PERCENTAGE OF SAWN TIMBER OF DIFFERENT AVAILABLE SPECIES FROM LOGS (ROUND TIMBER)

Final Report

Submitted to:
Province Government, Madhesh Province
Ministry of Forests and Environment
Forest Research and Training Centre
Sagarnath, Sarlahi

Submitted by:
Institute of Forestry, Tribhuvan University, Kathmandu

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Kathmandu, Nepal

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Executive Summary

Background

Forests are vital natural resources, providing essential ecosystem services, biodiversity, and economic benefits. Timber, a key forest product, plays a significant role in construction, furniture, and industrial applications. Efficient utilization of harvested logs is crucial for sustainable forest management, especially as global demand for wood products rises. Volumetric yield, the proportion of log volume converted into usable sawn timber, is a critical metric for assessing processing efficiency. However, in developing countries like Nepal, sawmilling often suffers from low recovery rates due to inadequate infrastructure, inefficient methods, and poor log selection. This inefficiency leads to economic losses and increased environmental degradation. Despite its importance, empirical data on timber recovery, particularly for different species and sawing systems, remains limited. This study aims to address this gap by analyzing volumetric yields for commonly available timber species in Madhesh Province, Nepal, and identifying factors influencing recovery rates.

Objectives

The primary objective of this study was to determine the sawing recovery percentage for different timber species in Madhesh Province. Specific objectives included:

- Estimating the volumetric yield of sawn timber by log grades for selected species.
- Identifying factors affecting volumetric yield within given log grades.

The study focused on eight species: Sal (*Shorea robusta*), Saj (*Terminalia tomentosa*), Karma (*Adina cordifolia*), Teak (*Tectona grandis*), Masala (*Eucalyptus spp.),* Sissoo (*Dalbergia sissoo*), Jamun (*Syzygium cumini*), and Simal (*Bombax ceiba*).

Study Area and Data Collection

The study was conducted in Madhesh Province, Nepal, where timber trade is regulated through formal auctions. Data were collected from sawmills using similar processing technologies to minimize variability. Sawmill staff were trained to record log dimensions, sawn timber volumes, and defects. A total of 467 logs across the eight species were measured, with species-specific sample sizes ranging from 17 (Saj/Asna) to 152 (Simal). Log volume was calculated using the quarter-girth formula, and volumetric yield was

determined as the percentage of log volume converted into sawn timber or veneer. Data were rigorously processed to exclude anomalies, such as cases where sawn timber volume exceeded log volume.

Key Findings

The analysis of volumetric yield across different species revealed significant variation in performance and influencing factors. For Simal used in veneer production, the average defect-free yield was 56.11%, while the total yield including defective portions reached 73.98%. Interestingly, while mid-girth had a positive influence on defect-free yield, it negatively affected the total yield, implying that larger logs tend to have more defects. Masala also showed strong performance in veneer production, with a defect-free yield of 58.18% and total yield of 73.18%; however, mid-girth had a significant negative effect, indicating that larger logs may be harder to process effectively.

In the case of Saj/Asna, the average yield was 56.85%, with clear distinctions across grades—Grade A logs yielded 61.39%, whereas Grades B and C yielded 51.65% and 47.15%, respectively, highlighting the critical role of log quality. Sal exhibited an average yield of 56.16%, where Grade A logs yielded 59.44% and Grade C logs only 49.61%; mid-girth was found to be a significant positive factor. Sissoo had a relatively lower average yield of 52.53%, with a wide range from 26% to 80.25%. No significant predictors of yield were identified for Sissoo, suggesting that other unmeasured factors may influence recovery.

Teak recorded the lowest average yield at 24.39%, with mid-girth having a negative effect on yield, pointing to inefficiencies in processing larger logs. For Karma, the average yield stood at 50.16%, and mid-girth showed a highly significant positive relationship, underlining its importance in maximizing yield. Jamun demonstrated an average yield of 53.73%, with Grade A logs yielding 61.07% and Grade C logs only 42.60%; mid-girth again had a positive influence. Lastly, Masala used for timber production had an average yield of 50.21%, where mid-girth emerged as a key positive determinant, reinforcing the trend observed across several species.

The study showed significant variability in volumetric yields across species, with Simal and Masala (veneer) showing higher recovery rates compared to Teak, which had the lowest yield. Log quality (grade) and mid-girth were critical factors influencing yield, though their effects varied by species. The findings underscore the need for species-specific processing strategies and technological upgrades to improve efficiency. Limitations, such as non-standardized sawn timber sizes and unaccounted by-products, highlight areas for future research.

- Enhance Log Sectioning and Grading: Prioritize sectioning of logs with larger mid-girths and minimal taper, as these characteristics were linked to higher yields in species like Sal and Karma. Implement stricter grading standards to ensure consistent quality and reduce variability in processing outcomes.
- Adopt Advanced Sawing Technologies: Invest in modern sawmills equipped with optimization algorithms to improve recovery rates. Improved technologies in sawing can minimize waste and enhance precision, particularly for high-value species like Teak.
- Conduct Species-Specific Research: Further investigate the unique processing challenges of low-yield species like Teak to identify root causes of inefficiency. Pilot studies could test alternative sawing techniques or pre-processing treatments.
- Policy Interventions: Develop policies that incentivize high-efficiency sawmills through subsidies or tax breaks. Regulations could also mandate minimum yield standards to discourage wasteful practices.
- Promote Silviculture Based Forestry Practices: target forest management interventions to produce large diameter individuals with defect free,
- Improve Data Collection: Future studies should control for variables like log freshness and operator skill to isolate the impact of log characteristics on yield. Collaborative efforts with sawmills could ensure more consistent data.
- Raise Awareness: Educate stakeholders—from loggers to policymakers—on the economic and environmental benefits of yield optimization. Workshops and case studies can demonstrate best practices and successful implementations.

सारांश

पृष्ठभूमि

वन अत्यन्त महत्वपूर्ण प्रकृतिक स्रोत हो , जसले पारिस्थितिक सेवा, जैविक विविधता संरक्षण, र आर्थिक लाभ प्रदान गर्छन्। वनबाट प्राप्त हुने पैदावारमा काठ प्रमुख हो, जसले निर्माण, फर्निचर, र औद्योगिक प्रयोजनमा भूमिका खेल्दछ । काठजन्य उत्पादनको विश्वव्यापी माग बढ्दो अवस्थामा काठको प्रभावकारी उपयोग दिगो वन व्यवस्थापनका लागि अत्यावश्यक हुन्छ। *Volumetric yield* वा आयातन उपज भन्नाले गोलियाको कुल आयातनबाट प्रयोगयोग्य चिरान काठ प्राप्त हुने अनुपातलाई जनाउँछ, जुन प्रशोधन क्षमता मूल्याङ्कन गर्ने महत्त्वपूर्ण सूचक हो। यद्यपि, नेपालजस्ता विकासशील मुलुकहरूमा चिरानी प्रक्रियामा उपयुक्त पूर्वाधारको अभाव, परम्परागत चिरान विधि, र गोलियाको गुणस्तरका कारण चिरानी काठको उत्पादन अत्यन्त न्यून दरमा देखिन्छ। यसले आर्थिक क्षति मात्र होइन, वातावरणीय क्षतिको जोखिम पनि बढाउँछ। आयातन उपज (Volumetric yield) महत्त्वपूर्ण विषय भए तापनि, विशेषगरी विभिन्न प्रजातिहरू र तिनिहरूको गुणस्तर अनुसार चिरान काठ उत्पादन हुने तथ्याङ्क सीमित छ। यस अध्ययनले नेपालको मधेश प्रदेशमा पाइने प्रमुख काठ प्रजातिहरूको आयातन उपज (Volumetric yield) विश्लेषण गरी उपज प्राप्तिमा प्रभाव पार्ने प्रमुख कारकहरू पहिचान गर्न खोजेको हो।

उद्देश्यहरू

यस अध्ययनको मुख्य उद्देश्य मधेश प्रदेशमा पाइने विभिन्न काठ प्रजातिहरूको गोलियाको आयातनको तुलनामा चिरान उत्पादनको प्रतिशत निर्धारण गर्नु थियो। विशिष्ट उद्देश्यहरू यसप्रकार छन्:

- छानिएका प्रजातिहरूका ग्रेडअनुसार चिरान काठको आयातन उपज (Volumetric yield)अनुमान गर्नु।
- आयातन उपज (Volumetric yield) मा असर पार्ने कारकहरू पहिचान गर्नु।

यो अध्ययन आठ प्रजातिमा केन्द्रित थियोः साल (*Shorea robusta*), साज (*Terminalia tomentosa*), कर्मा (*Adina cordifolia*), साग (*Tectona grandis*), मसला (*Eucalyptus spp.*), सिसौ (*Dalbergia sissoo*), जामुन (*Syzygium cumini*), र सिमल (*Bombax ceiba*)। मसलाको गोलिया काठ र भेनियर दुबै प्रयोजनका लागि अध्ययन गरिएको थियो ।

अध्ययन क्षेत्र र तथ्याङ्क सङ्कलन

यो अध्ययन मधेश प्रदेशमा गरिएको हो । गोलिया काठको व्यापार वन नियमाली २०७९ मा उल्लेख भएअनुसार सरकारी लिलामी प्रक्रिया मार्फत नियमन गरिन्छ। यो अध्ययनका लागि आवश्यक तथ्याङ्क विभिन्न चिरान मिलहरूबाट संकलन गरिएको थियो । किनकि एउटै मिलमा आवश्यक तथ्याङ्क उपलब्ध हुन सक्ने अवस्था थिएन । यसैले आयातन उपजमा चिरान प्रविधिले पार्न सक्ने असरलाई कम गर्न समान प्रविधि प्रयोग गर्ने चिरान मिलहरूबाट तथ्याङ्क संकलन गरिएको थियो। चिरान मिलका कर्मचारीहरूलाई गोलिया काठको मापन, चिरिएको काठको आयातन, र काठमा भएका Defect हरूको तथ्याङ्क राख्ने तालिम दिइयो। आठ प्रजातिका कुल ४६७ वटा गोलिया अध्ययन गरिएको थियो । जसमा साज/असनाको १७ देखि सिमल (भेनियर) को १५२ सम्म थियो। गोलियाको आयातन *quarter-girth* सूत्र प्रयोग गरी निकालिएको थियो ।

आयातन उपज (Volumetric yield) काठ वा भेनेयरमा परिणत गोलियाको प्रतिशतको रूपमा निर्धारण गरिएको थियो। अमिल्दा तथ्याङ्कहरू, जस्तै चिरिएको काठको आयातन गोलियाको भन्दा बढी हुने केस, हटाई विश्लेषण गरिएको थियो।

प्रमुख निष्कर्षहरू

विभिन्न प्रजातिहरूको आयातन उपज (Volumetric yield) विश्लेषण गर्दा प्रशोधन क्षमतामा उल्लेखनीय भिन्नता देखिएको छ। सिमल (veneer उत्पादनका लागि) मा औसत defect रहित उपज ५६.११% थियो भने defect समेत गरेर कुल उपज ७३.९८% थियो। गोलियाको मध्य भागमा नापिएको व्यासले defect रहित उपजमा सकारात्मक प्रभाव देखाए पनि कुल उपजमा नकारात्मक प्रभाव पारेको देखियो। जसले ठूलो गोलियामा बढी defect हुने संकेत गर्छ। मसला (veneer) मा औसत defect रहित उपज ५८.१८% र कुल उपज ७३.१८% देखियो । तर यहाँ पनि गोलियाको मध्य भागमा नापिएको व्यासको नकारात्मक प्रभाव देखियो, जसले ठूलो गोलिया भेनियरको लागि उपयुक्त नहुने इंकित गर्दछ।

साज/असना प्रजातिमा औसत उपज ५६.८५% थियो, जसमा ग्रेड अनुसार स्पष्ट भिन्नता थियो'ग्रेड A मा ६१.३९%, ग्रेड B मा ५१.६५% र ग्रेड C मा ४७.१५% उपज थियो, जसले गोलियाको गुणस्तरको महत्त्व दर्शाउँछ। साल प्रजातिमा औसत उपज ५६.१६% थियो, जहाँ ग्रेड A मा ५९.४४% र ग्रेड C मा ४९.६१% उपज देखिएको थियो। यहाँ गोलियाको मध्य भागमा नापिएको व्यासले चिरान काठ उत्पादनमा सकारात्मक भूमिका खेल्ने देखियो। सिसौमा औसत उपज ५२.५३% मात्र थियो, जुन २६% देखि ८०.२५% सम्मको फराकिलो दायरामा फैलिएको थियो। यहाँ उपजमा प्रभाव पार्ने कुनै उल्लेखनीय कारक फेला परेन, जुन अन्य अध्ययन र विश्लेषण नगरिएका कारणहरूको कारण हुन सक्छ भन्ने पनि हो।

कर्मा प्रजातिमा औसत उपज ५०.१६% थियो, जहाँ ठूला व्यासका गोलियाहरूको बढी उपज देखियो । जामुनको औसत उपज ५३.७३% थियो; ग्रेड A मा ६१.०७% र ग्रेड C मा ४२.६०% थियो। यहाँ पनि ठूला व्यासका गोलियाहरूको बढी उपज देखियो। अन्त्यमा, काठ उत्पादनका लागि प्रयोग गरिएको मसला प्रजातिमा औसत उपज ५०.२१% थियो, र यहाँ पनि गोलियाको साईजले सकरात्मक भूमिका खेलेको देखियो।

यस अध्ययनले प्रजातिहरू बीचको आयतन उपज (Volumetric yield) मा उल्लेखनीय अन्तर देखायो। सिमल र मसला (veneer) प्रजातिले उच्च उपज देखाए भने कर्मा प्रजातिमा सबैभन्दा कम उपज देखियो। गोलियाको गुणस्तर (ग्रेड) र व्यास उपजमा प्रभाव पार्ने महत्त्वपूर्ण कारकहरू थिए, यद्यपि यी कारकहरूको प्रभाव प्रजाति अनुसार फरक देखिएको थियो। चिरिएको काठको आकार एकरूप नहुनु र उप-उत्पादनहरूलाई समेट्न नसक्नु जस्ता सीमितताहरू भविष्यका अनुसन्धानका क्षेत्र हुन्।

सिफारिसहरू

- **गोलिया विभाजन** : गोलियाको व्यासले आयतन उपज (Volumetric yield) मा महत्वपर्ण भूमिका देखिएकोले रूख कटान गर्दा र गोलिया कटान गर्दा यि कुराहरूमा ध्यान दिन पर्ने देखिन्छ ।
- **वन व्यवस्थापन** : गोलियाको गुणस्तरले आयतन उपज (Volumetric yield) मा सकरात्मक प्रभाव रहेकोले वन सम्वर्दन प्रणालीमा आधारित वन व्यवस्थापन गरी स्वस्थ वन विकाश गर्नु जरूरी देखिन्छ।

INSTITUTE OF FORESTRY

- **आधुनिक चिरान प्रविधि** : उच्च उपज सुनिश्चित गर्न प्रविधिमा लगानी गर्नु आवश्यक छ।
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- **नीतिगत व्यवस्था**: उच्च क्षमता भएका चिरान मिलहरूलाई अनुदान वा कर छुट जस्ता प्रोत्साहन कार्यक्रम ल्याउनुपर्छ। न्यूनतम उपजको मापदण्ड अनिवार्य गरिनुपर्छ।
- **तथ्याङ्क सङ्कलन** : गोलियाको ताजापन, कामदारको दक्षता जस्ता विषयरूलाई नियन्त्रणमा राखी अध्ययन गर्दा अझ शुद्ध परिणाम आउन सक्छ।
- **सचेतना अभिवृद्धि**: काठ व्यापारीदेखि नीति निर्मातासम्मका सरोकारवालालाई उपज वृद्धि (yield optimization) बाट हुने आर्थिक तथा वातावरणीय लाभबारे जानकारी गराउनु आवश्यक छ। कार्यशाला गोष्ठी र घटना अध्ययनहरूले व्यावहारिक उदाहरणहरू प्रस्तुत गर्न सक्नेछन्।

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1. Introduction

1.1 Background

Forests serve as one of the most vital natural resources on the planet, providing essential ecosystem services, biodiversity, and economic benefits. Among the many products derived from forests, timber is one of significant products and it has importance due to its role in construction, furniture, energy, and industrial applications. In addition, timber has a long history with human, because shelter is one of the basic needs and timber is major factors of constructing shelter. As the global demand for wood and wood products increases, ensuring efficient utilization of harvested logs becomes crucial for sustainable forest management and long-term resource availability (Nepal et al. 2021).

One of the most commonly used metrics for assessing the efficiency of timber processing is the volumetric yield of sawn timber. This term refers to the proportion of the total volume of a log that is successfully converted into usable sawn timber after the sawing process (da Silva Luz et al. 2021). Expressed as a percentage, the volumetric yield provides a quantitative measure of material efficiency and is essential for evaluating the performance of sawmills, guiding improvements in wood processing technology, and reducing waste generation in the timber industry. This also helps to understand the relationship between timber demand and existing practices of log sectioning.

The volumetric yield is influenced by several factors, including log dimensions, shape, and quality, sawing techniques, the type of machinery used, blade kerf size, operator skill, and the intended dimensions of the final timber products. For example, logs that are straight and defect-free typically result in higher recovery rates compared to irregular or damaged logs. Similarly, modern sawmills using advanced, thin-kerf technologies and optimization algorithms can achieve yields of up to 70–80%, whereas traditional mills using outdated equipment may only recover 30–50% of the log volume as usable timber (da Silva Luz et al. 2021; Andrade et al. 2023; Rascón-Solano et al. 2023). In addition, log freshness is also a matter for timber volumetric yield.

In developing countries like Nepal, where wood is an important part of the economy and rural livelihoods, sawmilling is often characterized by low recovery rates due to inadequate infrastructure, inefficient processing methods, and poor log selection (Mandiringana et al. 2022; Mauya et al. 2024). This inefficiency contributes not only to economic loss but also to increased environmental degradation. The low yield necessitates higher harvesting rates to meet production needs, placing additional pressure on forest ecosystems and undermining national and international forest conservation efforts.

Understanding and improving the volumetric yield is therefore of paramount importance. First, it leads to more efficient use of forest resources, ensuring that a greater proportion of each harvested log is transformed into value-added products (Mandiringana et al. 2022). Second, it supports the goals of sustainable forest management by reducing logging pressure and waste generation (da Silva Luz et al. 2021). Third, it improves the profitability of sawmilling operations, which is essential for the competitiveness of the wood-processing sector in both domestic and international markets (Andrade et al. 2023).

Despite the critical importance of yield optimization, there is a noticeable lack of empirical data and research focused on timber recovery in many regions. In particular, there is limited documentation of yield patterns for different species, log sizes, sawn timber size and sawing systems used in various countries. The absence of such data hinders the formulation of evidence-based policies and the implementation of technical improvements at the mill level. This also affect the harvesting practices particularly on the sectioning part. Moreover, without a clear understanding of current yield levels and influencing factors, efforts to improve the efficiency and sustainability of timber production remain constrained.

This study aims to fill that gap by analyzing the volumetric yield of sawn timber from logs processed under existing conditions, identifying the key variables that influence yield, and recommending best practices and technological interventions to enhance timber recovery. The research is expected to generate valuable insights for sawmill operators, forest managers, policymakers, and other stakeholders in the forest sector.

1.2 Objectives

The primary objective of this study is to determine the sawing recovery percentage for different timber species commonly available in Madhesh Province, Nepal.

The specific objectives are to:

- estimate the volumetric yield of saw timber of logs by their grades of the selected species,

- to understand the factors affecting volumetric yield of sawn timber within the given grade of the selected species.

1.3 Scope of Work

Following eight species were studied. These species were selected based on the discussion with divisional forest officials and officials of the Province Forest Directorate.

i. Sal (*Shorea robusta)*
ii. Saj (*Terminalia tomentosa)*
iii. Karma (*Adina cordifolia)*
iv. Teak (*Tectona grandis)*
v. Masala *(Eucalyptus spp)*
vi. Sissoo (*Dalbergia sissoo)*
vii. Karma (*Adina cardifolia)*
viii. Jamun (*Syzygium cumini*)

1.4 Limitations

One key limitation is that the study did not control or standardize the size of the sawn timber produced, especially in terms of length and thickness. Producing uniform sizes of planks across different logs within the same grade would have allowed a more detailed analysis of how yield varies with log size within a grading category. In practice, however, sawmills produce sawn timber based on immediate market demands or specific customer orders, rather than fixed dimensions. As a result, the size and proportion of sawn timber vary across logs, which adds complexity to yield comparisons and limits the generalizability of findings.

Additionally, the study only considered the main sawn timber output and did not include secondary products such as sawdust, offcuts, or firewood, which are by-products of the sawing process and can significantly impact overall material recovery and economic yield. These by-products, while not part of volumetric yield in the strict sense, are important components of total resource utilization and value.

Another limitation arises from the data collection setting. The study was unable to gather all relevant data from a single sawmill for each species. To address potential biases arising from differences in sawmilling technology, the research team selected sawmills with similar processing technologies for each species studied. This helped reduce variability due to machinery differences. However, variation in human factors—particularly the skill and experience of sawmill operators—was not controlled. Since sawmill efficiency and accuracy can be influenced by operator expertise, this remains an unaccounted source of variability. For the purposes of analysis, the study assumed a similar level of skill and operational performance across the selected sawmills.

In summary, while the study offers valuable insights into the factors affecting volumetric yield, the findings are based on existing operational conditions, and interpretations should consider these methodological constraints. Future research could benefit from controlled experiments using standardized timber sizes and processing conditions, and a more comprehensive accounting of all product outputs.

2. Methodology

2.1 Study area

In Nepal, the commercial trade of timber is regulated and conducted primarily through a formal auction process, as outlined in the Forest Regulation, 2079 (GoN 2022). Participation in these auctions is restricted to forest-based industries, such as sawmills and timber-processing enterprises, which must be legally registered under existing laws. During the auction, interested bidders compete by offering prices, and the contractor who proposes the highest bid is awarded the timber lot.

The minimum sale price for timber is not uniform; it varies according to the grade of the logs and species. For instance: Grade A represents the highest quality. The royalty rates applicable to each timber species and their respective grades are officially specified in Annex-6 of the Forest Regulation (2022). These rates are critical for ensuring that the government receives appropriate revenue from the utilization of forest resources.

The grading of logs plays a crucial role in determining their market value and is based on multiple physical attributes, including girth (diameter), length, the number of insect or borer holes, the degree of hollowness (as a percentage of the cross-section), straightness, and the presence of defects such as knots, cracks, or rot. Importantly, not all timber species are categorized using the same number of grades. Some species may be divided into more quality classes than others, depending on their commercial importance and variability in wood properties (see Table 1).

Table 1: Log grades by species

Species	Log Grade			
	A	B	C	D
Sal	√	√	√	√
Sissoo (Jungli)	√	√	√	√
Karma, Asna, Jamun	√	√	√	×
Sissoo (Planted)	√	√	×	×

This system ensures that timber trade is transparent, competitive, and aligned with sustainable forest management principles, while also providing a structured framework for valuing forest products based on quality and species-specific characteristics.

2.2 Data Collection

2.2.1 Consultation

The study team discussed with the officials of the divisional forest offices of different division to understand the need of this study, choice of species to be studies, and also the contact of saw-mills. The team visited Parsa, Bara, Rautahat, Sarlahi, and Dhanusha divisional Forest Offices, and also discuss with the officials of the Province Forest Directorate. The details are included in Annex 1.

2.2.2 Log data

The primary data were collected from different saw-mills available in the market. While collecting data for the particular species, saw mills were selected with similar technology. As saw-mills saw logs as per the demand received from their customers, the saw-mill staffs were trained and provided orientation program to record the data. They were monitored every week to observe their data record quality. A total of seven species were measured (Table 2).

Table 2: Species measured and number of logs

SN	Species	Number	Remarks
1	Simal *(Bombax ceiba)*	152	Annex 2
2	Sal (*Shorea robusta)*	58	Annex 3
3	Asna/Saj (*Terminalia tomentosa)*	17	Annex 4
4	Sissoo (*Dalbergia sissoo)*	30	Annex 5
5	Masala *(Eucalyptus cameldulensis)* - Plywood	94	Annex 6
6	Teak *(Tectona grandis)*	33	Annex 7
7	Karma *(Adina cardifolia)*	23	Annex 8
8	Jamun (*Syzygium cumini*)	32	Annex 9
9	Masala *(Eucalyptus cameldulensis)* - Timber	28	Annex 10

All Simal and Masala logs for veneer have same length of 52 inch but girth varied. The size of each veneer produced from Simal is 52"×24"×2.40 mm (0.09") and Masala is 52"×24"×1.40 mm (0.055").

Prior to analysis, rigorous data processing was conducted to ensure the validity and reliability of the results. During this stage, any observations where the reported sawn timber volume exceeded the original log volume were systematically identified and eliminated from the dataset. This quality control measure was implemented to remove physically impossible cases that could distort the yield calculations and subsequent analyses.

2.3 Data Analysis

2.3.1 Log Volume

Log volume (V) was estimated using a quarter girth formula, according to the Forest Regulations (2022). The quarter-girth formula can be expressed as:

$$V = \left(\frac{g^2}{4}\right) l \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(i)}$$

Where, g is girth of the log at middle cross-section, and l is the length of log.

Then V_1 and V_2 of the log are estimated using g at thick end and thin end respectively.

2.3.2 Taper

Taper of a log refers to the gradual decrease in diameter from the base to the top of a log. This natural narrowing occurs as trees grow taller, with the widest part typically found near the base where structural support is needed most. Taper affects timber volume estimation, log grading, and sawing efficiency, as logs with less taper are generally more desirable for producing uniform sawn timber. It also varies among species, site conditions, and silvicultural treatments. Understanding taper is crucial in optimizing forest product utilization.

Taper of the log (t) was calculated using following formula:

$$t = \left(\frac{d_2 - d_1}{l}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

Where, d1 and d2 are diameter at thin and thick end respectively, and l is the length of log.

2.3.3 Calculation of Sawing Recovery/ Volumetric yield

The sawing recovery percentage or volumetric yield (VY) for each log and species using the following formula:

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$$VY = \left(\frac{VL}{V}\right) 100\% \text{ .... (iii)}$$

where, VY is the volumetric yield or the sawing recovery percentage, VL is the total volume of lumber produce from the particular log, and V is the log volume measured using quarter-girth formula.

2.3.4 Differences in log volume and Volume of log

To examine whether the differences in log volume and volume of lumber recovered are statistically significant, an independent t-test was conducted. This statistical test is appropriate when comparing the means of two independent groups to determine if there is a significant difference between them. In this context, the test evaluates whether the observed variation between the total volume of logs and the volume of sawn lumber recovered is due to random chance or reflects a true difference in means. Prior to applying the t-test, assumptions such as normality of data distribution and equality of variances were assessed to ensure the validity of the results.

2.3.5 Factors affecting volumetric yield

A linear regression analysis using the grade of log as an explanatory variable was performed to identify the factors influencing the volumetric yield of sawn timber. In this model, the volumetric yield—defined as the proportion of usable sawn timber recovered from a log—is treated as the dependent (response) variable, while log grade and other measurable log characteristics (such as diameter, length, taper, and defects) were included as independent (predictor) variables. Log grade, which reflects the overall quality of the log based on visual and structural properties, is expected to have a significant impact on the amount of usable timber that can be extracted. The linear regression can be helpful to quantify the relationship between log grade and yield, while also assessing the influence of other contributing factors. The model coefficients may indicate the direction and strength of these relationships, and statistical significance may determine which variables are most influential. The results of this analysis can provide practical insights for sawmill operations, such as prioritizing higher-grade logs or targeting specific log features to improve recovery rates and reduce waste.

The model can be expressed as:

$$y = \alpha + \beta_1 * taper\ ratio + \beta_2 * \log length + \beta_3 * mid\ diameter + \beta_4 * defect + \beta_5 * \log grade \text{ .... (iv)}$$

where, y is the volumetric yield in percentage.

3. Results

3.1 Simal

3.1.1 Descriptive statistics of Simal logs

The study analyzed 126 logs to evaluate key metrics related to log dimensions, production volumes, and processing efficiency. The Table-3 presents descriptive statistics for girth measurements, log volume, veneer production volumes, volumetric yields, and taper. In this table, *production volume1* refers to the volume of the veneer without any defect, while *production volume2* is the total volume of veneer produced including the defect. *Volumetric yield1* was calculated based on the *production volume1* and *volumetric yield2* was based on the *production volume2*. Girth difference is the ratio between girth at thin-end and mid-point. This is because while preparing veneer logs are made cylindrical based on the thin-end girth.

Table 3: Descriptive Statistics of Simal Log Characteristics and Veneer Production

Variable	Mean	Std. Dev.	Min	Max
Girth-Mid (inch)	36.04	8.64	24	63
Girth-Thick end (inch)	38.44	9.84	26	68
Girth- thin end (inch)	34.06	8.19	23	63
Log volume (cft)	2.59	1.33	1.08	7.95
Production volume1 (cft)	1.48	0.86	0.20	4.02
Volumetric yield1	56.11	15.84	13.88	88.26
Production volume2 (cft)	1.85	0.81	0.75	4.23
Volumetric yield 2	73.98	12.60	33.50	97.80
Taper	0.08	0.07	0	0.42
Girth difference (%)	94.56	3.17	85.18	100

The mid-point girth of the logs averaged 36.04 inches, with a standard deviation of 8.64 inches, indicating moderate variation across samples. The thick-end girth averaged slightly higher at 38.44 inches, while the thin-end girth was the smallest, averaging 34.06 inches. This variation in girth reflects the natural tapering of the logs. The girth difference, calculated as a percentage of the thin-end girth relative to the mid-point girth, averaged 94.56%. This indicates that logs are relatively uniform in shape, though some taper is present.

The average log volume was 2.59 cubic feet, but this ranged considerably from 1.08 to 7.95 cft, showing a wide diversity in log size. Veneer production is divided into two categories: *production volume1* represents the usable veneer volume without defects and averaged 1.48 cft. Similarly, *production volume2* includes all veneer produced, regardless of defects, and was higher at 1.85 cft. On average, *Production Volume2* is about 25% higher than *Production Volume1*. This suggest a substantial fraction of the veneer produced is not of acceptable quality for end-use without further processing or rejection.

The volumetric yield, which indicates the efficiency of converting raw logs into veneer, was calculated using both production volumes: *volumetric yield1*, based on defect-free production (*Production Volume1*), had an average of 56.11%, ranging from 13.88% to 88.26%, reflecting significant variability in veneer quality and recovery. *Volumetric Yield2*, which includes defective veneer (*Production Volume2*), averaged much higher at 73.98%, indicating that while a substantial portion of the log is converted into veneer, a noticeable fraction may have defects. In other words, approximately 18 percentage point difference between the two yield values highlights the impact of defects on recovery efficiency. This emphasizes the importance of reducing defects and improving log quality through appropriate forest management activities to enhance the proportion of high-quality, usable veneer.

Taper, which quantifies the change in diameter from one end of the log to the other, averaged 0.08, with a maximum value of 0.42. This suggests that most logs were relatively straight, but some had significant tapering that could impact processing efficiency.

Simal logs show moderate variability in girth and log volume. The veneer production process yields a substantial amount of usable product, though a notable proportion may include defects. The taper and girth difference metrics suggest relatively uniform logs, which is favorable for processing. The wide range in volumetric yields points to opportunities for improving processing practices and selecting higher-quality logs for optimal veneer recovery.

3.1.2 Determinants of volumetric yield of Simal

The regression analysis reported in Table-4 reveals important insights about the factors influencing Simal veneer production yields, with distinct patterns emerging between defect-free (Volumetric Yield1) and total yields (Volumetric Yield2).

For Volumetric Yield 1, the constant term is 69.84 but is statistically insignificant, indicating that the baseline yield without considering other variables is not reliable. Among the explanatory variables, girth at mid-point (Girth-mid) has a positive and statistically significant effect at the 5% level, with a coefficient of 0.42. This suggests that larger mid-point girth contributes positively to defect-free veneer yield or an increase in mid-girth contributes to an increase in volumetric yield of defect-free veneer. In contrast, taper and girth difference have negative coefficients (-10.01 and -0.29 respectively), but neither is statistically significant, implying that these variables do not have a strong or consistent influence on the yield of usable veneer.

Table 4: Results of regression analysis to understand the determinants of volumetric yield in Simal

Variables	Coefficients (SE)	
	Volumetric yield1	Volumetric yield2
Constant	69.84 (50.26)	105.10 (38.64)***
Taper	-10.01 (25.02)	-8.00 (19.24)
Girth-mid	0.42 (0.17)**	-0.47 (0.13)***
Girth difference	-0.29 (0.52)	-0.14 (0.40)

Note: *,**, and *** denote significant at 10%, 5% and 1% level of significance

In the case of Volumetric Yield 2, the constant term is 105.10 and is highly significant at the 1% level, indicating a strong baseline yield when defects are included. Interestingly, girth at mid-point in this model has a negative and highly significant effect (coefficient -0.47), meaning that as girth increases, the total veneer yield (including defects) actually decreases. This inverse relationship may suggest that larger logs, while capable of producing more veneer, might also be more prone to internal defects or processing challenges. Similar to the first model, taper and girth difference again show negative but statistically insignificant effects.

The analysis reveals that girth at mid-point is the only significant determinant of volumetric yield in both models, but it affects the two types of yield in opposite directions—positively for defect-free veneer and negatively for total veneer including defects. This highlights a trade-off in processing larger logs, which may yield higher-quality veneer but also generate more total defective material.

3.2 Masala (Veneer)

3.2.1 Descriptive statistics of Masala logs for veneer

The descriptive statistics reveal important patterns in Masala log processing and veneer production outcomes (Table 5). The girth measurements show the expected tapering from thick to thin ends, with mean values decreasing from 32.31 inches at the thick end to 30.26 inches at the thin end. The relatively small girth difference of 97.15% between thin end and midpoint indicates these logs were processed to near-cylindrical form with minimal diameter reduction (2.85% on average). Log volumes averaged 1.88 cft but ranged substantially from 0.75 to 3.48 cft, reflecting considerable variation in raw material size.

Table 5: Descriptive Statistics of Masala Log Characteristics and Veneer Production

Description	Observation	Mean	Std. Dev.	Min	Max
Girth at thick end (inch)	56	32.31	5.29	20.5	44
Girth at mid-point (inch)	56	31.14	5.28	20	43
Girth at thin end (inch)	56	30.26	5.15	19	40
Log volume (cft)	56	1.88	0.63	0.75	3.48
Production volume1 (defect-free, cft)	56	1.06	0.32	0.24	1.83
Production volume2 (total, cft)	56	1.31	0.3	0.4	2.07
Volumetric yield1 (%)	56	58.18	14.51	28.16	92.71
Volumetric yield2 (%)	56	73.18	15.91	38.95	99.98
Girth difference (%)	56	97.15	1.47	93.02	100

The results show a consistent gap between defect-free and total production volumes. Production Volume 1 (defect-free veneer) averaged 1.06 cft, while Production Volume 2 (total veneer including defects) was 23.6% higher at 1.31 cft. This 0.25 cft difference represents the volume lost to defects, accounting for about 19% of total production volume. Both measures show similar relative variability (coefficient of variation of 30.2% for PV1 vs

22.9% for PV2), though PV1 has a wider absolute range (0.24-1.83 cft vs 0.4-2.07 cft for PV2), suggesting defect occurrence is somewhat proportional to total output but becomes more variable at higher production levels.

The yield metrics demonstrate even more pronounced differences. Volumetric Yield 1 (defect-free) averaged 58.18%, substantially lower than the 73.18% average for Volumetric Yield 2 (total) - a 15 percentage point difference. Notably, Yield 1 shows greater variability (SD=14.51) compared to Yield 2 (SD=15.91), with a much wider relative range (28.16-92.71% vs 38.95-99.98%). This pattern suggests that while total recovery efficiency is generally high and consistent, the proportion of defect-free output varies more significantly depending on log characteristics and processing conditions.

There is a 19-23% production volume gap between defect-free and total output represents significant quality-related losses. In addition, the narrower range of girth differences (93.02-100%) compared to other species suggests Masala logs are more uniformly processed to cylindrical form. The results show that higher average yields (both Yield1 and Yield2) compared to other species indicate Masala may be more amenable to efficient veneer production. Similarly, the greater variability in defect-free yields points to opportunities for process optimization to improve consistent quality output.

3.2.2 Determinants of volumetric yield of Masala

Table 6 presents the results of a regression analysis conducted to identify the factors affecting volumetric yield in Masala logs, with separate models for *Volumetric Yield 1* (defect-free veneer) and *Volumetric Yield 2* (total veneer including defects). The independent variables considered are taper, girth at mid-point, and girth difference, while the dependent variables are the two types of volumetric yield.

The results show that girth at mid-point is the only statistically significant variable in both models, and it is significant at the 1% level. However, its coefficients are negative in both cases: -1.07 for *Volumetric Yield 1* and -2.02 for *Volumetric Yield 2*. This indicates that as the mid-point girth of the Masala log increases, both the defect-free and total veneer yields decrease. The stronger negative effect in *Volumetric Yield 2* suggests that larger logs may be more prone to internal defects or processing inefficiencies that reduce overall recovery, not just quality veneer.

Table 6: Results of regression analysis to understand the determinants of volumetric yield in Masala

Variables	Coefficients (SE)	
	Volumetric yield1	Volumetric yield2
Constant	55.25 (162.94)	96.06 (144.60)
Taper	76.67 (154.89)	39.12 (137.46)
Girth-mid	-1.07 (0.37) ***	-2.02 (0.33) ***
Girth difference	55.25 (162.94)	0.39 (1.46)

Note: *,**, and *** denote significant at 10%, 5% and 1% level of significance

The coefficients for taper are positive in both models (76.67 and 39.12), suggesting a potential positive association between taper and veneer yield, but these are not statistically significant, indicating no reliable effect of taper on yield. Similarly, girth difference has a coefficient of 55.25 for *Volumetric Yield 1* and 0.39 for *Volumetric Yield 2*, but these values are also statistically insignificant, meaning their influence on veneer recovery is uncertain or weak. The constant terms in both models (55.25 and 96.06) are also not statistically significant, implying that the baseline yield—when all predictors are held at zero—cannot be confidently interpreted.

The regression analysis shows that among the variables tested, girth at mid-point is the only significant determinant of veneer yield in Masala logs, and its negative effect highlights that larger logs may not always lead to higher recovery. This underlines the importance of log quality and form over size when aiming to maximize veneer production efficiency in Masala.

3.3 Saj/Asna

3.3.1 Descriptive statistics of Saj/Asna logs

Table 7 provides a statistical summary of key characteristics of Saj logs and their corresponding sawn timber production. The data includes measures of central tendency (mean), dispersion (standard deviation), and range (minimum and maximum values) for each variable, offering insights into the variability and distribution of log dimensions and processing outputs. Among the logs, 10 (59%) were Grade A, 5 (29%) were Grade B, and 2 (12%) were Grade C.

Table 7: Descriptive Statistics of Saj Log Characteristics and Sawn timber Production

Variable	Mean	Std. Dev.	Min	Max
Length (ft)	7.71	1.57	5.00	10.00
Girth-thick (inch)	67.59	17.14	39.00	100.00
Girth-mid (inch)	63.94	16.18	36.00	96.00
Girth-thin (inch)	60.65	15.94	34.00	93.00
Log volume (cft)	14.72	8.57	3.94	36.00
Sawn timber (cft)	8.71	5.72	1.75	22.31
Taper	0.08	0.03	0.04	0.14
Volumetric Yield	56.85	9.49	43.86	75.67
Volumetric Yield – Grade A log	61.39	9.18	46.20	75.67
Volumetric Yield – Grade B log	51.65	5.90	43.86	59.71
Volumetric Yield – Grade C log	47.15	3.83	44.44	49.85

The average length of the logs is 7.71 feet, with a standard deviation of 1.57 feet, indicating moderate variation around the mean. The lengths range from 5.00 feet (minimum) to 10.00 feet (maximum), suggesting a considerable spread in log sizes. Girth measurements, taken at three different points—thick, mid, and thin—show a gradual decrease in diameter from the thickest to the thinnest section. The thickest girth averages 67.59 inches (with a high standard deviation of 17.14 inches), while the mid and thin girths average 63.94 inches and 60.65 inches, respectively. The wide ranges in girth (e.g., 39.00 to 100.00 inches for the thickest point) highlight significant natural variability in log shapes.

Log volume, measured in cubic feet, has a mean of 14.72 cft, but the substantial standard deviation (8.57 cft) and range (3.94 to 36.00 cft) indicate that log sizes vary widely. Similarly, sawn timber production averages 8.71 cft, with values ranging from 1.75 to 22.31 cft, reflecting differences in processing yields. The taper, which measures the rate of diameter reduction along the log, averages 0.08 (std. dev. = 0.03), with a range of 0.04 to 0.14, suggesting that while most logs have a slight taper, some exhibit more pronounced narrowing.

The volumetric yield shows almost slightly higher than the half of the log volume ranging from 43.86% to 75.67%. Grade A logs yield around 61% sawn timber, which can go upto 75 percentage. Grade B and Grade C logs produce 51 and 47 percent sawn timber respectively. Overall, the statistics reveal considerable diversity in log dimensions and sawn timber output, which may influence processing efficiency, resource planning, and product quality in timber production. The high variability in girth and volume suggests that log selection and processing techniques may need to be adjusted to optimize yield and minimize waste.

3.4 Sal

3.4.1 Descriptive statistics of Sal

The dataset comprises a total of 55 Sal logs, categorized into three grades based on quality. Of these, 24 logs (44%) were classified as Grade A, 15 logs (27%) as Grade B, and 16 logs (29%) as Grade C. This distribution indicates that Grade A logs were the most prevalent, followed by Grade C and Grade B. Table 8 presents the descriptive statistics of Sal logs.

Table 8: Descriptive Statistics of Sal Log Characteristics and Sawn timber Production

Variable	Mean	Std. Dev.	Min	Max
Length (ft)	6.85	1.78	3	10
Girth-thick (inch)	58.21	16.93	32	104
Girth-mid (inch)	55.85	16.6	31	102
Girth-thin (inch)	52.8	15.59	30	100
Log volume (cft)	10.95	9.38	2.08	45.16
Sawn timber (cft)	6.61	6.44	0.56	29.17
Taper	0.064	0.062	-0.059	0.475
Girth difference	99.97	35.9	41.11	111.86
Volumetric yield	56.16	12.24	14.98	82.28
Volumetric Yield -Grade A	59.44	9.93	30.24	69.09
Volumetric Yield -Grade B	57.89	10.77	39.98	82.28
Volumetric Yield - Grade C	49.61	14.64	14.98	79.81

The average length of the logs was 6.85 feet, with a standard deviation of 1.78 feet, indicating moderate variability. Lengths ranged from a minimum of 3 feet to a maximum of 10 feet. The girth measurements—thick, mid, and thin—averaged 58.21 inches, 55.85 inches, and 52.8 inches, respectively, with standard deviations between 15.59 and 16.93 inches, suggesting considerable variation in log thickness.

Log volume averaged 10.95 cubic feet, with a wide range from 2.08 to 45.16 cubic feet, reflecting significant differences in log sizes. Sawn timber production averaged 6.61 cubic feet per log, with a maximum output of 29.17 cubic feet. Taper, which measures the reduction in log diameter, had a mean of 0.064, while girth difference averaged 99.97, indicating substantial variation in log shape.

Volumetric yield, a key efficiency metric, averaged 56.16% across all logs, with Grade A logs exhibiting the highest mean yield (59.44%), followed by Grade B (57.89%) and Grade C (49.61%). The lower yield in Grade C logs suggests reduced conversion efficiency due to the presence of hollow and other defects compared to higher-grade logs. The standard deviations for volumetric yields were notable, particularly for Grade C (14.64), indicating greater variability in processing outcomes for lower-quality logs.

3.4.2 Determinants of volumetric yield of Sal

The regression analysis was conducted to identify the key factors influencing volumetric yield in Sal logs (Table 9). In this analysis, girth (mid-point), taper, and grade of logs are considered as independent variables. In grade, Grade A is considered as a base.

Table 9: Results of regression analysis to understand the determinants of volumetric yield in Sal

Variables	Coefficients (SE)
Constant	30.64 (10.53)
Girth-mid	0.39 (0.15)**
Taper	14.93 (25.32)
Grade B	5.98 (4.55)
Grade C	2.47 (5.75)

Note: ** denotes significant at 5% level

The results indicate that mid-girth (Girth-mid) has a statistically significant positive effect on yield, with a coefficient of 0.39 (SE = 0.15, $p < 0.05$). This suggests that for every one-inch increase in mid-girth, volumetric yield increases by approximately 0.39 cubic feet, holding other variables constant. The strong significance implies that mid-girth is a reliable predictor of yield. In contrast, taper showed a coefficient of 14.93 (SE = 25.32), but this effect was not statistically significant ($p > 0.10$), meaning that log taper does not appear to have a meaningful impact on yield in this dataset.

The coefficients of grades are not significant, suggesting that grade classification may not be a strong determinant of volumetric yield in this model. The intercept (constant term) was 30.64 (SE = 10.53, $p < 0.01$), indicating the baseline volumetric yield when all predictors are zero. This suggests that even without considering girth, taper, or grade, there is a substantial inherent yield in Sal logs.

3.5 Sissoo

3.5.1 Descriptive statistics of Sissoo

The table 10 presents key descriptive statistics for 28 Sissoo logs, summarizing their physical characteristics and sawn timber production efficiency. On average, the logs measured 6.89 feet in length, with a standard deviation of 1.69 feet, indicating moderate variability (range: 3 to 10 feet). Girth measurements—taken at the thick end (56.04 inches), midpoint (53.54 inches), and thin end (50.89 inches)—show a gradual taper, with standard deviations between 10.33 and 11.33 inches, suggesting reasonable consistency in log shape.

The average log volume was 9.25 cubic feet, with significant variation (SD = 4.75 cubic feet, range: 1.88 to 19.93 cubic feet). After processing, the mean sawn timber volume was 5.00 cubic feet (SD = 3.11 cubic feet, range: 0.94 to 12.13 cubic feet), indicating that, on average, about 54% of the log volume was converted into usable timber.

The taper ratio averaged 0.06 (range: 0.03 to 0.15), while girth difference (a measure of log shape consistency) was highly stable at 95.16 (SD = 2.90, range: 83.61 to 100.00). Finally, volumetric yield—a key efficiency metric—averaged 52.53%, with substantial variability (SD = 14.66%, range: 26.00% to 80.25%). This suggests that while some logs achieved high

Among the examined variables, girth measurements show contrasting associations with yield. While mid-point girth demonstrates a negative coefficient (-0.37, SE = 1.74), thin-end girth shows a positive relationship (0.77, SE = 1.82), though neither parameter achieves statistical significance at conventional levels. Similarly, log length exhibits a negative coefficient (-0.56, SE = 1.95), indicating that longer logs may tend to produce slightly lower yields, but this relationship also lacks statistical significance.

Notably, none of the included variables reach the threshold for statistical significance (as indicated by the absence of asterisks in the table), suggesting that these particular log characteristics may not be strong predictors of volumetric yield in this dataset. The relatively large standard errors compared to the coefficient magnitudes further indicate considerable uncertainty in these estimates. This outcome could potentially reflect limitations in sample size, measurement precision, or the possibility that other unmeasured factors (such as log quality or processing techniques) may play more substantial roles in determining Sissoo timber yields than the physical dimensions examined here. The results highlight the need for additional research incorporating a broader range of potential yield determinants to better understand the production dynamics for this timber species.

3.6 Teak

3.6.1 Descriptive statistics of Teak

Table 10 presents descriptive statistics for Teak log characteristics and sawn timber production efficiency based on a sample of 33 logs. The average log length was 6.36 feet, with relatively low variability (standard deviation of 1.11 feet), ranging from 4 to 9 feet. Girth measurements—taken at the thick end (46.55 inches), mid-point (44.64 inches), and thin end (42.91 inches)—show a gradual taper, with substantial variation (standard deviations of ~16 inches). The log volume averaged 6.28 cubic feet, but with high variability (ranging from 0.78 to 21.95 cubic feet), indicating substantial differences in log sizes.

The girth difference between the thin end and the mid-point of the logs was found to be only 4.33%, meaning that the girth at the mid-point retained about 95.67% of the girth measured at the thinner end of the log. This relatively small difference indicates that the logs had a uniform shape along their length, with minimal tapering (i.e., narrowing from base to top).

In support of this, the mean taper value—which quantifies how much the diameter decreases along the length of the log—was calculated to be 0.57 with a standard deviation of ±0.21. This value indicates that on average, the logs taper gradually and predictably, without sharp changes in girth. The taper values ranged from as low as 0.28 to a maximum of 1.00, suggesting some variation among individual logs, but overall, the majority exhibited a gentle and consistent taper, reinforcing the observation of regular log form.

Table 12: Descriptive Statistics of Teak Log Characteristics and Sawn timber Production

Variable	Mean	Std. Dev.	Min	Max
Log length	6.36	1.11	4.00	9.00
Girth thick	46.55	16.04	20.00	89.00
Girth mid	44.64	15.63	19.00	85.00
Girth thin	42.91	15.63	17.00	83.00
Log volume	6.28	5.08	0.78	21.95
Sawn timber volume	1.25	0.97	0.19	4.08
Girth difference	95.67	2.46	89.47	98.31
Volumetric yield	24.39	13.86	5.81	63.55

The sawn timber volume averaged 1.25 cubic feet, with a range of 0.19 to 4.08 cubic feet, suggesting that only a fraction of the log volume was converted into usable timber. Most notably, the volumetric yield—the percentage of log volume successfully converted to sawn timber—averaged just 24.39%, with a wide range (5.81% to 63.55%) and high variability (standard deviation of 13.86%). This suggests that Teak processing is highly inefficient compared to other species, with significant losses during sawing.

3.6.2 Determinants of volumetric yield of Teak

The regression analysis presented in Table 13 assess the key factors influencing the volumetric yield in Teak (*Tectona grandis*) logs. The model includes three independent variables: girth at mid-point, taper, and log length, with the constant representing the baseline yield when all predictors are held at zero.

Table 13: Results of regression analysis to understand the determinants of volumetric yield in Teak

Variables	Coefficients (SE)
Constant	48.87 (15.38)***
Girth-mid	-0.39 (0.15)**
Taper	5.18 (11.01)
Length	-1.53 (2.09)

Note: *** and ** denote significant at 1%, and 5% level

The constant term is statistically significant at the 1% level (***), with a value of 48.87 (SE = 15.38). This indicates that when all explanatory variables are zero, the baseline volumetric yield is approximately 48.87 units. However, the constant alone has limited interpretive value without considering the context of the predictors.

Among the predictors, girth at mid-point shows a statistically significant negative relationship with volumetric yield (coefficient = -0.39, SE = 0.15, $p < 0.05$). This result suggests that as the girth at the mid-point increases, the volumetric yield decreases slightly. This may appear counterintuitive but could be explained by factors such as wood density variation, log shape irregularities, or volume estimation methods. In contrast, taper does not show a significant impact on volumetric yield (coefficient = 5.18, SE = 11.01). This lack of significance can be attributed to the low variability in taper values and log lengths across the sampled data. Since taper is relatively uniform in the dataset, its influence on yield cannot be reliably estimated, reducing its statistical relevance in the model.

Similarly, log length also shows a negative but statistically insignificant effect on volumetric yield (coefficient = -1.53, SE = 2.09). Again, this may be due to a narrow range of lengths among the samples, which limits the model's ability to detect a meaningful effect.

3.7 Karma

3.7.1 Descriptive statistics of Karma

Table 14 presents the descriptive statistics of Teak log characteristics and the resulting sawn timber production. The average log length was approximately 7.04 feet, with a standard deviation of 1.52 feet, ranging between 5 and 10 feet. The mean girth at the thick end of the logs was 62.91 inches, while the mid-point girth averaged 59.35 inches, and the thin end girth was 56.52 inches. These measurements indicate a gradual reduction in girth from the thick end to the thin end, reflecting relatively uniform taper across the logs.

Table 14: Descriptive Statistics of Teak Log Characteristics and Sawn timber Production

Variable	Mean	Std. Dev.	Min	Max
Length (feet)	7.04	1.52	5.00	10.00
Girth- Thick (inch)	62.91	17.88	33.00	90.00
Grith - Mid (inch)	59.35	16.59	32.00	85.00
Girth- Thin (inch)	56.52	15.98	30.00	81.00
Taper	0.08	0.03	0.05	0.13
Log volume (cft)	11.98	6.95	1.95	25.07
Sawn timber volume (cft)	6.68	4.74	0.45	16.55
Volumetric Yield	50.16	12.85	23.11	75.39
Girth differences	95.09	1.53	91.18	98.15

The results also show that average log volume was 11.98 cubic feet, and the mean sawn timber volume was 6.68 cubic feet. This indicates that a substantial portion of the log was converted into usable timber. The volumetric yield, which represents the percentage of the log converted into sawn timber, averaged 50.16%, with a range from 23.11% to 75.39%, reflecting some variability in processing efficiency.

The girth difference, which is the ratio between the girth at the thin end and the mid-point girth, expressed as a percentage. The results show that the mean girth difference is 95.09%, with a low standard deviation of 1.53, and values ranging from 91.18% to 98.15%. This indicates that, on average, the thin end of the log retains about 95% of the girth measured at the mid-point.

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Such a high girth difference percentage reflects minimal tapering, meaning there is very little reduction in girth from the mid-point to the thin end of the log. The mean taper was 0.08, with a small variation (±0.03), ranging from 0.05 to 0.13. This low taper value suggests that most logs were fairly cylindrical and had minimal shape distortion. This is beneficial for timber processing. Uniform logs with consistent girth throughout their length are easier to mill, result in less waste, and improve the efficiency of sawn timber recovery. The low variation in this ratio across the samples also reinforces the conclusion that the log shapes are generally consistent and well-formed.

3.7.2 Determinants of volumetric yield of Karma

Table 15 presents the results of a regression analysis conducted to identify the key factors influencing volumetric yield in Karma logs. The model includes girth at mid-point, taper, and log length as independent variables, with volumetric yield as the dependent variable.

The constant term is 13.83, with a standard error of 9.56, but it is not statistically significant, suggesting that the baseline yield value without the influence of the predictors may not be meaningful on its own.

Table 15: Results of regression analysis to understand the determinants of volumetric yield in Karma

Variables	Coefficients (SE)
Constant	13.83 (9.56)
Girth-mid	0.76 (0.16)***
Taper	-109.32 (96.50)
Length	-0.04 (1.35)

Note: *** denotes significant 1% level

Among the variables, girth at mid-point emerges as a highly significant determinant of volumetric yield, with a coefficient of 0.76 and a standard error of 0.16. This variable is significant at the 1% level (*), indicating a strong and positive relationship between girth at mid-point and volumetric yield. In practical terms, this means that as the girth at the mid-point of the log increases, the volumetric yield also increases significantly, making it a key factor in predicting yield efficiency.

In contrast, taper shows a large negative coefficient (-109.32) but with a very high standard error (96.50), and it is not statistically significant. This suggests that although the model estimates a strong negative impact of taper on yield, the variation and uncertainty around this estimate are too large to draw reliable conclusions. The likely reason is the low variation in taper among the Karma logs, limiting its explanatory power.

Similarly, log length has a very small negative coefficient (-0.04) with a standard error of 1.35, and is also not significant, indicating that changes in log length do not meaningfully affect volumetric yield in this dataset.

3.8 Jamun (*Syzygium cumini*)

3.8.1 Descriptive statistics of Jamun

Among the total of 32 Jamun logs analyzed, 15 logs (47%) were classified as Grade A, indicating superior quality with better dimensions and fewer defects. Grade B comprised 11 logs (34%), representing moderate quality, while the remaining 6 logs (19%) were categorized as Grade C, signifying lower-quality logs that likely contained defects or irregularities affecting processing efficiency.

Table 16: Descriptive Statistics of Jamun Log Characteristics and Sawn timber Production

Variable	Mean	Std. Dev.	Min	Max
Length (feet)	6.41	1.27	5.00	10.00
Girth-Thick (inch)	59.81	10.72	37.00	85.00
Girth-Mid (inch)	57.56	10.17	36.00	82.00
Girth-Thin (inch)	55.53	9.75	35.00	79.00
Log volume (cft)	9.73	4.46	2.81	20.43
Timber volume (cft)	5.52	3.18	1.14	12.25
Girth difference	96.50	2.00	93.02	104.17
Volumetric yield	53.73	11.65	27.44	71.68
Volumetric yield (Grade A)	61.07	8.22	44.52	71.67
Volumetric yield (Grade B)	49.78	10.98	27.43	62.65
Volumetric yield (Grade C)	42.60	8.13	30.40	53.55

Descriptive statistics of the log characteristics and their sawn timber production indicate considerable variation in physical dimensions and recovery performance (Table 16). The mean log length was 6.41 feet, with a standard deviation of 1.27 feet, suggesting some variability in length. The average girth at the thick end was 59.81 inches, decreasing slightly at the mid-point (57.56 inches) and further at the thin end (55.53 inches), indicating a typical taper pattern. The girth difference, which helps evaluate log form and taper, averaged 96.50 with a relatively low standard deviation (2.00), reflecting moderate uniformity across the logs. The mean taper is 0.68 (±0.33).

In terms of volume, the average log volume was 9.73 cubic feet, with a wide range from 2.81 to 20.43 cft. The mean timber volume recovered was 5.52 cft (SD = 3.18), indicating considerable variability in conversion outcomes. The overall volumetric yield, which represents the percentage of timber volume obtained from the total log volume, averaged 53.73%, ranging from 27.44% to 71.68%.

When analyzed by grade, Grade A logs showed the highest average volumetric yield of 61.07% (SD = 8.22), with a minimum of 44.52% and a maximum of 71.67%. Grade B logs followed with an average yield of 49.78% (SD = 10.98), while Grade C logs yielded only 42.60% on average (SD = 8.13). This clear gradation in yield demonstrates the strong influence of log quality on sawn timber recovery, highlighting the importance of proper log grading in maximizing sawmill efficiency and minimizing processing losses.

3.8.2 Determinants of volumetric yield of Jamun

Table 17 presents the results of a regression analysis carried out to assess the key determinants of volumetric yield in Jamun logs. The model indicates that girth at the mid-point (Girth-mid) is a statistically significant predictor of volumetric yield at the 5% significance level, with a coefficient of 0.58 and a standard error of 0.21. This suggests that, holding other factors constant, an increase of 1 inch in mid-girth is associated with a 0.58% increase in volumetric yield, highlighting the importance of log thickness at the center in determining conversion efficiency.

Other two variables, such as taper and length, showed positive but statistically non-significant relationships with yield. The coefficient for taper was 2.63 (SE = 6.29), implying a weak and uncertain effect of form variation along the log, while log length had a coefficient of 1.89 (SE = 1.69), indicating a moderate but not statistically strong influence. The intercept was 6.27 (SE = 11.57), representing the baseline yield when all independent variables are zero, though not significant on its own. Overall, the analysis underscores that among the variables considered, mid-girth is the most reliable determinant of timber recovery in Jamun logs.

Table 17: Results of regression analysis to understand the determinants of volumetric yield in Jamun

Variables	Coefficients (SE)
Constant	6.27 (11.57)
Girth-mid	0.58 (0.21)**
Taper	2.63 (6.29)
Length	1.89 (1.69)

Note: ** denotes significant 5% level

3.9 Masala- Timber

3.9.1 Descriptive statistics of Masala log for timber production

Table 18 presents the descriptive statistics of Masala log characteristics and the corresponding sawn timber production. The average log length was 7.44 feet with a standard deviation of 1.28 feet, indicating moderate variability in log sizes. The logs had an average girth at the thick end of 51.30 inches, while the mid and thin-end girths averaged 48.00 inches and 44.96 inches respectively, suggesting a typical tapering shape. The taper, which measures the difference in girth along the length of the log, had a mean value of 0.81 (±0.42), and ranged from 0.29 to 1.78, indicating varying degrees of taper across the logs.

In terms of volume, the mean log volume was 7.94 cft, with a wide range from 2.34 to 21.95 cft, reflecting differences in size and shape. The average sawn timber volume obtained from the logs was 4.27 cft, with a standard deviation of 3.17 cft, showing substantial variation in the amount of usable timber. The girth difference index, used to measure uniformity in log shape, averaged 93.46 with a relatively low standard deviation of 3.63, suggesting fairly consistent log form overall.

Table 18: Descriptive Statistics of Masala Log Characteristics and Sawn timber Production

Variable	Mean	Std. Dev.	Min	Max
Length (ft)	7.44	1.28	5	10
Girth-Thick (inch)	51.30	12.17	33	85
Girth- Mid (inch)	48.00	12.14	30	85
Girth- Thin (inch)	44.96	12.00	27	82
Taper	0.81	0.42	0.29	1.78
Log volume (cft)	7.94	4.47	2.34	21.95
Sawn timber volume (cft)	4.27	3.17	0.8	14.29
Girth difference	93.46	3.63	86.96	100
Volumetric yield	50.21	10.48	20.25	67.72

The volumetric yield, representing the efficiency of converting log volume into sawn timber, had a mean of 50.21%, but with considerable variation (SD = 10.48%), ranging from a low of 20.25% to a high of 67.72%. This variation highlights the influence of log dimensions and quality on processing efficiency, emphasizing the importance of log selection in maximizing timber recovery.

3.9.2 Determinants of volumetric yield (Timber) of Masala

Table 19 presents the results of a regression analysis carried out to identify the determinants of influencing volumetric yield (timber) in Masala logs. Among the variables included, girth at the mid-point (Girth-mid) is the highly significant predictor at the 1% significance level, with a coefficient of 0.49 and a standard error of 0.14. This indicates that, all else being equal, an increase of 1 inch in mid-girth leads to a 0.49% increase in volumetric yield, highlighting the critical role of log thickness at the center in determining timber recovery.

Table 19: Results of regression analysis to understand the determinants of volumetric yield (timber) in Masala

Variables	Coefficients (SE)
Constant	15.48 (11.35)
Girth-mid	0.49 (0.14) ***
Taper	1.40 (4.17)
Length	1.29 (1.39)

Note: *** denotes significant 1% level

The constant term was 15.48 (SE = 11.35), representing the baseline yield when all predictors are zero, though not statistically significant on its own. The coefficients for taper (1.40; SE = 4.17) and length (1.29; SE = 1.39) were positive but not statistically significant, suggesting that while these factors may have some influence on yield, their effects were not strong enough to be conclusive in this model. Overall, the results underscore that mid-girth is the most reliable determinant of sawn timber yield in Masala logs, and should be prioritized in log selection and grading processes to enhance sawmill efficiency.

4. Conclusions

The study on the volumetric yield of sawn timber from different species in Madhesh Province, Nepal, provides critical insights into the efficiency of timber processing and the factors influencing recovery rates. The findings reveal significant variability in volumetric yields across species, with Simal and Masala (veneer) showing higher yields (56.11% and 58.18% for defect-free production, respectively) compared to Teak, which had the lowest average yield of 24.39%. This variability underscores the importance of species-specific characteristics in determining processing efficiency. For instance, mid-girth emerged as a key determinant of yield for species like Sal and Karma, where larger girths positively correlated with higher recovery rates. Conversely, Teak exhibited an inverse relationship, suggesting that larger logs may be more prone to defects or processing inefficiencies. The study also highlighted the impact of log quality, with higher-grade logs (Grade A) consistently yielding more usable timber than lower grades (Grade B and C). However, the regression analyses indicated that log grade was not always a statistically significant predictor, emphasizing the need for a more nuanced understanding of log attributes beyond grading.

The study's limitations, such as the lack of standardized sawn timber sizes and the exclusion of by-products like sawdust, highlight areas for future research. Despite these constraints, the findings underscore the potential for improving yield through better log selection, advanced processing technologies, and operator training. The high variability in yields, particularly for species like Teak and Sissoo, suggests that optimizing processing techniques could significantly reduce waste and enhance resource utilization. Furthermore, the study's focus on operational conditions in Nepal provides a baseline for policymakers and industry stakeholders to develop targeted interventions. By addressing inefficiencies in sawmilling practices, Nepal can move toward more sustainable forest management, reducing pressure on forest ecosystems while meeting economic demands. Overall, the study underscores the need for species-specific strategies and technological upgrades to maximize timber recovery and promote sustainability in the forestry sector.

5. Recommendations

- Enhance Log Sectioning and Grading: Prioritize sectioning of logs with larger mid-girths and minimal taper, as these characteristics were linked to higher yields in species like Sal and Karma. Implement stricter grading standards to ensure consistent quality and reduce variability in processing outcomes.
- Adopt Advanced Sawing Technologies: Invest in modern sawmills equipped with optimization algorithms to improve recovery rates. Improved technologies in sawing can minimize waste and enhance precision, particularly for high-value species like Teak.
- Conduct Species-Specific Research: Further investigate the unique processing challenges of low-yield species like Teak to identify root causes of inefficiency. Pilot studies could test alternative sawing techniques or pre-processing treatments.
- Policy Interventions: Develop policies that incentivize high-efficiency sawmills through subsidies or tax breaks. Regulations could also mandate minimum yield standards to discourage wasteful practices.
- Promote Silviculture Based Forestry Practices: target forest management interventions to produce large diameter individuals with defect free,
- Improve Data Collection: Future studies should control for variables like log freshness and operator skill to isolate the impact of log characteristics on yield. Collaborative efforts with sawmills could ensure more consistent data.
- Raise Awareness: Educate stakeholders—from loggers to policymakers—on the economic and environmental benefits of yield optimization. Workshops and case studies can demonstrate best practices and successful implementations.

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Annexes
Annex 1: Meeting Minutes

२०७१/०४/२३.

वन अनुसन्धान तथा तालिम केन्द्र, सागरनाथ आ.व. २०७१/७२ को कार्यक्रम अनुसार वन विज्ञान अध्ययन संस्थान डिनको कार्यालय र हेटौंडा क्याम्पसले गर्ने विभिन्न कार्यक्रमहरू संचालन गर्नको लागि अध्ययन क्षेत्र छनोटको लागि छलफल गरियो।

उपस्थिति

(१) श्री जगन्नाथ [illegible], प्रदेश निर्देशक
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(४) श्री शिव कुमार [illegible], हेटौंडा क्याम्पस
(५) श्री दामोदर [illegible], हेटौंडा क्याम्पस
(६) श्री राजेश कुमार राई, डिनको कार्यालय

छलफल

- गएका वृक्षारोपणले पानीको उपलब्धतामा पारेको प्रभाव अध्ययन गर्न जनकपुर उपमहानगरपालिका वाडं नं. २२ लोहना मा ~~[illegible]~~ उपयुक्त हुने छलफल गरियो।
- Sample plot size को लागि वर्दिबास, महोत्तरी अन्तर्गत [illegible] मेडिकल [illegible] निर्माणको लागि [illegible] वन उपयुक्त हुने।

२०७९/०५/२२

वन अनुसन्धान तथा तालिम केन्द्र मधेश प्रदेशको आ.व. २०७९/८० को वार्षिक कार्यक्रम अन्तर्गत वन विज्ञान अध्ययन संस्थान डीनको कार्यालय र हेटौंडा ~~[illegible]~~ क्याम्पसले गर्ने विभिन्न अध्ययनहरूको लागि अध्ययन क्षेत्र छनौटको लागि छलफल गरियो।

उपस्थिति

(१) नीरज पोखरेल, रेन्जर, निजगढ डिभिजन वन कार्यालय

(२) डा. शिव [illegible], हेटौंडा क्याम्पस

(३) डा. दामोदर गैरे, हेटौंडा क्याम्पस

(४) प्रा. डा. राजेश कुमार राई, डीनको कार्यालय

निर्णय

- Forest growth study को लागि Shelterwood System अन्तर्गत सञ्चालित ब्लो.नं. ३ र ४ को Regeneration Felling plot र Shelterwood System अन्तर्गत सञ्चालित CFUG मा उपयुक्त हुने छलफल गरियो।

२०८१/०३/२२

वन अनुसन्धान तथा तालिम केन्द्र, मधेश प्रदेशको आ.व. २०८१/८२ को वार्षिक कार्यक्रम अन्तर्गत वन विज्ञान अध्ययन संस्थान डिनको कार्यालय र हेटौंडा क्याम्पसले गर्ने विभिन्न अध्ययनहरूको लागि अध्ययन क्षेत्र छनौटको लागि छलफल गरियो।

तपसिल

१. हेमन्त प्रसाद साह, डि.व.अ. रौतहट
२. महालक्ष्मी शर्मा, वन अधिकृत, रौतहट
३. लक्ष्मी कर्ण, रेन्जर [illegible]
४. डा. किरण कुमार मानन्धर, हेटौंडा क्याम्पस
५. डा. मनोहर गैरे, हेटौंडा क्याम्पस
६. प्रा.डा. राकेश कुमार राई, डिनको कार्यालय

छलफल

- Forest growth study को लागि रानीमाले सा.व.उ.स. उपयुक्त हुने,
- Effect of eucalyptus plantation on streamflow अध्ययनको लागि चन्द्रनिगाहपुर को [illegible] तर्फका plantation area हरू उपयुक्त हुने।

२०८१/०१/२३

वन अनुसन्धान तथा तालिम केन्द्र, बबरमहलको आव. २०८१/८२ को कार्यक्रम अन्तर्गत वन विज्ञान अध्ययन (संस्थान डिनको कार्यालय र हेटौंडा क्याम्पस) ले गर्ने विभिन्न अध्ययन हरूको लागि अध्ययन गरिने प्रजाति र अध्ययन क्षेत्रको बारेमा डि.व.अ. सलवन्धीमा छलफल गरियो।

उपस्थिति

(१) सन्तोष कुमार झा, डि.व.अ. सलोही

(२) डा. शिवकुमार मल्लन, हेटौंडा क्याम्पस

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(४) प्रा.डा. राजेश कुमार राई, डिनको कार्यालय

छलफल

- Volumetric yield को लागि साल, सागर, कर्मा, सिमल, सागुन, मसला र टिक उपयुक्त हुने।
- Eucalyptus को stream flow को लागि सगरमाथा वन विकास परियोजना र अन्य निजी वन क्षेत्र उपयुक्त हुने, यसको लागि मसला नर्सरीको तर पानी खुकेकाहरूहरू पनि अध्ययन गर्नुपर्ने।
- Sample plot size को लागि गाईघाटको मसको गैडिखेल कटैन प्रजाति वन उपयुक्त हुने।

२०७९/०३/२२.

डिभिजन वन कार्यालय, चितवनमा आज मिति २०७९/०३/२२ गते वन विज्ञान अध्ययन संस्थान डीनको कार्यालय र हेटौंडा क्याम्पस र वन अनुसन्धान तथा प्रशिक्षण केन्द्र बिच आ.व. २०७९/८० को विभिन्न अध्ययन अनुसन्धान कार्यको लागि अध्ययन क्षेत्र छनौटको लागि छलफल गरियो।

उपस्थिति

(१) सजीव झा, डि.व.अ. बारा

(२) मन्जुर अहमद, डि.व.अ. पर्सा

(३) डा. शिव कुमार मान्जन, हेटौंडा क्याम्पस

(४) डा. दामोदर गैरे, हेटौंडा क्याम्पस

(५) प्रा.डा. राजेश कुमार राई, डीनको कार्यालय

छलफल

- पर्सा ~~जि~~ जिल्लामा अवस्थित नेपाल वन निगमको ह. मिलमा सालको Volumetric yield को बारेमा अध्ययन गर्न सकिने।
- पर्सा डि.व.का. अन्तर्गत सर्वेक्षण सामुदायिक वनको stem mapping plot र बारा डि.व.का. अन्तर्गत ~~[illegible]~~ रहेका stem mapping हुने सा.व., धार्मिक वन र [illegible] प्रभावित निजगढ अन्तर्राष्ट्रिय विमानस्थल क्षेत्र,
- Forest growth को लागि Shelterwood system अन्तर्गत हलखोरिया साझेदारी वन र Selection अन्तर्गत वनगाउँ सा.व. कुस उपयुक्त हुने,
- Volumetric yield को लागि साल, [illegible] र [illegible] को लागि स्थानीय मिलहरूसंग समन्वय गर्ने।

Annex 2: Girth of and Veneer produced from Simal logs

SN	Girth-thick	Girth-Mid	Girth-Thin	Cylindrical Girth	Number of piece	defect piece
1	68	62	61	37	38	5
2	36	38	33	28	24	3
3	55	51	45	32	30	4
4	37	36	35	28	20	6
5	40	39	38	28	26	4
6	44	42	41	31	24	10
7	56	54	52	40	46	2
8	46	43	38	26	28	4
9	44	42	40	28	24	6
10	59	51	49	30	26	6
11	47	43	42	33	15	9
12	51	49	43	39	43	4
13	40	37	33	30	29	2
14	47	49	45	34	32	3
15	54	46	45	34	36	4
16	44	42	41	32	17	8
17	64	63	63	43	50	4
18	33	29	25	21	9	6
19	32	30	29	21	17	6
20	31	29	27	20	5	10
21	30	28	27	18	10	7
22	30	26	25	19	8	6
23	47	43	41	34	32	5
24	29	27	26	18	7	8
25	28	27	26	20	15	2
26	37	36	35	26	21	8
27	28	26	25	19	9	7
28	29	28	26	18	14	4
29	46	44	43	35	34	4
30	33	31	30	21	12	7
31	38	37	35	27	26	5
32	61	49	45	41	39	4
33	35	34	33	27	20	2
34	33	32	30	23	16	2
35	32	31	30	22	12	10
36	28	26	25	17	9	5
37	32	30	29	23	18	3
38	28	26	25	19	10	4
39	30	28	27	19	9	4
40	27	26	26	18	12	6
41	50	46	42	37	43	3
42	32	29	27	22	15	2
43	33	30	29	22	18	3
44	26	24	23	18	9	4

45	31	29	26	19	12	3
46	28	29	25	20	18	5
47	39	35	32	28	28	3
48	27	26	25	19	10	8
49	58	54	50	46	50	6
50	49	38	33	29	28	4
51	37	34	32	24	22	9
52	41	38	37	32	33	4
53	39	37	36	28	26	6
54	35	33	32	24	12	9
55	36	35	33	27	19	9
56	37	31	30	21	18	7
57	32	31	30	21	16	8
58	45	44	42	36	30	3
59	29	28	27	20	16	2
60	45	43	42	34	40	2
61	32	30	29	22	17	6
62	31	30	29	22	14	8
63	32	31	28	22	15	5
64	27	26	24	18	10	6
65	31	30	28	20	17	6
66	33	31	29	22	18	6
67	59	44	38	34	36	4
68	36	35	33	26	28	2
69	30	29	28	22	10	7
70	32	29	28	24	15	5
71	29	28	25.5	22	12	8
72	28	29	26	20	10	4
73	32	30	29	25	7	14
74	41	39	38	33	37	4
75	47	45	42	36	43	3
76	28	27	25	22	10	7
77	58	42	38	34	31	3
78	30	29	27	23	16	2
79	30	28	27	20	9	7
80	29	28	26	21	14	4
81	29	27	26	20	5	10
82	30	28	25	20	3	12
83	45	43	40	34	32	3
84	41.5	40	38	32	32	4
85	29	27	26	19	8	6
86	36	35	33	26	20	2
87	37	34	32	25	12	9
88	36	34	32	26	16	7
89	48	46	45	37	43	3
90	62	56	50	47	59	3

91	34	33	31	25	16	6
92	42	40	38	31	23	10
93	38	37	35	30	26	6
94	40	39	36	30	29	2
95	38	37	35	29	19	7
96	38	26	24.5	19	7	6
97	35	34	32	26	15	5
98	50	49	47	41	54	4
99	30	29	27	21	8	6
100	43	42	40	33	16	10
101	42	40	37	33	15	9
102	41	40	37	34	30	2
103	45	43	42	34	36	4
104	36	34	33	26	7	14
105	45	45	43	36	38	5
106	68	54	46	46	50	2
107	50	48	47	40	51	2
108	42	40	38	33	32	3
109	28	27	25	21	9	4
110	31	29	28	20	10	4
111	42	40	39	31	21	4
112	29	28	26.5	20	6	7
113	28	27	26	22	15	2
114	54	53	50	46	44	18
115	28	26	25	20	9	2
116	41	42	40	33	33	4
117	35	33	33	25	20	2
118	32	32	32	24	17	4
119	39	38	37	28	22	5
120	28	27	25	20	3	13
121	32	31	30	23	13	5
122	37	35	33	26	19	5
123	33	31	30	23	13	3
124	35	34	31	25	9	7
125	33	31	30	.24	18	3
126	55	54	52	44	50	3

Annex 3: Log Characteristics of Sal and Sawn timber volume

S N	Log Grade	Length (ft)	Girth (inch) Thick end	Mi d	Thin end	Log volume (cft)	Sawn timber volume (cft)
1	1	7	61	59	66	10.58	3.94
2	1	6	60	57	54	8.46	4.00
3	1	7	50	48	46	7.00	4.08
4	1	7	56	53	51	8.53	4.81
5	1	6	65	60	58	9.38	6.38
6	1	8	63	60	58	12.50	6.67
7	1	6	68	65	62	11.00	7.13
8	1	7	65	62	60	11.68	7.29
9	1	9	65	63	60	15.50	7.50
10	1	8	65	62	60	13.35	8.08
11	1	7	67	65	62	12.84	8.36
12	1	9	64	61	59	14.54	9.00
13	1	7	78	76	73	17.55	11.96
14	1	7	84	80	77	19.44	13.42
15	1	7	92	90	87	24.61	16.04
16	1	10	86	83	80	29.90	19.86
17	1	10	91	85	80	31.36	21.67
18	1	10	94	90	37	35.16	22.50
19	1	10	97	94	91	38.35	25.83
20	1	10	104	102	100	45.16	29.17
21	2	5	53	50	48	5.43	2.71
22	2	5	53	49	47	5.21	3.13
23	2	7	48	47	45	6.71	4.08
24	2	7	49	48	46	7.00	4.08
25	2	7	54	52	50	8.22	4.23
26	2	6	58	55	54	7.88	4.50
27	2	9	49	46	44	8.27	4.88
28	2	9	50	48	47	9.00	6.47
29	2	5	73	70	68	10.63	8.75
30	2	10	64	60	57	15.63	10.00
31	3	5	33	31	30	2.09	0.97
32	3	3	43	41	40	2.19	1.17
33	3	5	41	40	39	3.47	1.39
34	3	5	42	40	40	3.47	1.49
35	3	4	49	46	44	3.67	1.67
36	3	5	38	36	34	2.81	1.75
37	3	9	49	45	43	7.91	4.50
38	1	5	63	69	58	10.33	3.13
39	1	7	65	62	60	11.68	7.00
40	1	7	64	63	59	12.06	7.00
41	1	7	65	64	62	12.44	7.58

42	2	6	51	49	45	6.25	2.50
43	2	4	50	48	45	4.00	2.71
44	2	7	51	48	46	7.00	3.35
45	2	7	52	49	50	7.29	3.50
46	2	7	51	49	45	7.29	3.65
47	3	9	32	31	31	3.75	0.56
48	3	5	39	37	36	2.97	1.25
49	3	4	39	39	36	2.64	1.33
50	3	5	42	41	39	3.64	1.46
51	3	7	38	36	35	3.94	1.60
52	3	5	38	34	32	2.51	1.67
53	3	7	42	40	37	4.86	2.33
54	3	7	44	42	41	5.36	4.28
55	3	7	55	52	50	8.22	5.25

Annex 4: Log Characteristics of Saj/Asna and Sawn timber volume

Log Grade	Length (ft)	Log Girth (inch)			Log volume (cft)	Timber volume (cft)
		Thick	Mid	Thin		
1	10	65	60	56	15.63	7.22
1	7	66	62	58	11.68	7.58
1	8	74	70	67	17.01	8.00
1	7	69	66	62	13.23	8.45
1	7	68	65	60	12.84	8.75
1	9	64	61	58	14.54	11.00
1	7	84	80	78	19.44	12.05
1	7	96	89	84	24.07	13.70
1	9	93	87	83	29.57	19.87
1	9	100	96	93	36.00	22.31
2	5	54	51	49	5.64	2.91
2	7	52	49	45	7.29	3.20
2	5	58	56	52	6.81	3.33
2	7	62	58	59	10.22	5.54
2	10	57	55	50	13.13	7.84
3	7	39	36	34	3.94	1.75
3	10	48	46	43	9.18	4.58

Annex 5: Log Characteristics of Sissoo and Sawn timber volume

SN	Length (ft)	Girth (inch)			Log volume (cft)	Sawn timber volume (cft)
		Thick	Mid	Thin		
1	9	50	48	45	9.00	5.25
2	5	40	37	35	2.97	0.94
3	7	41	40	38	4.86	1.26
4	3	39	38	36	1.88	1.31
5	5	42	39	38	3.30	1.45
6	5	51	46	45	4.59	1.56
7	7	49	48	46	7.00	1.85
8	7	43	41	40	5.11	2.04
9	5	59	57	56	7.05	2.47
10	5	45	43	41	4.01	2.50
11	7	49	46	43	6.43	3.50
12	8	65	61	51	12.92	4.39
13	6	57	56	55	8.17	4.50
14	7	65	62	60	11.68	4.72
15	7	55	52	50	8.22	5.01
16	9	61	59	56	13.60	5.25
17	8	51	48	48	8.00	5.33
18	5	68	65	62	9.17	5.63
19	7	59	57	55	9.87	5.83
20	10	51	49	46	10.42	5.83
21	7	61	59	57	10.58	7.17
22	8	66	63	60	13.78	8.72
23	7	71	68	65	14.05	8.80
24	9	69	66	62	17.02	9.13
25	9	65	63	58	15.50	9.75
26	9	68	64	60	16.00	10.50
27	7	84	81	77	19.93	12.13
28	5	45	43	40	4.01	3.22

Annex 6: Log Characteristics of Masala and Veneer production

SN	Girth (inches)			cylindrical girth (inch)	Number of veneers	Defected pieces
	Thick	Mid	Thin			
1	34	33	32	25	30	6
2	31	30	29	24	24	6
3	23	22	21	15	19	10
4	27	26	25	19	20	12
5	30	28	27	20	33	14
6	26.5	26	26	19.5	31	10
7	35.5	34	33	27	36	6
8	20	19	18	14	14	8
9	29	28	28	21	28	2
10	31	30	30	22	12	8
11	31.5	30	29	21	30	6
12	15	14	13	8	4	12
13	28	27	26	20	25	4
14	38	37	36	29	28	11
15	28	27	26	18	17	14
16	26	25	24	18	19	6
17	29	28	27.5	21	27	4
18	28	27	26	21		.
19	29	27	26.5	20	25	6
20	35.5	34	33	27	27	5
21	33	32	31	26	32	2
22	36	35	34	27	19	8
23	21	20	19	14	.	.
24	30	29	28	21	19	14
25	33	32	31	24	34	4
26	32.5	31	30	24	23	4
27	18	16	15.5	10	5	8
28	18	17	16	10	9	6
29	28	27	26	19	34	3
30	38.5	37	36	30	30	5
31	33	32	31	25	22	8
32	40.5	39	38	0	.	.
33	28	27	26	20	25	6
34	32	31	31	23	23	12
35	25	24	24		17	7
36	25	24	23	18	22	8
37	37.5	35	35	30	23	12

38	32	31	30	35	30	6
39	31	30	29	25	25	8
40	30	29	28	22	20	4
41	14	13	12.5	8	4	10
42	15	14	13	7	5	12
43	16	15	14	8	4	12
44	21	20	19	12	18	6
45	15	14	13	9	6	5
46	18	17	17	10	11	9
47	23	22	21	16	10	6
48	20	19	18	15	9	10
49	21	20	19	16	6	4
50	28.5	27	26	21	24	10
51	21	20	19	14	18	6
52	21.5	20	19	14	22	4
53	26	25	24.5	18	17	10
54	21	20	19	15	20	4
55	26	25	24	21	19	8
56	25	24	23	20	20	8
57	25.5	24	23	21	18	10
58	24	23	22.5	18	25	3
59	23	22	21	18	20	10
60	30	29	27.5	21	27	6
61	27	26	25	18	28	4
62	28.5	25	24	20	22	5
63	30.5	29	28	21	28	4
64	41	40	39	32	34	2
65	28	27	26	22	32	2
66	35	34	32.5	26	33	2
67	41.5	42	40	30	46	6
68	35	34	33	27	16	8
69	39.5	39	38	31	.	.
70	38	37	36.5	30	40	7
71	44	43	40	37	35	6
72	36.5	35	34	28	38	3
73	42	41	40	33	26	5
74	41	39	38	30	35	8
75	38	36	35	29	33	3
76	37	36	35	29	36	7
77	39.5	38	38	31	32	10
78	26	25	24	19	27	6

79	16	15	14	9	8	12
80	34	33	33	25	30	4
81	20.5	20	19.5	12	12	5
82	19.5	18	17	11	12	5
83	25	24	23	18	26	8
84	34	33	32	27	39	2
85	20	19	18	11	17	7
86	22	21	20	12	23	4
87	21	20	19	12	15	8
88	33.5	32	31	24	36	4
89	36	35	34	28	30	10
90	30	30	29	23	32	12
91	18.5	18	18	10	8	14
92	16	15	14	8	6	8
93	22	21	20	13	20	15
94	30.5	30	30	22	34	6

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Annex 7: Log Characteristics of Teak and timber production

SN	Log length (ft)	Log girth (inch)			Log volume (cft)	Sawn Timber volume (Cft)
		Thick	Mid	Thin		
1	5	20	19	17	0.78	0.31
2	7	32.5	31	29	2.92	0.19
3	7	47	46	45	6.42	4.08
4	7	57	55	53	9.19	4.08
5	6	59.5	58	56	8.76	1.58
6	7	50	49	48	7.29	1.02
7	7	86	83	81	20.93	3.79
8	5	39	38	36	3.13	0.58
9	7	79	76	74	17.55	1.02
10	7	35	34	33	3.51	0.58
11	7	47	46	44	6.43	0.58
12	5	37	36	35	2.81	0.88
13	7	89	85	83	21.95	1.31
14	7	34	31	28	2.92	1.22
15	7	39	35	33	3.72	1.02
16	9	40	37	36	5.35	1.07
17	8	40	36	34	4.50	1.58
18	7	39	36	33	3.94	0.78
19	7	37	35	32	3.72	0.78
20	5	34	32	29	2.22	1.02
21	7	52	50	49	7.60	1.75
22	4	53	52	50	4.69	0.86
23	5	29	28	27	1.70	0.73
24	5	63	60	58	7.81	1.67
25	5	31	30	29	1.95	0.89
26	5	27	26	25	1.47	0.47
27	7	45	44	42	5.88	0.73
28	6	46	44	43	5.04	1.25
29	6	41	40	38	4.17	0.88
30	7	60	59	58	10.58	1.60
31	5	57	55	54	6.56	0.63
32	7	54	51	49	7.90	1.68
33	7	37	36	35	3.94	0.58

Annex 8: Log Characteristics of Karma and timber production

SN	Log Length (ft)	g1 inch	gm inch	g2 inch	taper	log volume cft	sawn timber volume cft
1	9	69	63	60	0.08	15.50	8.81
2	7	90	85	81	0.11	21.95	16.55
3	7	50	47	45	0.06	6.71	3.50
4	7	38	36	34	0.05	3.94	1.22
5	7	88	82	77	0.13	20.43	10.74
6	7	87	82	78	0.11	20.43	13.22
7	7	69	65	63	0.07	12.84	7.10
8	6	74	70	67	0.10	12.76	7.08
9	5	65	62	60	0.08	8.34	4.17
10	7	66	62	59	0.08	11.68	5.54
11	10	83	76	74	0.08	25.07	15.07
12	10	68	63	59	0.08	17.23	7.78
13	7	89	84	79	0.12	21.44	13.42
14	9	58	54	53	0.05	11.39	7.50
15	7	61	60	57	0.05	10.94	6.56
16	7	47	44	42	0.06	5.88	1.94
17	5	34	32	30	0.07	2.22	0.73
18	7	52	49	46	0.07	7.29	3.16
19	5	58	54	51	0.12	6.33	2.99
20	9	70	67	65	0.05	17.54	9.69
21	7	63	62	59	0.05	11.68	5.44
22	5	35	34	31	0.07	2.51	0.87
23	5	33	32	30	0.05	2.22	0.45

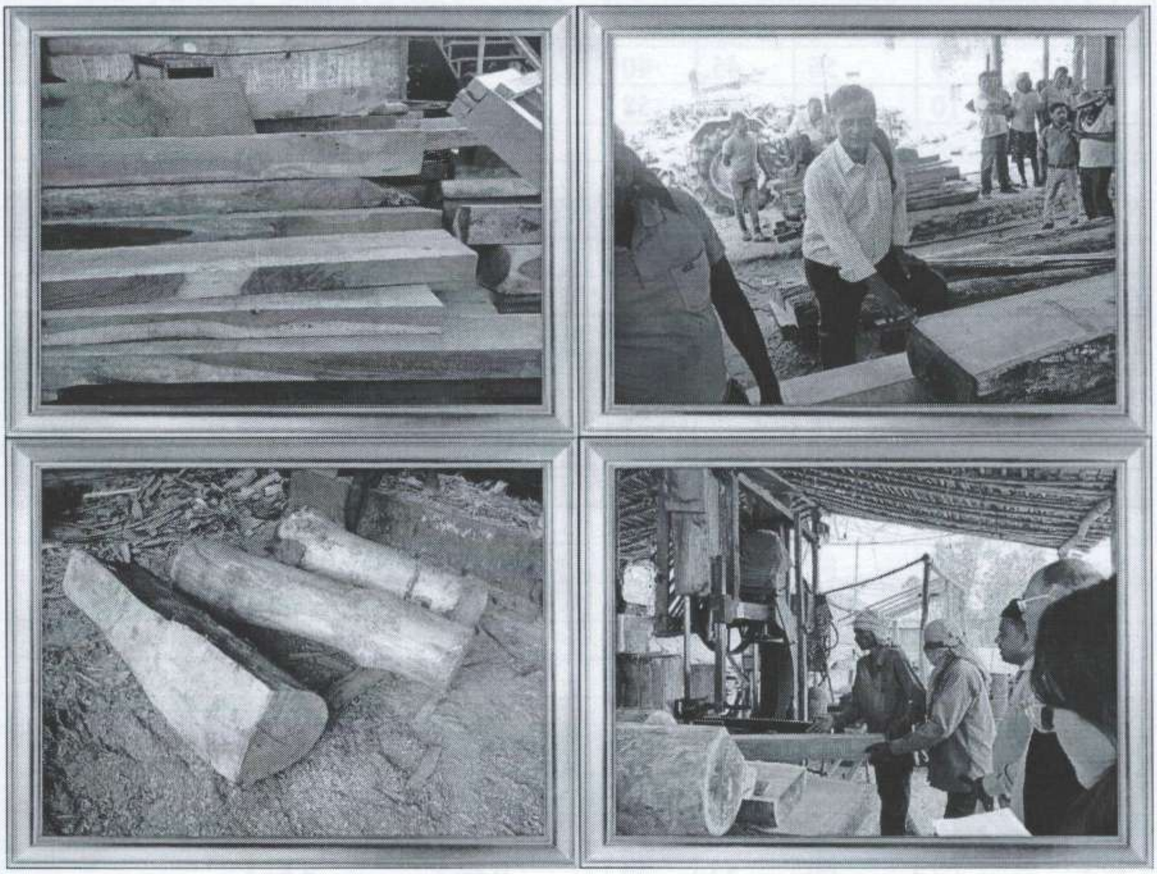
Annex 9: Log Characteristics of Jamun and timber production

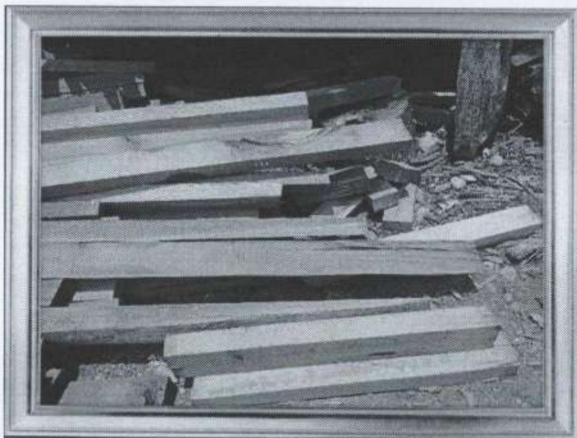
Grade	Length (ft)	Girth (inch)			Log volume (cft)	Piece	Timber volume (cft)
		Thick	Mid	Thin			
1	7	67	64	62	12.44	12	8.45
1	7	65	64	61	12.44	14	8.55
1	5	75	70	67	10.63	10	7.29
1	7	69	65	63	12.84	16	5.83
1	5	46	44	41	4.20	4	1.87
1	9	70	67	64	17.54	11	9.93
1	7	64	62	59	11.68	7	7
1	7	79	75	73	17.09	9	12.25
1	7	85	82	79	20.43	14	11.67
1	7	67	65	62	12.84	16	8.17
1	5	63	60	58	7.81	5	4.58
1	10	67	66	63	18.91	8	10.97
1	7	65	62	62	11.68	12	7.87
1	7	67	66	63	13.23	18	9.04
1	7	60	61	59	11.31	15	6.75
2	7	53	51	49	7.90	11	4.95
2	5	61	58	56	7.30	11	4.27
2	5	58	55	53	6.56	8	1.8
2	5	53	51	50	5.64	6	2.36
2	7	60	57	56	9.87	11	4.22
2	7	51	49	47	7.29	8	4.08
2	7	49	47	45	6.71	7	2.57
2	5	69	65	62	9.17	7	4.44
2	7	60	58	55	10.22	8	6.12
2	7	60	58	55	10.22	12	5.83
2	5	53	52	51	5.87	9	3.22
3	7	44	43	40	5.62	6	3.01
3	5	37	36	35	2.81	3	1.14
3	5	53	50	48	5.43	7	2.6
3	5	50	49	48	5.00	6	1.52
3	5	48	46	45	4.59	6	2.08
3	7	47	45	44	6.15	2	2.33

Annex 10: Log Characteristics of Masala and timber production

SN	Timber length (ft)	Girth (inch)			Taper	Log volume (cft)	Sawn Timber volume (cft)
		Thick	Mid	Thin			
1	9	56	45	40	1.78	7.91	3.56
2	10	68	63	58	1.00	17.23	11.11
3	8	51	46	40	1.38	7.35	3.56
4	9	56	54	52	0.44	11.39	7.50
5	9	51	46	40	1.22	8.27	3.56
6	10	55	48	44	1.10	10.00	5.56
7	8	49	45	43	0.75	7.03	3.56
8	6	35	31	27	1.33	2.50	1.25
9	6	42	40	39	0.33	3.96	0.80
10	7	65	63	60	0.50	10.94	7.00
11	7	50	47	44	0.55	6.71	4.08
12	7	68	65	61	1.00	12.84	6.71
13	5	50	47	43	1.40	4.79	2.33
14	7	85	85	82	0.43	21.95	14.29
15	7	36	34	32	0.57	3.51	1.75
16	7	65	63	61	0.57	12.06	8.17
17	6	33	30	28	0.83	2.34	1.17
18	7	44	42	41	0.43	5.36	2.63
19	7	42	40	40	0.29	4.86	2.19
20	7	55	52	50	0.71	8.22	3.50
21	7	50	48	47	0.43	7.00	2.63
22	7	60	57	54	0.86	9.87	5.25
23	7	34	36	32	0.29	3.94	1.46
24	7	56	50	45	1.57	7.60	4.08
26	7	41	38	36	0.71	4.39	1.75
27	7	40	39	37	0.43	4.62	2.19
28	10	48	42	38	1.00	7.66	3.75

Annex 11: Field Photographs








Annex 12: List of Experts

1. Prof. Dr. Rajesh Kumar Rai — Team Leader
2. Associate Prof. Vijay Kumar Yadav — Forestry Utilization Expert
3. Assistant Prof. Dr. Dhruba Bijay GC — Forestry Expert

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