Regeneration Patterns following Regeneration Felling in Sal (*Shorea robusta* Gaertn.f.) Forests Managed under the Shelterwood System

Ram Bichari Thakur[1*], Rajesh Kumar Rai[2], Ridish Kumar Pokharel[1], Prem Raj Neupane[3]

Received: 10 February 2025 Revised: 15 August 2025 Accepted: 5 September 2025 Published: 30 September 2025

A shelterwood system was implemented, with regeneration felling carried out in the most degraded areas and mother trees retained to support seedling establishment. Empirical findings indicate high regeneration density but low species richness. Additionally, concerns remain regarding the quality of regeneration, including the origin of seedlings following regeneration felling. In this context, this study examines regeneration dynamics in six community-managed Sal (*Shorea robusta*) forests in Nepal's far-western region, where dry climatic conditions and forest fragmentation pose significant challenges to regeneration. A total of 376 sample plots were surveyed, with managed plots (subjected to regeneration felling) compared to natural stands. Seedling and sapling densities were assessed using systematic sampling, and a semi-destructive method was employed to determine the origin of seedlings (seed vs. seedling coppice). The findings revealed that managed plots had significantly higher density and species richness across both seedling and sapling stages of regeneration. Seedling coppice dominated both managed and natural stands, with significantly higher seed-originated seedlings in natural stands. Overall, the study highlights the effectiveness of regeneration felling under a shelterwood system, which enhances regeneration density and species richness, and improves the mechanical properties of wood by promoting seed-originated seedlings.

Keywords: Forest management, Natural stands, Seedling coppice, Seed-originated seedlings

Sal (*Shorea robusta* Gaertn.f.) forests are the most ecologically and economically significant ecosystems in the Hindu Kush Himalayan Region and the surrounding Gangetic plain, particularly in Nepal, Bangladesh, India, and Bhutan. These forests play a crucial role in biodiversity conservation, carbon sequestration, and provide a diverse range of forest products (Webb & Sah, 2003; Gautam & Devoe, 2006; Soni et al., 2013). However, these forests are gradually degrading due to anthropogenic pressures, including grazing and forest fires, as well as poor management (Rahman et al., 2010). In this context, there is a risk of declining Sal forest area, which requires an appropriate strategy for conservation and restoration of these ecosystems (Shishir et al., 2020).

Natural regeneration of Sal is the appropriate method for forest restoration and management; however, it is often challenged by high seedling mortality and periodic disturbances (Chauhan et al., 2010). These disturbances include seasonal flooding, selective logging, and forest management activities aimed at increasing yield. As Sal can be propagated by both seed and coppice, most of the Sal forests are dominated by seedling coppice (Suoheimo, 1999). Seedling coppice originates from the rootstock of a plant, which has remained in the soil for several years (Kermode, 1954). This is mainly due to the dieback phenomenon in Sal forests. The dieback typically occurs during the recruitment phase of Sal seedlings, where the root system remains viable and produces new sprouts annually until the shoot successfully

[1]Institute of Forestry, Tribhuvan University, Nepal. *Email: rbthakur@gmail.com
[2]School of Forestry and Natural Resource Management, Institute of Forestry, Tribhuvan University, Nepal
[3]University of Hamburg, Germany

matures into a tree (Troup, 1921; Jackson et al., 1994). Seedlings exposed to extreme environmental conditions, such as frost, drought, or fire, may experience dieback. Even surface fire is sufficient to kill seedlings (Kermode, 1954).

Dieback has both ecological and economic consequences in Sal forests. It delays the establishment of regeneration by repeatedly damaging young seedlings. Since the root system often remains alive, seedlings may continue to sprout annually, but recurrent dieback weakens their growth, leading to prolonged recruitment phases. This cycle significantly slows down the natural regeneration process, especially in the absence of protective measures, which may take 30 to 60 years to establish the new generation of Sal (Troup, 1921; Jackson et al., 1994). Coppice-originated trees exhibit rapid growth rates; they tend to develop irregular stems and lower wood density, making them less suitable for high-value timber production (Bailey & Harjanto, 2005). In contrast, seed-originated trees grow more slowly but produce superior timber due to their straight bowl, high mechanical strength, and uniform wood properties (Krainovic et al., 2023; Savidge, 2003).

In Nepal, natural regeneration of Sal forests is predominantly characterized by coppice regeneration, rather than by seed-originated seedlings (Suoheimo, 1999; Pokhrel et al., 2024). The high density of coppice seedlings in Sal forests raises concerns about the long-term quality of timber and the sustainability of forest management. Strategies to reduce coppice dominance and encourage seed-originated regeneration—such as controlled burning, reducing tree density, and selective thinning—are essential for maintaining forest health and economic value (Chauhan et al., 2010). Similarly, regeneration felling retaining an appropriate number of shelter trees and selective removal of less desirable species for timber can also reduce the dieback phenomenon in Sal seedlings (Rautiainen & Suoheimo, 1997). This can be performed under the shelterwood system, in which mature trees are removed in a series of partial cuttings to establish and protect natural regeneration under the shelter of remaining trees. This gradual removal of the canopy creates favorable microclimatic conditions, such as moderated light and temperature, and moisture levels, which are essential for the successful germination and growth of light-demanding species like Sal (Klopcic & Boncina, 2012).

However, there is a consistent critique of the implication of regeneration felling under a shelterwood system as it reduces plant species diversity and increases the dominance of Sal (Awasthi et al., 2020; Pokhrel et al., 2024). Most of these studies have focused on regeneration density and species richness in the regeneration layer, but have excluded the aspect of forest condition in terms of the origin of regeneration. Understanding the origin of regenerations offers valuable insights for designing silvicultural treatments that promote seed-originated Sal forests. This study aims to evaluate the regeneration dynamics of Sal forests by comparing forest areas where regeneration felling has been implemented with areas where no forest management interventions have taken place. The evaluation focuses on key indicators of forest regeneration, including the composition of regenerating vegetation-particularly seedling density and species richness -and the origin of the regeneration (i.e., whether it arises from coppice (rootstock) or seed germination). By analyzing these parameters, the study aims to understand how silvicultural interventions, such as regeneration felling, influence the natural regeneration processes of Sal forests and whether these management practices support or hinder ecological recovery and species diversity compared to natural forest stands.

Materials and methods

Study area

The study was conducted across six community-managed Sal forests of the far-western region of Nepal. These are the Barhaban Collaborative Forest Management (CFM) of Kailali district, and Hariyali Community Forest (CF), Jagadhamba CF, Krishna CF, Mahakali CF, and Sita CF of Kanchanpur district. The far-western region has a relatively drier climate. Kailali and Kanchanpur districts receive an average annual rainfall of 1,550 -1,650 mm, with the highest precipitation occurring between July and September (Gautam et al., 2010). Prolonged dry periods and seasonal drought stress make Sal regeneration more challenging (Garkoti et al., 2003). This could be the reason behind the higher species richness and diversity of seasonally dry, Sal-dominated forests in the lowland of the eastern Himalayan region compared to other regions (Shankar, 2001). Sal forests in most areas are becoming increasingly fragmented, with reduced tree density, primarily due to the clearing of adjacent forest land for farming and other purposes (DFRS, 2014).

All these forests have been subjected to the irregular shelterwood management system. According to the Scientific Forest Management Guidelines (2014), Sal forests were divided into compartments based on area, with an 80-year rotational period (DoF, 2014). Each compartment was further divided into eight sub-compartments, where regeneration felling was carried out over 10 years. In those plots with regeneration felling, only individuals above 30 cm diameter at breast height (DBH) were felled, and 15-25 individuals per hectare were retained as shelter/mother trees. Regeneration felling in these forests was carried out four to five years ago. After the regeneration felling, all plots were fenced, and cleaning operations (removing debris, shrubs, and weeds) were carried out to promote regeneration.

The characteristic features of these forests are presented in Table 1. Individuals with a DBH of 10–29.9 cm are classified as poles, and those with a DBH of 30 cm or greater are classified as trees (DFRS, 2015a). In accordance with the guidelines, mother or shelter trees have been retained in Barhaban and Sita forests (20-21 trees/ha), while other forests have a higher number of retentions (>31/ha) compared to the number of mother/shelter trees recommended by the guidelines (15-25 trees/ha). Although the growing stock varies among the forests, all have initiated regeneration felling in the areas with little or no regeneration. In regeneration felling, mother trees are retained to open the canopy and allow more light to facilitate regeneration.

Data collection

This study is based on the primary data collected through a forest inventory. In all selected forests, plots with regeneration harvesting were classified as managed, while those without regeneration harvesting were considered natural stands. The natural stands were selected immediately adjacent to the managed plots to ensure comparability. A systematic approach was used to sample the plots within the forests. In each forest, the first plot of 10 m² (5m × 2m) was selected 30 m west of the southeastern corner and then 50 m inward from the edge, perpendicular to it, to avoid edge effect. Different distances, ranging from 20 to 100 meters into the forest interior, have been utilized to reduce the edge effect on regeneration in tropical forests (Benítez-Malvido et al., 2018).

The distance between two consecutive plots was 100 m, and between two transects was 50 m. A total of 376 plots were studied across these areas (Table 2). The number of sample plots was determined based on the area of each plot, whether managed or not, selected for the study, and thus varied among the community forests. In each sample plot, regenerations of tree species were counted by species. This is because the management approach, the shelterwood system, adopted in these forests, focused on timber production. In this study, a seedling refers to a young plant less than 1.3 meters in height, while a sapling is a young plant with a height greater than 1.3 meters and a DBH of less than 5 cm (Community and Private Forest Division, 2004). Both seedlings and saplings of the tree category are collectively referred to as regeneration (FRTC, 2022). A measuring stick of 1.3 meters in height was used to classify the regenerating plants as either seedlings (height < 1.3 m) or saplings (height ≥ 1.3 m). Seedlings were counted by species, and height and DBH of all saplings were measured and counted by species (Community and Private Forest Division, 2004).

Similarly, a sub-plot of 1 m² (1m × 1m) was nested within the main plot. A semi-destructive approach was used to determine the mode of regeneration, whether the seedling germinated through the seed or the seedling coppice. In this approach, carefully digging around a seedling can reveal its origin, exposing the root system without damaging it (Kermode, 1954). Only Sal seedlings within the subplots were excavated and examined to determine

Table 1: Structural characteristics of the studied Sal forests, including growing stock, tree and pole density, and the number of mother or shelter trees retained per hectare

Name of Forest	Growing stock (m^3/ha)	Number of Trees/ha	Number of Poles/ha	Mother or Shelter trees retained / ha
Barhaban CFM	218.13	73	75	20
Sita CF	214.12	58	67	21.5
Mahakali CF	169.83	58	225	35
Hariyali CF	165.83	77	38	45
Jagadamba CF	234.8	76	83	31
Shree Krishna CF	159.03	102	68	60

Source: Operational plan of respective forests

Table 2: Distribution of Sample plots

	Forests						
	Barhaban CFM	**Hariyali CF**	**Jagadhamba CF**	**Krishna CF**	**Mahakali CF**	**Sita CF**	**Tot al**
Managed plots	40	40	20	20	16	20	156
Natural stands	20	40	40	40	40	40	220
Total	60	80	60	60	56	60	376

Table 3: **Average seedling, sapling, and overall regeneration density (per ha) and species richness in managed and natural Sal forests (n = 376, df = 374) for Sal, other woody species, and all species combined**

Attributes	Seedling		Sapling		Regeneration	
	Managed	Natural	Managed	Natural	Managed	Natural
Density: Sal	4,519[a]	4,318[a]	1,006[ab]	309[ab]	5,525[a]	4,627[a]
Density: Others	1,064[ab]	622[ab]	134[a]	54[a]	1198[ab]	676[ab]
Density: all species	5,583[a]	4,940[a]	1,140[ab]	363[ab]	6,723[ab]	5,303[ab]
Species Richness	1.368[ab]	1.257[ab]	1.176[ab]	1.017[ab]	1.455[ab]	1.280[ab]

Note: Letters in the superscript denote significant difference ($p<0.05$) between Managed and Natural Stands

their origin- whether from coppice shoots or seed germination. Each seedling was individually recorded. As seedling coppice grows from the dormant buds in the hypocotyledonary region of damaged Sal seedlings, it has a swelling part between the cotyledons and root (Suoheimo, 1998).

Data analysis

Statistical analysis

A normality test was conducted to assess whether the data follow a normal distribution; a key assumption for a parametric test. This test helps decide whether to apply parametric tests or opt for non-parametric methods based on the data distribution. The Jarque-Bera test was performed for all variables by the origins of seedlings (Glinskiy et al., 2024). Since parametric tests are generally more robust than non-parametric alternatives, data transformations (e.g., log, Box-Cox) are often applied to adjust non-normal data toward normality. Data transformation is favorable for statistical tests but requires back-transformation of the results to make them interpretable (Lee, 2020). Since finding a valid transformation is not always possible, non-parametric tests, despite being less robust, may provide a viable solution (Habibzadeh, 2024).

Therefore, the Mann-Whitney U test, a non-parametric statistical test, was used to compare seedling and sapling densities between managed and natural stands, as well as to examine differences in seedling establishment between seedling coppice and seed origin. It evaluates whether one group has significantly higher or lower values than the other by ranking all observations and calculating a test statistic based on rank sums. IBM SPSS 29.0 was used to analyse the data.

Results

Descriptive statistics

Table 3 presents the descriptive statistics of the sample plots categorized by management regime and the results of the Mann-Whitney U Test. The managed plots exhibited 1.26 times higher regeneration density compared to natural stands. Within the regeneration layer, sapling density in managed plots was 3.25 times greater than in natural stands, while seedling density remained nearly the same. Additionally, the regeneration density of other tree species (excluding Sal) was significantly higher in managed plots, with an overall increase of 1.77 times-specifically, 1.71 times higher seedling density and 2.48 times higher sapling density. These species include Saj (*Terminalia eliptica),* Sindure (*Mallotus philippensis)*, Rajbriksha (*Cassia fistula),* Kusum (*Schleichera oleosa),* Jamun (*Syzygium cumini),* Barro (*Terminalia bellirica),* and Haldu (*Adina cardifolia).* Furthermore, species richness was greater in managed plots, with the sapling layer showing an 18-fold increase in the diversity index. However, the total regeneration layer maintained an equal diversity index across both management regimes.

The findings of the Mann-Whitney U test (Table 3) indicate that species richness is consistently and significantly higher in managed forests across all stages-seedlings, saplings, and overall regeneration -highlighting greater species variety in managed areas. In terms of total density, managed forests exhibit significantly higher sapling density and overall regeneration density, while no significant difference is observed for seedlings. A similar pattern is seen in Sal density, with a significant difference only in the sapling layer. For other species, managed forests have significantly higher density in seedlings and overall regeneration, whereas no significant difference is found in saplings.

Seedling origin

Table 4 presents seedling densities by regeneration method. In both management regimes, seedling coppice of Sal dominates the regeneration layer. The density of seedling coppice is 4.14 and 18.80 times higher than the density of seed-originated seedlings in managed and natural stands, respectively. Between management regimes, Sal seedlings originating from seeds are significantly higher in the managed plot compared to natural stands. However, the density of Sal seedling coppice is not significantly different between these management regimes. The density of seedlings (originating from seed) of other species is significantly higher in managed plots compared to natural stands. Overall, the data reveal that managed stands have more consistent Sal seed-origin regeneration, while natural stands show greater variability, particularly in seedling coppice density.

Discussion

The findings of this study indicate that creating a gap by removing mature crops contributes to promoting regeneration and species richness, while also supporting the development of future forests with denser and stronger wood through the encouragement of seed-originated seedlings. Seedling coppices constitute a significant portion of Sal forests, regardless of management interventions. The dominance of seedling coppices is a common trend in Sal forests, as observed in the past, where only four percent of seedlings originated from seeds, while the remaining 96 percent were coppice seedlings (Suoheimo, 1999).

Although shelterwood regeneration aims to promote natural regeneration through seed-originated growth by retaining mother trees, the dominance of seedling coppices raises questions about the necessity of retaining these trees. This may be primarily due to the dieback phenomenon observed in Sal forests, which, though often perceived as harmful during the regeneration phase, serves as a crucial survival mechanism (Rautiainen & Suoheimo, 1997). High seedling mortality is a common occurrence in Sal forests (Chauhan et al., 2010). The high density of coppice seedlings is primarily attributed to the stimulation of Sal regeneration by the dieback phenomenon under favorable conditions within 3-10 years (Jackson et al., 1994).

Coppice shoots often exhibit rapid early growth due to the existing root system, which can result in wood with different anatomical properties compared to seed-origin trees (Lei et al., 1997; Savidge, 2003; Longui et al., 2016). Typically, coppices are managed for small-scale forest products, as most species never reach the dimensions of trees grown from seed (Savill, 2004). Seed origin is better for stronger and more resilient wood due to narrower vessels at the transition zone (Longui et al., 2016). Therefore, it would be better to focus on promoting the seed-originated seedlings and reducing the dominance of seedling coppice. Several strategies exist to mitigate dieback and reduce seedling coppice in Sal forests. These include reducing tree density to allow light penetration and minimize competition for nutrients

Table 4: Average density (mean ± SD) and range (min–max) of Sal regeneration by seed origin, seedling coppice, and other species in managed and natural stands

Attributes	mean ± SD		min–max	
	Managed	Natural	Managed	Natural
Sal- Seed Origin	878±809[ab]	218± 1,779[ab]	0-12,000	0- 6,000
Sal-Seedling Coppice	3,641±4,880[a]	4,100± 4,366[a]	0-22,000	0-36,000
Other Species	1,064±1,476[ab]	622±1,919 [ab]	0-10,000	0-8,000

Note: Letters in the superscript denote the significant difference (p<0.05) between Managed and Natural stands and water, controlled burning, and the removal of diseased trees (Troup, 1921; Chauhan et al., 2010). In the absence of such management interventions, Sal forests may be dominated by individuals that grow from seedling coppice, which may affect the future of the forests. This could have negative ecological implications, as seed-originated individuals possess greater genetic diversity and natural growth patterns (Mejstřík et al., 2024).

The regenerations of Sal and other species are significantly enhanced under the shelterwood system. This aligns with previous studies that have measured regeneration density under the shelterwood system in other parts of the country (Khanal & Adhikari, 2018; Pokhrel et al., 2024). These results reaffirm that canopy openings in Sal forests play a crucial role in shaping future forest development. Additionally, the sapling layer is significantly influenced by management practices, consistent with existing research, which highlights that while tree species in Sal forests germinate under both gap and canopy conditions, sapling density is higher in gaps (Sharma et al., 2019).

The higher species richness in managed forests contrasts with previous studies, which suggest that regeneration felling may reduce diversity due to the dominance of Sal (Awasthi et al., 2020; Ojha et al., 2023; Pokhrel et al., 2024). These studies were conducted approximately three years after regeneration felling, during which light-demanding species are likely to dominate following canopy opening. Over time, as seedlings develop into saplings, they can create a more favorable environment for other species, particularly those that are shade-tolerant (Thakur et al., 2025). Therefore, it is likely that managed forests will have more species richness in the regeneration layer. Consequently, the regeneration layer in managed forests is likely to have higher species richness. Spatio-temporal fluctuations in light availability may contribute to the diversity of tropical tree species by providing opportunities for niche differentiation based on varying light requirements for regeneration (Rüger et al., 2009).

Conclusions

The findings of this study highlight the critical role of management interventions, canopy opening through regeneration felling, in shaping the regeneration dynamics and species composition of Sal forests. While the shelterwood system has been effective in promoting natural regeneration, the dominance of seedling coppices raises important concerns regarding the quality and long-term sustainability of Sal timber production. The high prevalence of coppice seedlings, driven by the dieback phenomenon, suggests that current regeneration strategies may need refinement to enhance seed-originated growth. Forest management could benefit from prioritizing the promotion of seed-originated seedlings, which may improve timber quality and enhance the ecological stability of Sal forests.

Given the substantial differences in timber quality between seed-originated and coppice-originated trees, it may be beneficial for management strategies to promote the establishment of seed-originated seedlings. Without intervention, Sal forests risk being dominated by lower-quality coppice-originated trees, which may have long-term economic and ecological consequences.

This study reaffirms that while canopy openings enhance sapling density and encourage the recruitment of diverse species, spatio-temporal variations in light availability create opportunities for niche differentiation, supporting a richer biodiversity over time. These findings suggest that balancing regeneration felling with conservation efforts can enhance both species richness and timber quality of future stands. Future research should focus on refining silvicultural techniques that help to minimize the abundance of seedling coppice following regeneration felling, as well as evaluating the diversity of entire plant communities to better understand ecological impacts.

Acknowledgements

The authors would like to thank the anonymous reviewers for their valuable comments, which significantly improved the quality of the paper. This paper is part of a PhD thesis supported by the Institute of Forestry under the Higher Education Reform Project (HERP-DLI-7B) at Tribhuvan University (TU), Nepal.

Author contribution

RBT: Conceptualization, Methodology, Data collection, Data analysis, Original Draft.; **RKR**: Methodology, Data analysis, Review & Editing, Validation, Supervision.; **RKP**: Data analysis, Review & Editing, Supervision.; **PRN**: Review & Editing, Supervision

Conflict of interest

The authors declare no conflicts of interest.

References

Awasthi, N., Aryal, K., Chhetri, B. B. K., Bhandari, S. K., Khanal, Y., Gotame, P., & Baral, K. (2020). Reflecting on species diversity and regeneration dynamics of scientific forest management practices in Nepal. *Forest Ecology and Management*, *474*, 118378. https://doi.org/10.1016/j.foreco.2020.118378

Bailey, J. D., & Harjanto, N. A. (2005). Teak (Tectona grandis L.) tree growth, stem quality and health in coppiced plantations in Java, Indonesia. *New Forests*, *30*, 55–65. https://doi.org/10.1007/s11056-004-1116-5

Benítez Malvido, J., Lázaro, A., & Ferraz, I. D. K. (2018). Effect of distance to edge and edge interaction on seedling regeneration and biotic damage in tropical rainforest fragments: A long term experiment. *Journal of Ecology*, *106*(6), 2204-2217. https://doi.org/10.1093/treephys/23.15.1021

Chauhan, D. S., Singh, B., Chauhan, S., Dhanai, C. S., & Todaria, N. P. (2010). Regeneration and plant diversity of natural and planted sal (*Shorea robusta* Gaertn. F.) forests in the Terai-Bhabhar of Sohagibarwa Wildlife Sanctuary, India. *Journal of American Science*, *6*(3), 32-45.

Community and Private Forest Division. (2004). *Revised guidelines for community forest resource inventory* (M. of F. and S. C. Community and Private Forest Division, Ed.).

DFRS. (2014). *Terai Forests of Nepal 2010-2012* (Vol. 53, Issue 9). Department of Forest Research and Survey. Department of Forest Research and Survey (DFRS), Kathmandu, Nepal.

DFRS. (2015a). *Middle Mountains Forests of Nepal: Forest Resource Assessment (FRA) Nepal*. Department of Forest Research and Survey (DFRS), Kathmandu, Nepal.

DoF. (2014). *Scientific Forest Management Guidelines 2071*. Department of Forests (DoF), Kathmandu, Nepal.

FRTC. (2022). *Forest Resource Assessment in Nepal [Re-Measurement of Permanent Sample Plots] Field Manual 2022*. Forest Research and Training Center (FRTC), Kathmandu, Nepal.

Garkoti, S. C., Zobel, D. B., & Singh, S. P. (2003). Variation in drought response of sal (*Shorea robusta*) seedlings. *Tree physiology*, *23*(15), 1021-1030. https://doi.org/10.1093/treephys/23.15.1021

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

Gautam, S. K., Pokharel, Y. P., Goutam, K. R., Khanal, S., & Giri, R. K. (2010). Forest structure in the Far Western Terai of Nepal: Implications for management. *Banko Janakari*, *20*(2), 21-25. https://doi.org/10.1093/forestry/cpi063

Glinskiy, V., Ismayilova, Y., Khrushchev, S., Logachov, A., Logachova, O., Serga, L., Yambartsev, A., & Zaykov, K. (2024). Modifications to the Jarque–Bera Test. *Mathematics*, *12*(16), 2523. https://doi.org/10.3390/math12162523

Habibzadeh, F. (2024). Data distribution: Normal or abnormal? *Journal of Korean Medical Science*, *39*(3). https://doi.org/10.3346/jkms.2024.39.e35

Jackson, J. K., Stapleton, C. M. A., & Jeanrenaud, J.-P. (1994). *Manual of afforestation in Nepal-Volume 2*. Forest Research and Survey Center, Ministry of Forests and Soil Conservation, Kathmandu, Nepal.

Kermode, C. W. D. (1954). Seedling coppice and the seedling coppice system of regeneration. *Empire Forestry Review*, 366-374.

Khanal, Y., & Adhikari, S. (2018). Regeneration promotion and income generation through scientific forest management in community forestry: A case study from Rupandehi district, Nepal. *Banko Janakari*, 45–53. https://doi.org/10.3126/banko.v27i3.20541

Klopcic, M., & Boncina, A. (2012). Recruitment of tree species in mixed selection and irregular shelterwood forest stands. *Annals of Forest Science*, *69*, 915-925. https://doi.org/10.1007/s13595-012-0224-1

Krainovic, P. M., de Resende, A. F., Amazonas, N. T., de Almeida, C. T., de Almeida, D. R. A., Silva, C. C., de Andrade, H. S. F., Rodrigues, R. R., & Brancalion, P. H. S. (2023). Potential native timber production in tropical forest restoration plantations. *Perspectives in Ecology and Conservation*, *21*(4), 294-301. https://doi.org/10.1016/j.pecon.2023.10.002

Lee, D. K. (2020). Data transformation: a focus on the interpretation. *Korean Journal of Anesthesiology*, *73*(6), 503–508. https://doi.org/10.4097/kja.20137

Lei, H., Gartner, B. L., & Milota, M. R. (1997). Effect of growth rate on the anatomy, specific gravity, and bending properties of wood from 7-year-old red alder (Alnus rubra). *Canadian Journal of Forest Research*, *27*(1), 80–85. https://doi.org/10.1139/x96-165

Longui, E. L., Sonsin, J., Santos, M., Arzolla, F. A. R. D. P., Vilela, F. E. S. P., Lima, I. L. de, Florsheim, S. M. B., & Descio, F. (2016). Differences between root and stem wood in seedlings and sprouts of *Sessea brasiliensis* (Solanaceae). *Rodriguésia*, *67*(3), 615–626. https://doi.org/10.1590/2175-7860201667306

Mejstřík, M., Svátek, M., Pollastrini, M., Šrámek, M., & Matula, R. (2024). Differential roles of seed and sprout regeneration in forest diversity and productivity after disturbance. *Forest Ecosystems*, *11*, 100198. https://doi.org/10.1016/j.fecs.2024.100198

Ojha, P., Acharya, K. R., Subedi, A., & Regmi, S. (2023). Impact of silviculture system on regeneration status and species diversity: reflection from far-western lowland, Nepal. *Banko Janakari*, *33*(2), 24-37. https://doi.org/10.3126/banko.v33i2.58280

Pokhrel, N., Timilsina, S., Awasthi, N., Adhikari, A., Adhikari, B., Ayer, S., & Bhatta, K. P. (2024). Implications of irregular shelterwood system on regeneration and species diversity of Sal (*Shorea robusta* Gaertn. f.) forest in Nepal. *Heliyon*, *10*(1). https://doi.org/10.1016/j.heliyon.2023.e23156

Rahman, M. M., Rahman, M. M., Guogang, Z., & Islam, K. S. (2010). A review of the present threats to tropical moist deciduous Sal (*Shorea robusta*) forest ecosystem of central Bangladesh. *Tropical Conservation Science*, *3*(1), 90-102. https://doi.org/10.1177/194008291000300

Rautiainen, O., & Suoheimo, J. (1997). Natural regeneration potential and early development of *Shorea robusta* Gaertn. f. forest after regeneration felling in the Bhabar-Terai zone in Nepal. *Forest Ecology and Management*, *92*(1-3), 243-251. https://doi.org/10.1016/S0378-1127(96)03911-4

Rüger, N., Huth, A., Hubbell, S. P., & Condit, R. (2009). Response of recruitment to light availability across a tropical lowland rain forest community. *Journal of Ecology*, *97*(6), 1360-1368. https://doi.org/10.1111/j.1365-2745.2009.01552.x

Savidge, R. A. (2003). Tree growth and wood quality. In J. R. Barnett & G. Jeronimidis (Eds.), *Wood Quality and its Biological Basis* (pp. 1–29). Blackwell Publishing.

Savill, P. S. (2004). Silviculture: Silvicultural systems. In J. Burley, J. Evans, & J. A. Youngquist (Eds.), *Encyclopedia of Forest Sciences* (pp. 1003–1011). Elsevier Academic Press.

Shankar, U. (2001). A case of high tree diversity in a sal (*Shorea robusta*)-dominated lowland forest of Eastern Himalaya: Floristic composition, regeneration and conservation. *Current Science*, 776-786.

Sharma, L. N., Shrestha, K. B., & Måren, I. E. (2019). Tree regeneration in gap-understory mosaics in a subtropical *Shorea robusta* (Sal) forest. *Journal of Forestry Research*, *30*(6), 2061-2068. https://doi.org/10.1007/s11676-018-0747-x

Shishir, S., Mollah, T. H., Tsuyuzaki, S., & Wada, N. (2020). Predicting the probable impact of climate change on the distribution of threatened *Shorea robusta* forest in Purbachal, Bangladesh. *Global Ecology and Conservation*, *24*, e01250. https://doi.org/10.1016/j.gecco.2020.e01250

Soni, R. K., Dixit, V., Irchhaiya, R., & Singh, H. (2013). A review update on *Shorea robusta* Gaertn f. (Sal). *Journal of Drug Delivery & Therapeutics*, *3*(6), 127-132. DOI:10.36808/if/2022/v148i6/

Suoheimo, J. (1998). *Shorea robusta* Gaertn.F. (Sal) in the Forestry of Nepal. *Thai Journal of Forestry*, *17*, 43-54.

Suoheimo, J. (1999). *Natural regeneration of Sal (Shorea robusta) in the Terai region, Nepal*. University of Helsinki, Department of Forest Ecology, Tropical Silviculture Unit.

Thakur, R.B., Rai, R.K., Pokharel, R.K., & Neupane, P.R. (2025). Regeneration dynamics in Sal (*Shorea robusta*) forests under the shelterwood system. *Forest Systems, 34 (2), 20959*. https://doi.org/10.5424/fs/2025342-20959

Troup, R. S. (1921). *The silviculture of Indian trees. 1. Dilleniaceae to Leguminosae (Papilionaceae)* (Vol. 1). Clarendon Press.

Webb, E. L., & Sah, R. N. (2003). Structure and diversity of natural and managed sal (*Shorea robusta* Gaertn. f.) forest in the Terai of Nepal. *Forest Ecology and Management*, *176*(1–3), 337-353. https://doi.org/10.1016/S0378-1127(02)00272-4