlation was observed between canopy coverage and total regeneration density: r = -0.74 in Pashupati CF and r = -0.87 in Janakinagar CFM. This result shows that increased canopy closure significantly reduces regeneration potential in the *Shorea robusta* forest.

DISCUSSION

The regeneration status of a forest indicates its health and vitality, while a healthy forest promotes good future regeneration. There is a considerable difference in regeneration density between open canopy and dense canopy (Table 2 and 3). The overall regeneration (seedling and sapling density combined) was found to be higher in the open canopy strata (0-50% crown cover) compared to dense canopy areas (51-100% crown cover). The result aligns with the findings that the regeneration of most tree species in lowland areas of Nepal, including Sal forests, is promoted by a moderate level of disturbance[4,7]. The regeneration performance of *Shorea robusta* and other associated species in Nepal's lowland was found to be better in open space than under shade[14,15].

The study found that canopy coverage has a vital role in the regeneration density of plant species, particularly in the regeneration composition of *Shorea robusta* species (Table 2 and 3). The findings from Pashupati CF (Makwanpur) and Janakinagar CFM (Sarlahi) indicate a strong relationship between canopy coverage and regeneration dynamics of tree species, particularly *Shorea robusta*. In both community-managed (CFM) and traditionally managed (CF) forests, the highest regeneration densities of *Shorea robusta* were recorded in the lowest canopy cover class (0-50%). This suggests that light availability is a critical factor influencing the germination and early growth of seedlings and saplings. Therefore, the opening of the canopy is one of the important factors in the study of plant growth and development that influences the phenology of plant communities[11,16]. A strong negative correlation between canopy cover and regeneration density was observed (r = -0.74 in Pashupati CF and r = -0.87 in Janakinagar CFM), further confirming that denser canopy conditions suppress natural regeneration. These findings are consistent with previous research indicating that moderate light-demanding species such as *Shorea robusta* regenerate better under partial to open canopy conditions communities[10]. These findings have important implications for sustainable forest management. This suggests that controlled canopy manipulation (e.g., thinning or regulated harvesting) may be necessary to maintain or

enhance regeneration, particularly for moderate light-demanding species like *Shorea robusta*. Furthermore, this study highlights the importance of site-specific management interventions in optimizing forest regeneration and biodiversity conservation.

CONCLUSION

The study revealed that lower canopy cover (0-50%) significantly enhances regeneration in *Shorea robusta* forests, due to improved light availability. A strong negative correlation between canopy coverage and regeneration density highlights the importance of canopy management in both community forest (CF) and collaborative forest management (CFM) contexts. The slightly better regeneration in Janakinagar CFM suggests that collaborative, science-based forest management promotes better regeneration outcomes. However, these findings imply that incorporating canopy regulation into community forest management plans is vital for sustainable forest management, ensuring long-term forest productivity. Future studies explore the long-term growth performance under different canopy and silvicultural regimes, as well as assess the impact of other ecological and socio-economic variables on regeneration success.

SIGNIFICANCE STATEMENT

This study discovered the strong influence of canopy openness on regeneration density, which can be beneficial for developing ecologically sound and sustainable forest management strategies. By revealing how light availability regulates natural regeneration in Sal forests, the findings offer practical guidance for applying controlled silvicultural interventions. Such strategies can improve forest regeneration, maintain biodiversity, and support ecosystem service delivery. This is particularly crucial for Nepal's Sal forests, which sustain the livelihoods of many forest-dependent communities. The insights gained provide a scientific foundation for enhancing forest productivity while conserving ecological integrity. This study will help researchers uncover the critical areas of regeneration ecology and light dynamics that many researchers were not able to explore. Thus, a new theory on light-mediated forest restoration may be arrived at.

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