FAO-EU FLEGT PROGRAMME

Food and Agriculture Organization of the United Nations

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Forestry Commission

Project Title: Assessing the Chain of Custody and Improving Efficiency in Permit Issuance for Plantation Timber Using the Case of Public and Private Forest Plantations in Ghana (PO 341965)

FAO-EU FLEGT Programme-Sponsored Project. Implemented by the Forest Services Division of the Forestry Commission of Ghana

SYNTHESIS OF MAJOR PROJECT OUTPUTS

- Guidelines for Plantation Timber Harvesting (Chain of Custody System for Plantation Timber in Ghana)
- Form and Conversion Factors of the Major Forest Plantation Timber Species

June, 2021

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Acronyms

CoC	Chain of Custody
DBH	Diameter at Breast Height
DOTIC	Domestic Timber Inspection Certificate
ED	Executive Director
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations Organisation
FC	Forestry Commission
FLEGT	Forest Law Enforcement, Governance and Trade
FR	Forest Reserve
FSD	Forest Services Division
GPS	Global Positioning System
GPTH	Guidelines for Plantation Timber Harvesting
GWTS	Ghana Wood Tracking System
KWC	Kumasi Wood Cluster
LIC	Lumber Inspection Certificate
LOGIC	Log Inspection Certificate
MoP	Manual of Procedures
MSS	Medium and Small-scale Private Developers
PLMCC	Plantation Log Measurement Conveyance Certificate
PM	Property Mark
PPC	Plantation Production Certificates

PSP	Permanent Sample Plot
QA	Quality Assurance
QC	Quality Control
RMSC	Resource Management Support Centre of Forestry Commission
RMSE	Root Mean Square Error
STV	Standing Tree Value (or Standing Tree Volume)
TIDD	Timber Industry Development Division of the Forestry Commission
TVD	Timber Validation Department of the Forestry Commission
VPA	Voluntary Partnership Agreement

1. BACKGROUND

Forest plantation timber currently constitutes a significant proportion of timber harvested in Ghana. Over the past decade, plantation timber volume exported from Ghana has increased from 16 percent of total timber exports in 2010 (i.e., 65,607 m^3) to 57 percent of timber volume exported in 2019 (i.e., 170,382 m^3). The increasing importance of forest plantation timber in Ghana is attributable to the enhanced investment by the government and private sector as well as improved public-private partnerships in forest plantation development since 2001 when the National Forest Plantation Development Programme (2001 – 2016) was launched. A total area of 134,535.7 ha of forest plantations was established under the Programme, out of which 62,567 ha, representing 46.5% of the area, was established by private plantation developers.

These investments and partnerships in forest plantation development have been further boosted with the implementation of the Ghana Forest Plantation Strategy (2016 – 2040) which amongst others, prescribes a target for the development of 25,000 hectares of forest plantations per annum by the public sector (15,000 ha per annum) and private investors (10,000 ha per annum) [1]. The estimated area of forest plantations developed under the Ghana Forest Plantation Strategy (GFPS) from 2017 – 2020 is presented in Table 1:

Table 1: Forest Plantations Established under the implementation of the GFPS: 2017 - 2020

YEAR	AREA ESTABLISHED (ha)		
	PUBLIC	**PRIVATE**	**TOTAL**
2017	5,540.5	3,184.5	8,725.0
2018	14,749.4	4,856.5	19,605.9
2019	19,038.7	5,965.5	25,004.2
2020	14,084.6	5,086.8	19,171.4
TOTAL	**53,547.0**	**18,535.1**	**72,082.0**

The predominant tree species planted in Ghana is *Tectona grandis* (Teak) which accounts for about 60 percent of planted tree species. The other major plantation species are: *Cedrela odorata* (about 15 percent); *Eucalyptus spp.* (about 10 percent); *Gmelina arborea* (about 5 percent); and indigenous species (*Terminalia spp., Khaya spp.* etc.) which constitutes about 10 percent of planted tree species in Ghana.

An estimated area of 147,000 hectares of degraded forest reserve land has been allocated for commercial forest plantation development by private developers since 2001. Consequently, various private investors, including small, medium and large-scale developers have established large areas of forest plantations within their allocated degraded forest lands with some of these plantations being progressively thinned for use as poles for domestic electricity transmission and/or harvested for export or domestic use. The major commercial private plantation developers in Ghana are as follows:

Table 2: Major Commercial Private Forest Plantation Developers in Ghana

Private Developer	**Predominant Species Planted**	**Total Area Planted (ha)**	**Location**
Miro Forestry Ghana Limited	Eucalyptus	11,058.4	1. Boumfum Forest Reserve, Kumawu Forest District, Ashanti Region; 2. Chirimfa and Awura Forest Reserves, Mampong Forest District, Ashanti Region; 3. Off-Reserve Site in the Kumawu Forest District
Form Ghana Company Limited	Teak	10,840.4	1. Afrensu Brohuma and Asubima Forest Reserves, Offinso Forest District, Ashanti Region; 2. Tain II Tributaries Forest Reserve, Sunyani Forest District, Bono Region
African Plantations for Sustainable Development Ghana Limited	Eucalyptus	8,337.0	Off-Reserve Site in the Atebubu Forest District, Bono East Region
Greenfields Plantations Limited	Cedrela and various indigenous species	6,047.4	1. Bosomkese Forest Reserve, Bechem Forest District, Ahafo Region; 2. Bia Shelterbelt Forest Reserve, Goaso, Ahafo Region; 3. Mpameso Forest Reserve, Dormaa Forest District, Bono Region; 4. Amama Forest Reserve, Sunyani Forest District, Bono Region
Private Afforestation Developers Organisation (PADO)	Teak	~3,000.0	PADO is an association of private developers undertaking commercial forest plantation development primarily in the Kwamisa Forest Reserve, Offinso Forest District
Mere Plantations Limited	Teak	1,570.4	Afram Headwaters Forest Reserve, Offinso Forest District, Ashanti Region

The established private commercial forest plantations coupled with government-owned plantations, which are due for thinning/ harvesting have resulted in the significant increase in the volume of forest plantation timber harvested in recent years. Commercial thinnings for Teak is being undertaken at 10 – 12 years in most of the established private commercial forest plantation whiles final harvesting of Teak is undertaken at about 15 - 25 years for production of sawlogs.

Most of the plantation timber is converted into air-dried and kiln-dried lumber for export predominantly using portable mobile mills (mainly Wood-Mizer machines) dotted across the country, and usually close to forest plantation sites where the timber is processed. In the case

of Teak, a significant volume is still exported as primary timber products, especially as billets. Miro Forestry Ghana Limited has set up a state-of-the-art timber processing facility for the production of veneer, with a ply mill under construction. This development has resulted in the utilisation of small-sized Eucalyptus and Gmelina for veneer and plywood production, and consequently contributed to a significant reduction in the rotation period of these species within their plantation holdings to about 6 – 8 years.

In accordance with the requirements of the FLEGT Voluntary Partnership Agreement (VPA) signed between the Government of Ghana and the European Union (EU), Ghana is implementing a Chain of Custody (CoC) system and procedures to ensure that only verified legal timber is made available on the local and export markets. As a result of the increasing volumes of forest plantation timber harvested, it has become obvious that the current CoC procedures and guidelines governing the harvesting of forest plantation timber impedes the work process and thereby inefficiently restricts volumes of plantation timber that can be harvested within a given period, with its attendant challenges particularly for private commercial forest plantation developers.

The Forestry Commission of Ghana is currently reviewing the Manual of Procedures (MoP) for forest plantations to ensure its alignment with the strategic focus of the Ghana Forest Plantation Strategy. However, the revision of the Plantations MoP is being driven primarily from the perspective of the regulator to ensure efficient control of the sub-sector and has therefore not fully integrated the major concerns of the private sector for more business-friendly, effective and efficient procedures. These concerns include bureaucratic CoC procedures imposed on the plantation timber value chain, discrepancies in volume estimates and delays in processing of plantation timber documents such as permits and Plantation Log Measurement Conveyance Certificates (PLMCCs).

As part of measures to streamline the prevailing forest plantation timber CoC systems and reflect the perspectives of the private sector for a more investor-friendly forest plantation industry, the Forest Services Division of the Forestry Commission received support from the FAO EU FLEGT programme to implement the project titled: ‘Assessing the Chain of Custody and Improving Efficiency in Permit Issuance for Plantation Timber Using the case of Private and Public Forest Plantations in Ghana’. The major outputs of the project are the development, field-testing and validation of Guidelines for Plantation Timber Harvesting and Determination of Form Factor and Conversion Factor of the major forest plantation timber species.

1.1 Objective of the Report

The objective of this publication is to present the methodology and key outputs from project implementation as well as recommendations for further studies and policy actions. The publication therefore serves as synthesis report for the different project outputs. The report is structured to present the sequence of activities undertaken under the project with pointers showing the specific chapters where the detailed information on the issue could be accessed.

2. OVERVIEW OF PROJECT ACTIVITIES AND OUTPUS

The project seeks to improve efficiency and transparency of the plantation timber industry in line with the strategic focus of the GFPS (2016 – 2040).

The project outputs and activities are as follows:

Output 1: Current Procedures for Plantation Timber Harvesting documented and Draft Guidelines for Plantation Timber Harvesting (GPTH) developed.

Activities

Activity 1.1: Collect information on the current procedures/processes for plantation timber harvesting, the Ghana Chain of Custody requirements, and functioning of the Wood Tracking System with reference to plantation timber.

Activity 1.2: Develop draft Guidelines for Plantation Timber Harvesting (GPTH).

Output 2: Draft GPTH Assessed, Field-tested and Improved.

Activities

Activity 2.1: Further assessment and field test of initial draft GPTH developed under Activity 1.2;

Activity 2.2: Determine accurate conversion factors for plantation timber.

Output 3: Proposed GPTH Pilot-tested and validated.

Activity 3.1: Pilot testing the proposed GPTH and application of the Wood Tracking System (WTS) in forest plantations across the entire chain (i.e., from harvesting to export).

Activity 3.2: Validation of the final draft GPTH.

Output 4: Communication and Visibility is ensured throughout the Project.

Activity 4.1: Develop project visibility material (information sheets) for publicizing project activities, results and expected impacts

Activity 4.2: Organize project inception workshop

Activity 4.3: Organize project close-out workshop

3. METHODOLOGY & SHORT DESCRIPTION OF ACHIEVEMENTS

a. Desk Study and Review of the Current Procedures/ Processes for Plantation Timber Harvesting

This phase involved collection of information on the current procedures/ processes governing plantation timber harvesting in Ghana including the CoC requirements and functioning of the Wood Tracking System in relation to plantation timber. Consultations were also held with private commercial plantation developers (large-scale and small-medium-scale developers) to learn about their experiences with the prevailing procedures for plantation timber harvesting and to seek their comments and inputs for improvement. An output of this phase was the development of a Working Document with suggested improvements of the current procedures for plantation timber harvesting. **See Chapter 4**.

b. Development and Field Assessment of the Proposed Procedures for Plantation Timber Harvesting

Based on the information collected from the desk study and review of the current procedures, an initial set of options were proposed to address some of the challenges noted in the current procedures. Field assessments were also undertaken to determine the feasibility of the proposed options at various private forest plantation stands (large scale and small-medium scale private commercial forest plantations) across the major ecological zones. This preliminary field assessment sought to determine the availability of the required information including Inventory/ Permanent Sample Plot (PSP) data from the different categories of the targeted forest plantation developers. **See Chapters 5 & 6.**

c. Determination of accurate conversion factors for plantation timber

During the field visits, measurements were also taken of various tree parameters (including dbh, section measurements of diameters at one-metre intervals, heights, lengths and dimensions of processed plantation timber) for estimation of form and conversion factors of the major forest plantation timber species (Teak, Cedrela, Gmelina and Eucalyptus). Determination of accurate conversion and form factors is essential to improve the effectiveness of tracking of plantation timber transformations along the entire supply chain and also for the accurate estimation of standing tree value of forest plantation timber. **See Chapter 7**.

d. Consultations with Stakeholders on the Proposed Options

Further consultations were held with the Plantations Department of the Forest Services Division and Private Commercial Forest Plantation Developers on the proposed guidelines. The guidelines were subsequently reviewed to incorporate the suggestions of the stakeholders. **See Chapter 4.**

e. Pilot Testing of the Proposed Guidelines for Plantation Timber Harvesting:

Pilot Testing of the major proposed modifications of the current procedures was undertaken on 7^{th} – 16^{th} April 2021 within the Offinso and Kumawu Forest Districts. The pilot testing involved an assessment of the robustness of PSP data from plantation holdings of two major large-scale commercial forest plantation developers in Ghana and its reliability for use in estimating Standing Tree Volume of plantation stands earmarked for harvesting within these holdings. In addition, assessments were also undertaken to determine the optimal volume per truck or container of plantation materials conveyed from harvesting sites. **See Chapter 6.**

f. Validation and Finalisation of the Proposed GPTH:

A multi-stakeholder workshop was held on 21st May, 2021 to validate the proposed GPTH. Feedback and comments received from stakeholders during the workshop served as an important guide for the final review and finalisation of the GPTH. **See Chapter 5**.

4. OVERVIEW OF INPUTS RECEIVED FROM PRIVATE DEVELOPERS ON THE DRAFT FOREST PLANTATIONS MOP

Discussions have been ongoing between the Forest Services Division (FSD) and private developers on the draft composite Forest Plantations MOP since 2018. During these interactions, the large-scale private plantation developers have expressed concerns with the current procedures associated with harvesting of plantation timber and the timelines associated with them. The key concern raised is related to the requirement by the Forestry Commission (FC) for the mandatory enumeration of plantation trees earmarked for harvesting within their stands. As evidenced with the fast-planting rates, the private developers indicated that a 100% inventory of the marked standing trees is not feasible when areas earmarked for harvesting surpass a few hundred hectares. For emphasis, some of the developers establish up to 2000 hectares of forest plantations in a single year. It is therefore envisaged that similar large areas will require thinning or harvesting at the same time, a situation which will overwhelm FC if the current procedures are maintained.

A 100% inventory of marked trees will thus require several staff from the Forestry Commission. Additionally, the use of the limited staff strength by FC to undertake this activity which could be done by the developers is not a very efficient use of manpower.

Accordingly, the private developers propose that the Forestry Commission should explore alternative means, possibly through spot checks in an audit style, where sufficient control can be exerted while at the same time allowing business operations to continue unhampered.

Under this project, several plantation developers have made suggestions on what could be changed in the current procedures and have also indicated what they would like to see as an outcome. These suggestions are enumerated below:

I. The process for applying for harvesting permits should become sufficiently flexible to allow private developers to respond to market demands within a reasonable time frame. Additionally, they hope for an approach where they will not be required to request for harvesting permits frequently. The latter could be attained if the validity of permits is extended, possibly to a year to ensure alignment with the Annual Plans of Operations of the companies.

II. The preference of large-scale private plantation developers is that the data collected from their PSPs could serve as a basis for estimation of yield from the areas earmarked for harvesting within their plantation. Having tested the viability of such an option through field testing, this project is of the view that such information should be accepted as sufficient by FC for the issuance of a felling permit. The FC could focus on verifying the accuracy of the data submitted through periodic spot checks.

III. For companies that do not have PSPs, it is proposed that the Forestry Commission undertakes a one-off 20 percent inventory of the stand to determine the Standing Tree Volume (STV) if the trees earmarked for harvesting are not more than 2,500

stems (i.e., there should be no verification by the FSD regional office). However, if the trees to be harvested are more than 2,500 stems, the district office will undertake a 10 percent inventory of the stand to determine the STV. Afterwards, the relevant FSD Regional Verification Team will assess 20 percent of the trees inventoried by the district office.

IV. The issuance of PLMCCs and PPCs is cumbersome and prone to error. A more efficient system could be developed which involves digital information collection based on the methods currently available or in use. Although a robust scientific approach is required for an accurate estimation of Standing Tree Value which forms the basis for disbursement of revenue to the stakeholders, it is important for an efficient and effective system to be deployed for timely sharing of information to the relevant stakeholders.

V. For companies that convey plantation materials to nearby processing sites, the optimal volume conveyed based on the size and bucket volume of the trucks or weighbridge could be used to estimate the volume of timber for issuance of PLMCCs instead of measurements of the individual logs to compute their volumes. which may be quite time-consuming especially for large-scale operations.

In furtherance of the above, the following specific modifications to the current schedule for thinning/ harvesting of forest plantation timber were proposed by stakeholders:

I. PRIVATE PLANTATIONS

CURRENT PROCEDURES	PROPOSED MODIFICATIONS		
	Forest Plantations with PSPs	**Forest Plantations Without PSPs**	**Off-Reserve Plantations**
1. Private Developer (or their nominated company) submits an application to the Executive Director (ED) of the Forest Services Division (FSD) to thin/ harvest a specified number of trees within their plantation.	Private developer submits a harvesting request, that is accompanied with estimated timber yield based on their PSP data. The PSP data has to be of verifiable high standard.	Remains same	N/A
2. ED grants approval for a 10 percent (100% for Medium and Small Scale (MSS) Private Developers) assessment of the stand to be undertaken by the FSD District Office;	Remove. FSD shall periodically carry out an assessment of the PSPs within the large-scale commercial developers.	If the trees to be harvested are not more than 2,500, a one-off 20% inventory of the stand will be undertaken by the FSD District Office. If trees to be harvested are more than 2,500 stems, the FSD District office will undertake a 10% assessment, followed by 20% verification of the assessed trees by the FSD Regional Verification Team.	N/A
3. The FSD District Office constitutes a team to demarcate and undertake inventory of 10 percent of the trees earmarked for harvesting.	For private developers with clearly defined and well-maintained rides/ boundaries which align with the boundaries of the compartments allocated to them by FC, demarcation will not be conducted. For private developers without clearly defined boundaries,	For private developers with clearly defined and well-maintained rides/ boundaries which align with the boundaries of the compartments allocated to them by FC, demarcation will not be conducted. For private developers without clearly defined boundaries, demarcation will be undertaken by the Forest Services Division.	N/A

	demarcation will be undertaken by the Forest Services Division.		
4. The District Manager submits the inventory report to the Regional Manager.	Not applicable if proposed modifications are accepted. Inventory data will be uploaded on the GWTS at FSD Head Office. However, FC may also authorise the developer to upload the data on the GWTS and undertake vetting and approval at Head Office.	Maintain. The inventory data should be uploaded to the GWTS by the district office, validated at the regional office and endorsed by FSD Head office.	N/A
5. The Regional Manager constitutes a team to undertake 20 percent verification of the data submitted by the district office.	Not applicable if proposed modifications are accepted.	Verification should only be undertaken if trees to be harvested are more than 2,500 stems (refer to step 2).	N/A
6. Regional Manager submits the inventory and verification data as well as the associated stand statistics and his/ her comments to ED.	Not applicable if proposed modifications are accepted.	Maintain but with due consideration of recommendations made on step 2.	N/A
7. Data is vetted at FSD Head Office and company issued an invoice to pay 80 percent of the Standing Tree Value (STV) due the Forestry Commission, Stool and Local Community (i.e., either 10 or 20 percent, of the total STV depending on the	The vetting process should be carried out within 2 – 3 days. If no major issues are identified, for example, no discrepancies are associated with PSP analysis by FSD, STV invoicing should be done within a day.	Pre-harvesting invoice should be 80% STV. Variation of more than 10 percent between the mean volumes estimated by the district inventory team and regional verification team will require further investigations by the Regional office/ FSD Head office to determine an accurate STV for the company.	N/A

Benefit Sharing Arrangements). The company is also tasked to fulfil the required statutory obligations.	If some major issues are identified, then, the District/ Regional Managers should be directed to investigate and submit their comments to the Executive Director.		
8. ED issues an entry permit to company after all requirements have been fulfilled.	Remains but validity of permits should be extended to one year to align with the Annual Plans of Operations of the Company.	Remains but validity of permits should be extended to one year to align with the Annual Plans of Operations of the Company.	N/A
9. Property mark (PM) is issued to the company upon receipt of an application and fulfilment of required conditions. If the company already has an existing valid property mark, there will be no need for issuance of a new one.	Validity of PM may be extended to 1 year subject to review of NRCD 273 Section 4.	Validity of PM may be extended to 1 year subject to review of NRCD 273 Section 4.	N/A
10. Regional and District Mangers are tasked to monitor operations of the company and submit monthly reports on progress of harvesting operations.	Remains but should be done jointly with private developers to enhance efficiency. RMSC will also undertake quarterly control checks to ensure compliance with requirements of the GWTS.	Remains but should be done jointly with private developers to enhance efficiency. RMSC will also undertake quarter control checks to ensure compliance with requirements of the GWTS.	N/A
11. Company undertakes harvesting of the approved/ earmarked trees.	Remains	Remains	Remains
12. Stumps are marked with the Property mark and inventory number. Post-harvest monitoring is also	Requirement for stump marking should remain but exemptions should be made for companies undertaking large-scale operations	Remains but exemptions should be made for companies undertaking large-scale operations or mechanical harvesting which may even lead to loss of stumps. Post-harvest audits	Not cost effective. Intensify monitoring during harvesting.

undertaken by FSD/ RMSC/ TVD to ensure that all operational standards were adhered to by the company during the harvesting operations.	or mechanical harvesting which may even lead to loss of stumps. Post-harvest audits should be undertaken by FSD/ RMSC within a month after completion of harvesting operations. If the audits are not completed within the one (1) month period, the company can proceed to prepare the site for re-planting.	should be undertaken by FSD/ RMSC within a month after completion of harvesting operations as the site may be prepared for re-planting. If the audits are not completed within the one (1) month period, the company can proceed to prepare the site for re-planting.	
13. Designated staff of the district office measures all felled trees and record the log parameters (length, mid-point diameters and calculated volume) in the Plantation Production Certificate (PPC).	Measurement of harvested trees by FSD should be maintained. However, for exceptional circumstances e.g., if a company has specialized vehicles for conveying logs to a nearby factory/ plant for processing or a weighbridge, FSD should undertake field measurements to estimate the volume per truck or weight-to-volume factor and utilize this estimated volume to issue PLMCC to the company instead of measuring each harvested log. For these circumstances, the truck volume should be captured and uploaded on the GWTS prior to issuance of PLMCCs to the company.	Measurement of harvested trees by FSD should be maintained. However, for exceptional circumstances e.g., if a company has specialized vehicles for conveying logs to a nearby factory/ plant for processing or a weighbridge, FSD should undertake field measurements to estimate the volume per truck or weight-to-volume factor and utilize this estimated volume to issue PLMCC to the company instead of measuring each harvested log. For these circumstances, the truck volume should be captured and uploaded on the GWTS prior to issuance of PLMCCs to the company.	A 3:2 team comprising FSD: Private entity constituted to inspect, measure and generate PPC within 3 days of submission of application
14. Designated staff of the FSD district office issue Plantation Log Measurement	As much as possible, PLMCCs should be issued as soon as practicable by FSD. Depending on	As much as possible, PLMCCs should be issued as soon as practicable by FSD. Depending on the scale of operations, special	As much as possible, PLMCCs should be issued as soon as practicable by FSD. Depending

Conveyance Certificate (PLMCC) for logs conveyed from the site.	the scale of operations, special arrangements could be made for large-scale developers, for example setting up of dedicated PLMCC issuing stations close to the harvesting sites for issuance of the PLMCCs, joint measurements of logs by FSD and Company or use of volume per vehicle or weighbridge to guide issuance of PLMCCs. These modifications should be formally documented to serve as national guide for certification bodies.	arrangements could be made for large-scale developers, for example setting up of dedicated PLMCC issuing stations close to the harvesting sites for issuance of the PLMCCs, joint measurements of logs by FSD and Company or use of volume per vehicle or weighbridge to guide issuance of PLMCCs. These modifications should be formally documented to serve as national guide for certification bodies.	on the scale of operations, special arrangements could be made for large-scale developers, for example setting up of dedicated PLMCC issuing stations close to the harvesting sites for issuance of the PLMCCs, joint measurements of logs by FSD and Company or use of volume per vehicle or weighbridge to guide issuance of PLMCCs. These modifications should be formally documented to serve as national guide for certification bodies.
15. TIDD officers at designated checkpoints inspect the PLMCCs by checking whether the consignment has been captured in the GWTS. The logs are then graded in the GWTS. If no illegality is detected, the PLMCC is then stamped by the TIDD officers.	Remains	Remains	Remains
16. Logs are then transported to the Sawmill/ Processing Site.	Remains	Remains	Remains
17. After registration of the logs at the mill, the logs are processed into the contract	Remains	Remains	Remains

lengths (bolt, lumber, billets etc.)			
18. The products are measured and dimensions input in the GWTS. Afterwards a Log Inspection Certificate (LOGIC), Lumber Inspection Certificate (LIC) or Domestic Timber Inspection Certificate (DOTIC) is issued to the company by TIDD.	Remains	Remains	Remains
19. At the ports, the products and associated documents (i.e. LIC, Contract Specs.) are inspected by the schedule TIDD officer.	Remains	Remains	Remains
20. Company provides evidence of payment of all applicable levies, taxes, commissions and premiums.	Remains	Remains	Remains
21. Export permit, FLEGT license, DOTIC is issued by TIDD if all conditions have been fulfilled by the exporter/producer.	Remains	Remains	Remains
22. Consignment is then cleared under the UNIPASS platform and by the Customs Division of GRA prior to shipment to the destination.	Remains	Remains	Remains

II. PUBLIC PLANTATIONS

The field assessments undertaken indicated that public plantations being currently harvested exist as fragmented plantations or coppice shoots, usually unmanaged, from previously harvested stands. These stands are thereby associated with major variabilities in individual tree volumes. Consequently, a poorly designed sampling approach to estimate the mean volume of the stand is likely to be associated with significant errors.

It is therefore recommended that the current approach which is based on an assessment of 100 percent of the trees earmarked for harvesting should be maintained. During discussions with stakeholders, it was also noted that the Resource Management Support Centre (RMSC) intends to lay additional and representative Permanent Sample Plots within public plantations to monitor various growth dynamics of these stands. If this process is completed, the recommended guidelines for use of PSP data to estimate STV could be considered by the Forestry Commission for implementation for public plantations.

5. PROPOSED GUIDELINES FOR PLANTATION TIMBER HARVESTING (CHAIN OF CUSTODY PROCEDURES)

A key component of the project involved the development of Guidelines for Plantation Timber Harvesting (GPTH). The GPTH prescribes recommended roles, responsibilities, procedures and processes along the entire plantation timber supply chain with an objective of ensuring that these processes address the major concerns of private commercial forest plantation developers to reduce transaction time for the award of harvesting permits and processing of other documentation along the supply chain.

It is expected that the application of the GPTH will improve efficiency, effectiveness and transparency of the forest plantation timber industry in line with Ghana's CoC system and legality and sustainability requirements. It is also envisaged that GPTH will serve as an integral input in the finalisation of the revised Forest Plantations MoP.
Based on the feedback received from stakeholders, the following guidelines are proposed for plantation timber harvesting in private commercial forest plantations in Ghana:

Forest Plantations with PSPs

For private commercial forest plantation developers on-reserve with the requisite capacity to set up Permanent Sample Plots (PSPs) and undertake periodic collection of reliable data from these PSPs, the mean volume estimated from the PSPs per coupe should be used as a basis for estimation of Standing Tree Volume (STV) of trees earmarked for harvesting. The PSP system should be well set-up with good representation per stratum and calculated reliability. Quality of the PSP data would be checked periodically by the Forestry Commission. These quality checks will involve an assessment of the accuracy of the predictive capacity of the PSP data for estimation of STV and representativeness of PSPs within the stand. If an assessment by the Forestry Commission indicates a variation of more than 20 percent in STV estimates between the use of PSP data and a sampled inventory of the stand, the PSP data from the company will be deemed as unreliable for estimation of STV of the trees earmarked for harvesting. In such circumstances, the processes adopted for companies without PSPs will be applied to the affected company.

After estimation of the STV, the company will be tasked to pay 8% or 16% of the STV to the Forestry Commission and other stakeholders. This payment represents 80 percent of the value of the trees due the Forestry Commission and other stakeholders for commercial plantations established under the Public-Private Partnership (PPP) module or the Private Plantation Development On-Reserve (PPD) module respectively.

Actual measurements will be undertaken during harvesting of the allocated trees by FSD. The log volume will then be reconciled with the STV by FSD/ private plantation developer using the estimated conversion factor (for tree to log) and any outstanding payments made by the developer. The proposed harvesting procedures for these developers are outlined below:

a. The company will submit the following information to the Forest Services Division (with a copy to RMSC) at least six (6) months prior to the commencement of harvesting within a specified site in their reforestation area:
    i. Estimation of STV based on data from the company's PSPs;
    ii. A map of the area to be harvested, including GPS coordinates, total area, species and compartment numbers.

iii. Proposed period for harvesting.

b. The FSD will vet the submitted information and issue an invoice to the company to pay 80 percent of the STV due the Forestry Commission and other stakeholders as set out in the Benefit Sharing Agreement governing the commercial forest plantation development being undertaken by the company. FSD/ RMSC will undertake periodic monitoring visits to the PSPs to validate data received from the company.

c. Upon fulfilment of the requirements by the company, FSD will issue an entry permit to the company within three (3) working days.

d. After the harvesting operations, the company will submit records of volume harvested and extracted from the area. This volume will be reconciled with FSD's records based on a compilation of the PLMCC volumes. Any excess payment made or received will then be paid by the affected party.

Forest Plantations without PSPs

It is expected that over time, these developers will enhance their capacity to set up PSPs within their sites. However, if PSPs are absent at the time of harvesting, the following procedures will be adopted.

a. The company submits a request for a felling permit to the Executive Director, FSD.

b. If the trees to be harvested are less than 2,500, the Executive Director, FSD will task the District Manager to undertake a one-off 20% assessment of the stand. However, if the trees to be harvested are more than 2,500 stems, the District Manager will undertake a 10% assessment of the stand whiles 20% of the assessed stand is verified by the Regional Team.

c. The data is processed and a felling permit is issued by FSD to the company.

d. If the verification shows significant disparities (i.e. more than 10 percent variation between district and regional data), the relevant Regional Office will be tasked to undertake the appropriate remedial measures and re-submit the request for a felling permit.

ISSUANCE OF PLMCCs IN SPECIAL CIRCUMSTANCES

For private forest plantation developers that have specialised trucks for conveyance of logs from harvesting sites to processing sites, the optimal volume conveyed by the trucks will serve as a basis for issuance of Plantation Log Measurement and Conveyance Certificates. This approach will eliminate the need for preparation of Plantation Production Certificates for the companies and thereby improve timeliness of their operations. In addition, for companies that have set up weighbridges, FC will undertake field measurements to determine a weight-to-volume factor for estimation of the applicable PLMCC volume per truck.

6. PILOT TESTING OF THE PROPOSED GUIDELINES FOR PLANTATION TIMBER HARVESTING

The specific activities undertaken during the pilot testing exercise are as follows:

I. Independent re-measurements of tree parameters within sampled PSPs in forest plantation holdings of Form Ghana Limited and Miro Forestry Ghana Limited in the Asubima Forest Reserve of the Offinso Forest District and the Boumfum Forest Reserve of the Kumawu Forest District respectively.

II. Estimation of volume of teak billets and rough squared lumber loaded in 20 ft containers.

III. Estimation of volume per truckload of Gmelina and Eucalyptus logs/ billets conveyed to the processing site of Miro Forestry Gh. Limited from their plantation holdings within the Kumawu and Mampong Forest Districts.

The field team constituted for the exercise comprised representatives from the following Divisions/ Departments of the Forestry Commission:

- Forest Services Division (FSD),
- Timber Industry Development Division (TIDD),
- Timber Validation Department (TVD) and the
- Resource Management Support Centre (RMSC).

The field team also included representatives from the Kumasi Wood Cluster, Offinso, Mampong and Kumawu FSD District Offices and private forest plantation developers.

The approach adopted for pilot testing of the GPTH is outlined below:

A. Assessment of PSPs within Large Scale Commercial Forest Plantation Sites

I. Sampling of PSPs for re-measurements

a. The two companies provided a list and parameters of all their Permanent Sample Plots (PSPs) within their forest plantation holdings.
b. Form Ghana Limited have set up a total of 444 PSPs within their plantations in the Asubima Forest Reserve. The field team randomly selected five percent of PSPs from each coupe for re-measurements of the relevant parameters.
c. Miro Forestry Gh. Limited have also set up 51 PSPs, out of which 9 (~18%) was randomly selected for re-measurements.

II. Desk Review of QA/ QC Procedures Adopted by Companies

The field team conducted interviews and review of relevant literature to assess the robustness of the QA/ QC procedures adopted in the set-up, measurements and estimation of various parameters from the PSPs within the plantation holdings.

III. Field Measurements of Various Tree Parameters in the PSPs

For each selected PSP, all planted trees were enumerated and the following parameters measured and/ or noted:

a. Diameter at breast height (Dbh);
b. Total Tree Height;
c. Commercial Tree Height
d. Stand age, condition and history

B. Determination of Volume Conveyed Per Truck Load/ Container of Plantation Material

I. Teak

Teak products (billets and lumber) are conveyed in 20ft and 40ft containers for export. Teak logs are often crosscut into billets at harvesting sites and conveyed to a central site, usually the closest community to the harvesting site. The billets are either loaded directly into containers or further processed into clean or rough sawn lumber through the use of portable wood processing equipment (Wood-Mizer). The billets or sawn products are containerized for export after the necessary documentations are issued by FSD and TIDD. The field assessment to determine the volume of teak conveyed in 20ft container was undertaken at the log yard of Rainbow Love Company Limited in the Offinso Forest District.

The field team adopted the following approach to estimate the total volume of teak billets and lumber loaded into 20 ft containers:

a. Teak Billets

i. The dimensions (length, width and height) of the 20ft containers were taken;
ii. The lengths and mid-point diameters of the billets were measured before they were loaded in the containers.
iii. The field team ensured that the 20ft container was fully loaded, in accordance with standard practice employed by the exporters.

b. Teak Rough Sawn Lumber

i. The following measurements were taken prior to loading:

- Length of each product
- Widths at mid-point and both ends of the product (labelled W1, W2 and W3)
- Thickness at mid-point and both ends of the product (labelled T1, T2 and T3)

c. Eucalyptus/ Gmelina

i. The dimensions (length, width and height) of the trucks were measured;
ii. The trees were felled and crosscut into billets. The Gmelina trees were crosscut into billets of lengths of about 1.35 m whiles the Eucalyptus trees were crosscut into logs of about 2.7 m.
iii. The billets were numbered serially on both ends.
iv. The lengths and mid-point diameter of each log/ billet was measured before loading into the truck.
v. After the trucks were fully loaded, the number of billets in each truck was noted.

vi. The volume of each billet/ log was estimated using Huber's formula (Akossou et al., 2013):

$$v = \pi \times l \times \frac{d^2}{4}$$

where v is the volume, l is the length and d is the mid-point diameter of the log/ billet.

vii. The individual volumes of the logs/ billets were summed to determine the total volume conveyed by the truck/container.

6.1 Findings of Pilot Test of the Draft Guidelines for Plantation Timber Harvesting

6.1.1 PSP Assessment

The field team assessed 24 (5.4%) PSPs in the teak stand within Asubima Forest Reserve established by Form Ghana. Additionally, nine (9) (17.6%) PSPs were assessed within Miro Forestry Gh. Limited's forest plantations in the Boumfum Forest Reserve. The key findings from the field assessment are as follows:

I. Form Ghana Limited

a. The PSPs are circular plots with radius of 15.8m.
b. A systematic sampling approach was adopted by Form Ghana Ltd. to set up the PSPs within the plantations. This approach ensured that there was good representation of the PSPs within the various coupes.
c. The estimated parameters of the PSPs visited are outlined below:

Table 3: Sampled PSPs within Form Ghana's plantations

COUPE	FORM GHANA BLOCK NO.	PLOT	NO. OF STEMS	AVERAGE DBH (cm)	AVGERAGE TOTAL TREE HEIGHT (m)	AVERAGE MERCHANTABLE TREE HEIGHT (m)
2001	1A	16A	19	31.62	23.68	11.87
2006	20	445	19	23.84	14.67	6.43
2008	2	1	30	17.72	15.12	6.30
	3A	123	37	17.41	14.54	6.86
2009	7	39	36	17.73	14.07	7.11
	9	20	34	17.33	14.39	4.89
	9	298	30	18.31	13.91	5.92
	22	53	26	24.40	18.50	10.75
2010	12	649	27	20.35	16.57	8.94
	13	133	43	16.60	16.60	8.19
	14	151	14	15.00	11.42	5.68
	15	169	25	18.72	13.08	6.26
	17	96A	31	14.38	14.38	7.74
2011	25	610	27	20.93	14.87	6.53
	28	208	38	19.41	14.79	8.78
	32	239	43	19.20	18.50	8.50
	22	189	35	19.26	15.12	7.65
	32	233	35	18.12	14.98	6.16
	28	219	20	22.80	13.56	5.90
2012	40	500	31	17.96	14.36	7.52
	35	45	38	16.69	12.83	6.22
	30	529	32	17.18	13.27	6.85
	42	520	39	17.44	14.35	7.62
	47	477	41	17.53	13.34	7.40

d. A comparative assessment of the field measurements undertaken under the project and the most recent measurements undertaken by Form Ghana within the PSPs indicated that there is an average difference of 0.18 and 3.6 percent (between the two measurements) for the estimated average dbh and average heights of trees within the PSPs respectively. It must be noted however that the PSP data provided by Form Ghana Ltd. were collected in January, 2021 which may account for some of the observed differences in the two field measurements. However, significant differences were recorded

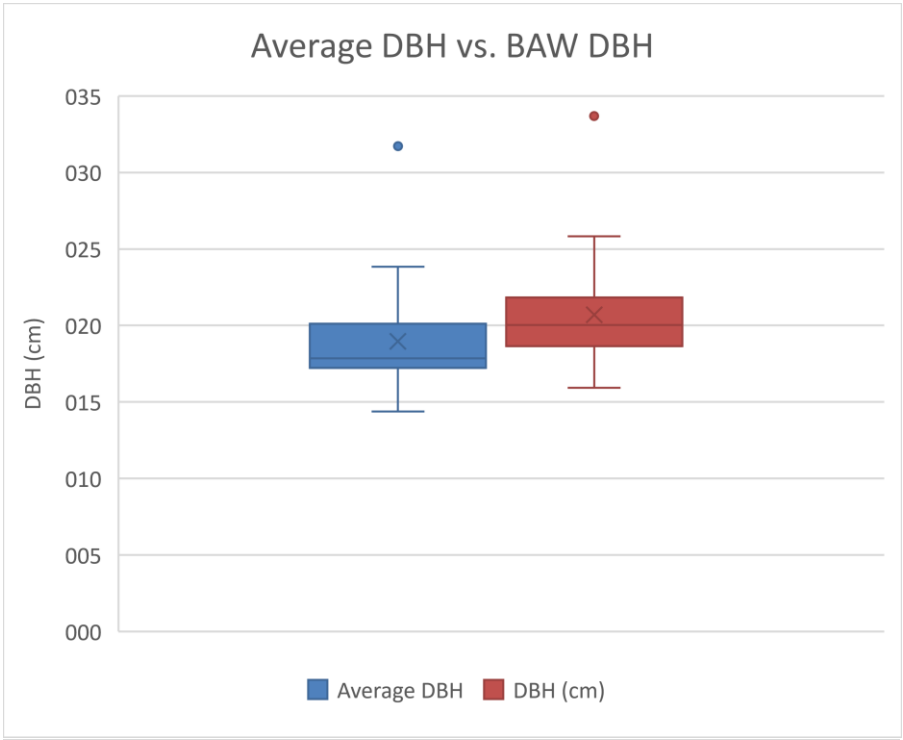
in a few PSPs (i.e., Plot Nos. 45, 53, 96A, 133 and 239) which require further verification. The details are as follows:

Table 4: Comparative Analysis of Field Data and Predicted Data of Parameters of Sampled PSPs within Form Ghana's Sites

Coupe	Plot No.	Data from Field Assessment			Data Provided by Form Ghana				Difference (Av. Dbh)	Difference (Av. Tree Height)
		No. of Stems	Average Dbh (cm)	Average Tree Height (m)	No. of Stems	Data Collection Date	Average Dbh (cm)	Average Tree Height (m)		
2001	16A	19	31.62	23.68	18		30.79	22.96	2.70%	3%
2008	1	30	17.72	15.12	29		17.38	14.17	1.96%	7%
	123	37	17.41	14.54	36		17.27	13.89	0.81%	5%
2009	39	36	17.73	14.07	32		17.64	13.69	0.51%	3%
	20	34	17.33	14.39	37		16.89	13.64	2.61%	5%
	298	30	18.31	13.91	30		17.97	13.97	1.89%	0%
	53	26	24.40	18.50	24		20.66	15.13	18.10%	22%
2010	649	27	20.35	16.57	27		19.87	16.25	2.42%	2%
	133	43	16.60	16.60	43		19.72	14.93	-15.82%	11%
	151	14	15.00	11.42	39		14.79	11.15	1.42%	2%
	169	25	18.72	13.08	29		19.26	12.37	-2.80%	6%
	96A	31	14.38	14.38	31		19.77	13.71	-27.26%	5%
2011	610	27	20.93	14.87	27		20.44	14.31	2.40%	4%
	208	38	19.41	14.79	38		19.01	14.06	2.10%	5%
	239	43	19.20	18.50	41		17.11	15.37	12.22%	20%
	189	35	19.26	15.12	35		18.74	14.97	2.77%	1%
	233	35	18.12	14.98	35		17.8	14.94	1.80%	0%
	219	20	22.80	13.56	20		21.95	13.41	3.87%	1%
2012	500	31	17.96	14.36	31		17.4	13.6	3.22%	6%
	45	38	16.69	12.83	26		23.15	17.89	-27.90%	-28%
	529	32	17.18	13.27	32		16.91	12.58	1.60%	5%
	520	39	17.44	14.35	39		16.6	12.96	5.06%	11%
	477	41	17.53	13.34	41		16.71	13.3	4.91%	0%
2006	445	19	23.84	14.67	14		24.54	15.27	-2.85%	-4%

e. Basal area weighted DBH (BAWDBH) and basal area weighted height (BAWH) were calculated for each plot by summing the product of basal area and the variable in question for each viable tree in a plot and dividing that by the total plot basal area. The basal area weighted mean gives more weight to larger DBH or height and therefore under-weighs small, understory trees. Consequently, BAWDH and BAWH will usually be higher than the unweighted average, as shown in Table 5. The only exception is plot number 239. The height distribution in this plot is skewed to the left. A BAW that is much higher than the unweighted average indicates a larger amount of relatively large trees than would be expected based on a normal distribution. This is the case for plot 96A. The DBH distribution for this plot is skewed right. Moreover, the BAWH can give an indication of site productivity differences between plots.

The BAWDBH vs. average DBH and BAWH vs. average height are plotted below:


Average DBH vs. BAW DBH
035
030
025
020
015
010
005
000
DBH (cm)
Average DBH
DBH (cm)

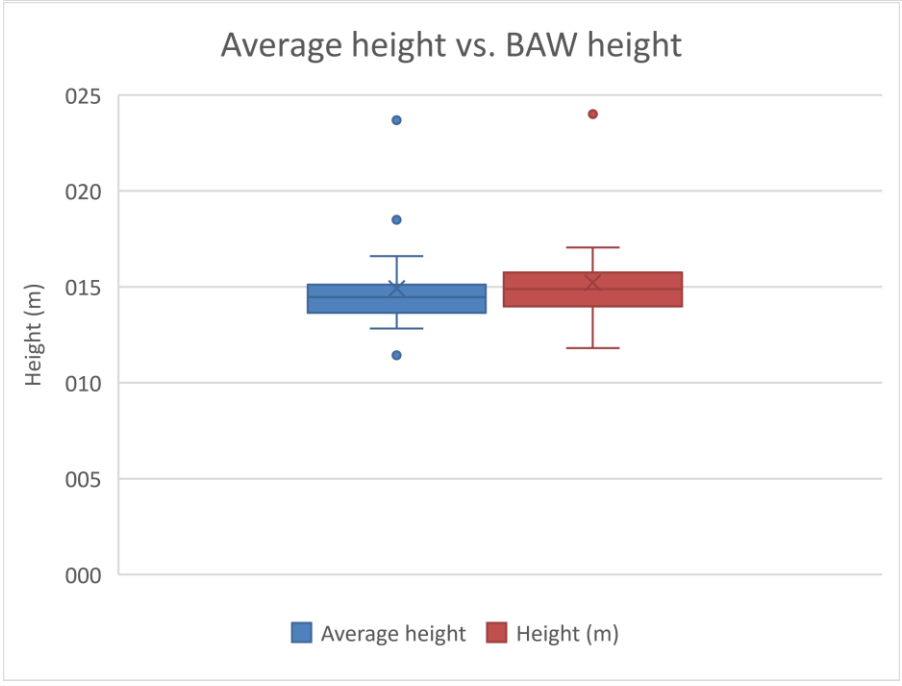

Average height vs. BAW height
025
020
015
010
005
000
Height (m)
Average height
Height (m)

Table 5: Basal Area Weighted Mean DBH and Height of PSP Plots in Form Ghana's Plantations

COUPE	BLOCK	PLOT	NO. OF STEMS	AVERAGE DBH	AVERAGE TOTAL TREE HEIGHT	BASAL AREA WEIGHTED MEAN DHB	BASAL AREA WEIGHTED MEAN HEIGHT	AVERAGE MERCHANTABLE HEIGHT
2001	1A	16A	18	31.71	23.69	33.70	24.00	12.53
2006	20	445	19	23.84	14.67	25.84	15.86	6.43
2008	2	1	30	17.72	15.12	18.65	15.43	6.30
	3A	123	37	17,41	14.54	20.42	15.07	6.86
2009	7	39	36	17.73	14.07	19.12	14.34	7.11
	9	20	34	17.33	14.39	18.52	14.71	4.89
	9	298	30	18.31	13.91	19.77	14.25	5.92
	22	53	26	21.60	15.25	22.03	16.35	8.00
2010	12	649	27	20.35	16.57	21.64	17.04	8.94
	13	133	43	16.60	16.60	21.88	17.05	8.19
	14	151	15	15.00	11.42	15.93	11.81	5.68
	15	169	25	18.72	13.08	20.96	13.86	6.26
	17	96A	31	14.38	14.38	20.86	14.59	7.74
2011	25	610	27	20.93	14.87	22.31	15.06	6.53
	28	208	38	19.41	14.79	20.26	15.09	8.78
	32	239	43	17.19	18.50	19.03	16.60	12.25
	22	189	35	19.26	15.12	20.07	15.29	7.65
	32	233	34	18.24	15.05	19.97	15.24	6.34
	28	219	20	22.80	13.56	24.24	13.89	5.90
2012	40	500	31	17.96	14.36	18.64	14.54	7.52
	35	45	38	16.69	12.83	17.97	13.12	6.22
	30	529	32	17.18	13.27	17.95	13.57	6.85
	42	520	39	17.44	14.35	19.05	14.69	7.62
	47	477	41	17.53	13.34	18.03	13.57	7.40
TOTAL			749					
Average			31	18.97	14.91	20.70	15.21	7.41

Figure 1: Height estimation of a tree in a PSP in Form Ghana's plantations

f. Table 6 includes unpaired two-sided t-tests that were used to assess if data collected by Form Ghana and under the Field Assessment differed significantly. T-tests were carried out using the T.TEST function in Excel where a two-sided distribution and unpaired methodology were indicated. The usual alpha value was corrected for multiple testing using the Bonferroni correction whereby the alpha is divided by the number of tested hypothesis (K):

$$\alpha_{corrected} = \frac{\alpha_{uncorrected}}{K}$$

Thus:

$$0.001086957 = \frac{0.05}{46}$$

None of the plots differ significantly regarding DBH measurements. Concerning height, two plots differ significantly after Bonferroni correction: 133 and 520. It is to be expected that height differs more than DBH given that height is approximated using a clinometer and thus vulnerable to error. As a whole, the differences between the measurements from Form Ghana and the Field Assessment are small. However, what is interesting is that the measurements for both DBH and height are almost always slightly higher in the Field Assessment data than the Form Ghana data. This could be attributable to the different period of data collection for the two (2) datasets – Form Ghana's data was collected in January, 2021 whiles FC's Assessment of the data was undertaken in April, 2021.

Table 6: Unpaired T-test of Assessed Data from Form Ghana's PSPs

Coupe	Plot No.	Data from Field Assessment			Data Provided by Form Ghana				Difference (Av. Tree Height)	Tested difference between DBH from Form Ghana and Field Assessment	Tested difference between H from Form Ghana and Field Assessment
		No. of Stems	Average Dbh (cm)	Average Tree Height (m)	No. of Stems	Average Dbh (cm)	Average Tree Height (m)	Difference (Av. Dbh)			
2001	16A	19	31.62	23.68	18	30.79	22.96	3%	3%	0.6586338	0.360182527
2006	445	19	23.84	14.67	16	24.54	15.27	-3%	-4%	0.7876717	0.84121424
2008	1	30	17.72	15.12	29	17.38	14.17	2%	7%	0.6501879	0.01648383
	123	37	17.41	14.54	36	17.27	13.89	1%	5%	0.767406	0.095522357
2009	39	34	17.73	14.07	32	17.64	13.69	1%	3%	0.9153721	0.212978309
	20	36	17.33	14.39	37	16.89	13.64	3%	5%	0.5700354	0.041967008
	298	30	18.31	13.91	30	17.97	13.97	2%	0%	0.7032512	0.885353959
	53	26	20.73	15.99	24	20.57	15.03	1%	6%	0.8788852	0.036241083
2010	649	27	20.35	16.57	27	19.87	16.25	2%	2%	0.645805	0,.60776586
	133	43	20.10	16.60	43	19.72	14.93	2%	11%	0.6878472	0.000165035
	151	39	15.00	11.42	39	14.79	11.15	1%	2%	0.7201406	0.377657998
	169	25	19.25	13.22	29	19.26	12.37	0%	7%	0.9994354	0.168615816
	96A	31	19.89	14.38	31	19.77	13.71	1%	5%	0.877617	0.062412404
2011	610	27	20.93	14.87	27	20.44	14.31	2%	4%	0.656719	0.102651452
	208	38	19.41	14.79	38	19.01	14.06	2%	5%	0.5538104	0.03356059
	239	43	17.19	15.53	41	16.98	15.18	1%	2%	0.8142594	0.589667949
	189	35	19.26	15.12	35	18.74	14.97	3%	1%	0.4565416	0.60878185
	233	35	18.12	14.98	35	17.8	14.94	2%	0%	0.6381083	0.712447991
	219	20	22.80	13.56	20	21.95	13.41	4%	1%	0.5296617	0.742232157
2012	500	31	17.96	14.36	31	17.4	13.60	3%	6%	0.3981256	0.004538086
	45	38	16.69	12.83	26	23.15	17.89	-28%	-28%		
	529	32	17.18	13.27	32	16.91	12.58	2%	5%	0.6725878	0.054341516
	520	39	17.44	14.35	39	16.6	12.96	5%	11%	0.2525556	2,642438E-05
	477	41	17.53	13.34	41	16.71	13.30	5%	0%	0.088161	0.884009244

- *Significant differences between DBH and height are coloured: yellow indicates significance with $\alpha = 0.05$; green indicates a significant difference with $\alpha = 0.001086957$ after multiple testing correction.* If the values are below 0,05, the difference between the field assessment data and the FG data is significant. If larger than 0,05, the difference is not significant. However, when a number of tests are undertaken as occurred during this study, there is a need to correct the alpha value of 0,05 to a lower value as a result of increased probability of false positives. This is why the Bonferroni correction is used.

II. PSPs within Miro Forestry Ghana Limited

a. The PSPs are square plots with dimensions of 30m.
b. The PSPs were purposively set up by Miro Forestry Gh. Ltd. based on an assessment of the different coupes and plantation species within the plantations. A proportionate number of PSPs were therefore set up per coupe and plantation type.
c. The estimated parameters of the PSPs visited are outlined below:

Table 7: Sampled PSPs within Miro Forestry Ghana's plantations

Coupe	FC Compartment No.	Miro Block No.	PSP No.	Species	No. of stems	Average Dbh (cm)	Average Tree Height (m)
2017	220	K18a	39	Gmelina Arborea	66	18.0	18.3
2016	217	K30	37	Acacia mangium	71	15.6	16.1
2015	11	G5b	12	Eucalyptus pellita	43	14.5	14.8
2016	106	G35b	47	Eucalyptus pellita	88	13.9	18.2
2015	87	E7	38	Eucalyptus pellita	53	15.5	18.3
2015	87	E5	41	Eucalyptus pellita	64	15.4	18.8
2016	87	E10	42	Acacia mangium	83	13.6	16.7
2017	121	C53	46	Acacia mangium	73	14.4	16.0
2017	5	21A	50	Acacia mangium	68	13.8	13.9

d. A comparative assessment of the field measurements and the most recent measurements undertaken within the PSPs by Miro Forestry showed an average difference of 2 and 5 percent for the estimated average dbh and average heights of trees within the PSPs respectively. The generally positive difference between both measurements (except for PSP No. 12) is not very significant and could be attributable to the measurements being undertaken at different time periods.

Table 8: Comparative Analysis of Field Data and Predicted Data of Parameters of Sampled PSPs within Miro's plantations

PSP No.	Species	Data from Field Assessment			Data Provided by Miro Forestry Ghana Limited				Difference (Av. Dbh)	Difference (Av. Tree Height)
		No. of stems	Average Dbh (cm)	Average Tree Height (m)	No. of stems	Data Collection Date	Average Dbh (cm)	Average Tree Height (m)		
39	Gmelina Arborea	66	18	18.3	66	5th August, 2020	17.3	17.96	4%	2%
37	Acacia mangium	71	15.6	16.1	69	13th August, 2020	15.17	13.49	3%	19%
12	Eucalyptus pellita	43	14.5	14.8	31	3rd November, 2020	15.55	14.72	-7%	1%
47	Eucalyptus pellita	88	13.9	18.2	87	17th December, 2020	13.76	17.59	1%	3%
38	Eucalyptus pellita	53	15.5	18.3	51	3rd September, 2020	14.9	17.37	4%	5%
41	Eucalyptus pellita	64	15.4	18.8	62	7th September, 2020	14.94	18.3	3%	3%
42	Acacia mangium	83	13.6	16.7	83	3rd September, 2020	13.28	15.85	2%	5%
46	Acacia mangium	73	14.4	16	73	27th July, 2020	14.01	14.96	3%	7%
50	Acacia mangium	68	13.8	13.9	62	31st August, 2020	13.55	13.44	2%	3%

Figure 2: Measurement of tree parameters within a PSP in Miro's plantation

Basal Area Weighted Mean and T-test analyses could not be undertaken for Miro's PSP data as the data presented by Miro did not include DBH and Height measurements of individual trees (only average dimensions per plot was provided by the company).

6.1.2 Volume of Plantation Material Conveyed by Container/ Truck

I. Teak Billets

A total volume of **17.112 m^3** of teak billets was loaded into the 20ft container, as detailed below:

Dimensions of 20ft Container	**Total No. of Billets**	**Average Length (m)**	**Average Mid-point Diameter (cm)**	**Average Volume (m^3)**
5.90m long x 2.35m wide x 2.39m high	186	2.51	21.15	0.092

Figure 3: Measurement of Teak Billets Before Loading

Figure 4: Manual loading of 20ft container with Teak Billets

Figure 5: Fully Loaded 20ft Container

II. Teak Rough Sawn Lumber

A total volume of **21.34 m^3** of rough sawn teak lumber was loaded into the 20ft container, as detailed below:

Dimensions of 20ft Container	**Total Pieces of Rough Sawn Lumber**	**Average Length (m)**	**Average Width (cm)**	**Average Thickness (cm)**	**Average Volume (m^3)**
5.90m long x 2.35m wide x 2.39m high	334	2.37	16.31	15.79	0.064

Figure 6: Loading of Rough Sawn Teak Lumber in 20ft Container

Figure 7: Fully Loaded Rough Sawn Teak Lumber

III. Gmelina Billets

Four (4) Gmelina consignments were measured, loaded and subsequently processed at Miro Forestry Gh. Limited's plymill. An overview of the measurements taken for each consignment is detailed below:

Vehicle Type	Vehicle Dimensions	Total No. of billets loaded	Average Length (m)	Average Mid-Point Diameter (cm)	Average Volume (m^3)	Total Volume (m^3)
Log Carrier Truck (Main Body)	4.2m long x 2.7m wide x 0.9m high	215	1.351	17.588	0.035	7.496
Log Carrier Truck (Trailer)	6m long x 2.7m wide x 0.9m high	351	1.384	17.313	0.034	12.065
Log Carrier Truck (Bucket Type)	4.46m long x 2.4m wide x 1.6m high	207	1.353	19.325	0.042	8.720
Log Carrier Truck (Bucket Type)	4.46m long x 2.4m wide x 1.6m high	196	1.357	20.692	0.048	9.346

The total volume of Gmelina billets conveyed to the plymill was 31.89 m^3 (underbark volume using an estimated bark thickness of 1.56cm). All the billets were processed at the plymill and yielded a total of 8,525 veneer sheets of dimensions 1.27m x 0.67m x 0.0021m and a total volume of 15.23m^3. Consequently, the estimated recovery rate for processing of the Gmelina billets to veneer at the plymill was **47.76%.**

Figure 8: Trailer being loaded with Gmelina Billets in the Boumfum Forest Reserve

Figure 9: Measurements of Gmelina Billets at Miro Forestry Gh. Ltd.'s plymill

IV. Eucalyptus Logs

Four (4) Eucalyptus consignments were also measured and loaded for processing at Miro Forestry Gh. Limited's plymill. An overview of the measurements taken for each consignment is detailed below:

Vehicle Type	Vehicle Dimensions	Total No. of logs loaded	Average Length (m)	Average Mid-Point Diameter (cm)	Average Volume (m^3)	Total Volume (m^3)
Log Carrier Truck (Main Body)	4.2m long x 2.7m wide x 0.9m high	190	2.711	14.633	0.047	8.935
Log Carrier Truck (Main Body)	4.2m long x 2.7m wide x 0.9m high	232	2.716	14.872	0.049	11.318
Log Carrier Truck (Bucket Type)	4.46m long x 2.4m wide x 1.6m high	203	2.680	14.678	0.046	9.429
Log Carrier Truck (Trailer)	6m long x 2.7m wide x 0.9m high	264	2.719	14.764	0.048	12.670

Figure 10: Measurements of Eucalyptus Logs

7. ESTIMATION OF FORM AND CONVERSION FACTORS OF THE MAJOR FOREST PLANTATION TIMBER SPECIES IN GHANA

7.1 Introduction

To estimate Standing Tree Value (STV) and product recovery, measurements were undertaken of specified parameters for the 4 major forest plantation species of Ghana (Teak, Cedrela, Gmelina and Eucalyptus). The measurements consisted of the following elements:

- Section measurements of trees
- Round log recovery from the trees
- Product (e.g., billets, poles) recovery from the round logs
- Processed product (e.g., squared lumber, veneer) recovery from roundwood

This section summarizes the results of the data analysis.

7.2 Quality control

A detailed quality control analysis of the collected data was conducted. The data was submitted in different batches and versions. Collation of the data in one database was therefore cumbersome and time consuming. The following issues were identified with quality control:

- In the first round of data collection, the stump height was not recorded, which meant that the corresponding height/ length for the butt end diameter was unknown. As a correction, an average stump height per species was calculated and applied for the trees.
- For a number of trees, the butt end diameter was inconsistent with the section measurement data, as it was often smaller than the diameter at breast height. As a correction, the butt end diameter was estimated based on diameter at breast height.
- For some section measurements, the observed height or diameter was inconsistent with the rest of the data for the specific tree. Observations were made of increases in diameter higher up in the tree. These measurements were taken out of the data set.
- For the trees measured in the first data collection, the total tree height was not recorded. It was intended that this information should be included in order to calculate tree taper. As the total tree height was not available for quite a number of

trees, tree taper was not estimated.

All corrections made are recorded in the data file to enable further data improvement in a later stage.

7.3 Sampling

Management quality

Sampling was conducted in stands under different management quality. It must be noted that in well managed stands, trees of lower quality are usually thinned, as the best trees are left behind for clear felling. In poorly managed stands the situation is the other way around as the best trees are usually felled to maximize short-term revenue. As a consequence, the recovery in well-managed stands will be relatively lower than poorly managed stands. While overall, the recovery should be higher in well-managed stands. As a result of this effect and the fact that the number of sampled trees per species was relatively low, no distinction in recovery is made based on management.

Ecological zone

Figure 11 shows the sampling per tree species in the different ecological zones. For Eucalyptus, the sampling was only conducted in the moist semi- deciduous zone. The number of trees sampled in the different zones under different management are not sufficiently representative of the entire range of diameter classes to get a reliable estimate of recoveries per zone. Therefore, the recovery is calculated per species as the average figure will be most accurate as it is based on the largest sample covering all variation.

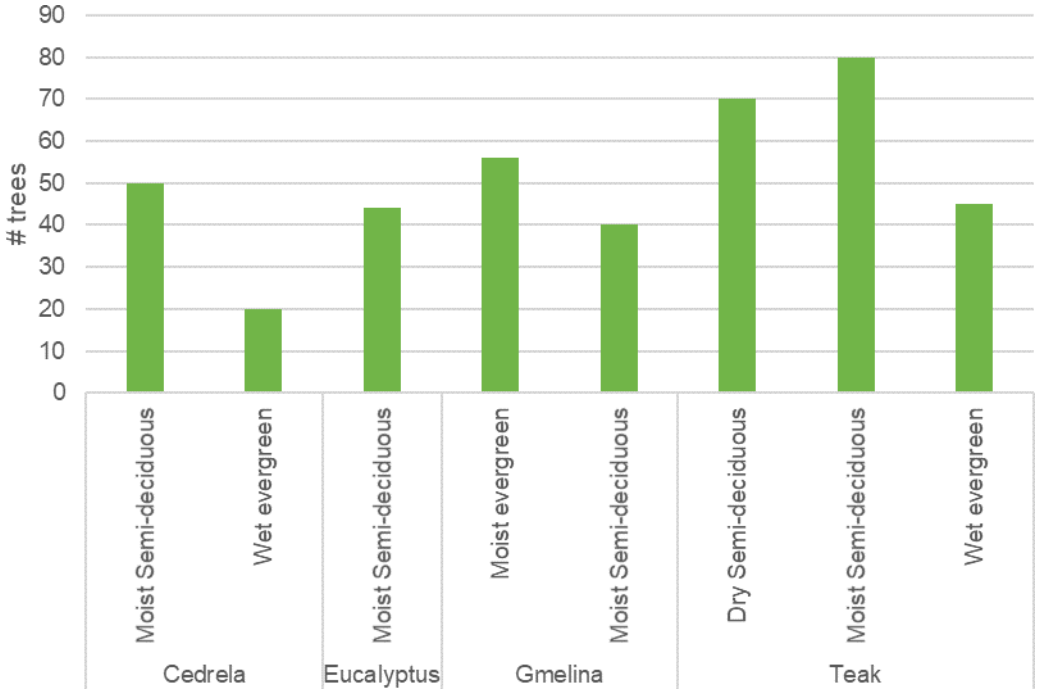


Figure 11: Sampling summary of species in different ecological zones

7.4 Commercial tree volume estimation

Based on section measurements, the commercial log volume was estimated. This estimation represented the best approximation of the real log volume. The volume (V) of each section was calculated using Smalian's formula:

$$V_{SMALIAN} = H \times \underline{(S + s)/2}$$

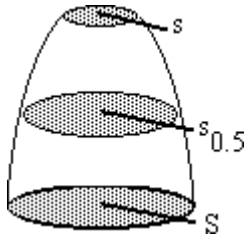


Figure 12: Log measurement points

wherre S is basal sectional area, s is the top sectional area and H is section height.

This calculation provides the most accurate estimate of the log volumes and is used as the reference figure in evaluating other methods. For the section measurements, only top and bottom diameters were measured, hence, any method using mid-diameter / mid- sectional area could not be applied. In order to estimate underbark volume, bark deduction was applied for each section based on the calculated average bark thickness of the sampled trees at mid-point of the log.

7.5 Form factors

In Ghana the use of form factors is commonly applied when determining Standing Tree Volume based on an internal study undertaken by the Forestry Commission. This is done through the use of the following formula:

$$V = \pi r^2 \times H \times ff$$

where r is the radius (cm) at breast height, H is the commercial tree height and *ff* is the form factor.

In current calculations by the Forestry Commission, a deduction for bark is applied in order to estimate underbark volume. Table 9 shows the form factors and bark deductions that are currently applied by the Forestry Commission.

Table 9: Form Factors and bark deductions currently used by the Forestry Commission

Species	Form factor	Bark deduction (cm)	Remark
Teak	0.7857	-2.0	Multiple form factors are used depending on the district and forest reserves. The form factor listed here is the generic form factor for teak.
Cedrela	0.6779	-1.5	
Gmelina	0.7764	-2.0	Two form factors are used, depending on the district. The district closest to where the samples were taken for this study is Mampong and therefore this form factor is mentioned.
Eucalyptus	0.8	- 1.0	As used for Miro forestry.

In the calculations for this study, a further distinction is made in diameter class, since form factors do not only vary per species but also with diameter class. This provides a more accurate result for the trees in the sample, but for general application in the field it is easier to apply a species-specific form factor.

7.6 Volume estimation based on formulae

Instead of applying form factors that require both DBH and height information, there are various single and double-entry equations that can be used to estimate commercial volume. These equations are easy to use and only require DBH or DBH and height as input value, which makes it very efficient to use. It is also often more accurate, because estimation of commercial tree height of a standing tree is prone to errors. Alternatively, inclusion of commercial height in a double-entry formula allows for the effects of management and ecological zone to be taken into account. Various equations were evaluated based on literature, and the best performing equation per species is mentioned in this report.

7.7 Log measurement

Several basic formulas are used in forest mensuration to measure log volume, particularly Huber, Smalian and Newton. Huber's formula is the common basis of log tables which provide log volume for various lengths and mid-point diameters or girths. Huber's formula was found to be more robust than other formulae when long intervals between measurements are used. Also, given the low intensity of measurement with Huber's formula, the value of the information obtained from the small-end and irregular butt-end, as required by Newton's and Smalian's formulae, is poor compared to that from the mid-point [2].

The different equations for estimation of log volumes are as follows:

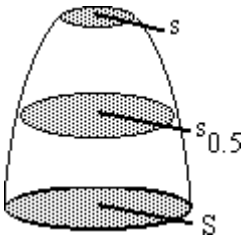


Figure 13: Log Measurement Points

$$V_{HUBER} = H \times s_{0.5}$$

Where $s_{0.5}$ is the mid-section sectional area (Figure 13), and H the height or length.

$$V_{SMALIAN} = H \times \underline{(S + s)/2}$$

where S is the basal sectional area, s is the top basal area (Figure 13), and H the height or length.

$$V_{NEWTON} = H \times \underline{(D^2 + 4 \times d_{0.5} + d^2) \times \pi/24}$$

where D is basal diameter, d is top diameter and $d_{0.5}$ is mid-section diameter, and H is the height or length.

7.8 Volume estimation methods

This section evaluates the accuracy of commercial log volume estimation methods. The volume estimation based on section measurements served as the reference volume for evaluation of the other estimation methods. Estimation of accuracy of the various volume calculation methods is expressed using the Root Mean Square Error (RMSE). The lower the value, the higher the accuracy. It must be noted that the form factor-based approach is based on form factor estimated per diameter class for a specific tree species. It can be expected that the use of one form factor per tree species regardless of tree diameter will provide less reliable results. For calculation of the form factor, the felled length of the tree is used, rather than the commercial height of the standing tree.

Table 10: Accuracy of commercial volume estimation methods based on standing trees

Volume estimate	Volume calculation method	Input variables	RMSE: Teak	RMSE: Cedrela	RMSE: Gmelina	RMSE: Eucalyptus
Over bark	Formula	• DBH	0.183	0.534	0.191	0.083
	Formula	• DBH • Commercial height	0.139*	0.483*	0.170*	0.064
	Form factor	• DBH • Commercial height	0.274	1.259	0.191	0.051*
Under bark	Formula	• DBH	0.168	0.503	0.173	0.073
	Formula	• DBH • Commercial height	0.128*	0.460*	0.154*	0.057
	Form factor	• DBH • Commercial height	0.225	1.105	0.173	0.044*

Table 11: Accuracy of commercial volume estimation methods based on felled trees

Volume estimate	Volume calculation method	Input variables	RMSE: Teak	RMSE: Cedrela	RMSE: Gmelina	RMSE: Eucalyptus
Over bark	Huber	• Mid-point diameter • Commercial length	0.237	0.845	0.167	0.046
	Smalian	• Bottom diameter • Top diameter • Commercial length	0.600	1.303	0.529	0.378
	Newton	• Bottom diameter • Mid-point diameter • Top diameter • Commercial length	0.182	0.578	0.50*	0.114
	Formula	• DBH	0.183	0.534	0.191	0.083
	Formula	• DBH • Commercial length	0.139*	0.483*	0.170	0.064
	Form factor	• DBH • Commercial length	0.274	1.259	0.191	0.051*
Under bark	Huber	• Mid-point diameter • Commercial length	0.227	0.806	0.153	0.055
	Smalian	• Bottom diameter • Top diameter • Commercial length	0.595	1.253	0.527	0.364
	Newton	• Bottom diameter • Mid-point diameter • Top diameter • Commercial length	0.182	0.546	0.144*	0.100
	Formula	• DBH	0.168	0.503	0.173	0.073
	Formula	• DBH • Commercial length	0.128*	0.460*	0.154	0.057
	Form factor	• DBH • Commercial length	0.225	1.105	0.173	0.044*

In order to choose an appropriate method, distinction should be made between standing and felled trees. As length measurements can be carried out accurately for felled trees, more alternatives become available. A trade-off must be made between accuracy of measurements and ease of application in the field. It is not recommended to use the Smalian calculation method, as it is relatively inaccurate (high RMSE). On the other hand, it is also not recommended to use the Newton calculation method, as it is operationally more inefficient.
For standing trees, the use of a formula (with both dbh and height as input variables) is recommended, because of its flexibility and generally more accurate results (lower RMSE).

7.9 Summary of results: Teak

Table 12 shows the summary of sampled teak trees in the different ecological zones and with different management.

Table 12: Summary of Teak sampling

Species	Zone	Management	# trees	Average DBH (cm)
Teak	Dry Semi-deciduous	Well managed	50	28.9
Teak	Dry Semi-deciduous	Coppice - Poorly managed	20	23.3
Teak	Moist Semi-deciduous	Well managed	45	28.5
Teak	Moist Semi-deciduous	Poorly managed	33	48.9
Teak	Wet evergreen	Poorly managed	45	27.0

Based on section measurements of the sampled trees the commercial log volume can be estimated using the following single-entry equation [3]:

$$V_{comm,overback} = -0.26684 + 0.017119 * DBH + 0.00033576 * DBH^2$$

The commercial log volume can also be estimated using the following double-entry equation [4], where H is merchantable height:

$$V_{comm,overback} = 0.00045749 * DBH^{1.66828} *_H^{0.51044}$$

Figure 14 shows the predicted values using the single-entry over-bark equation against the observed commercial volume calculated using section measurements.

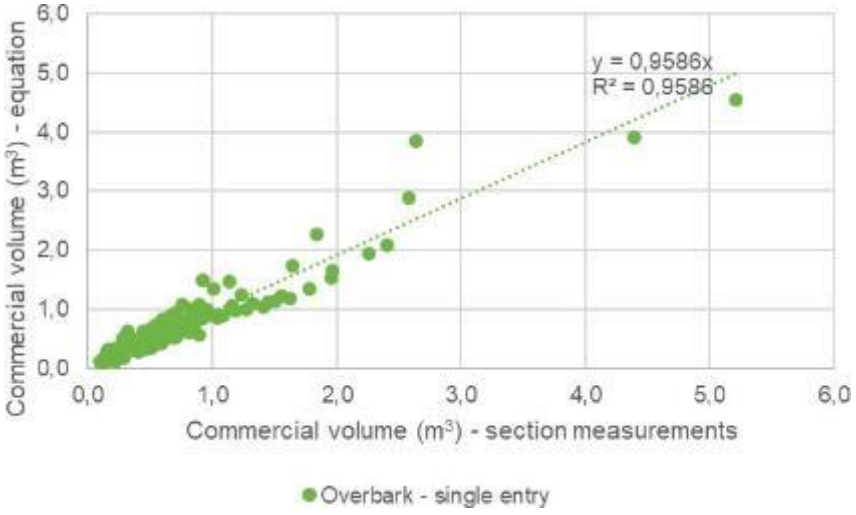


Figure 14: Performance of overbark single-entry equation for Teak

Figure 15 shows the predicted values using the double-entry over-bark equation against the observed commercial volume calculated using section measurements.

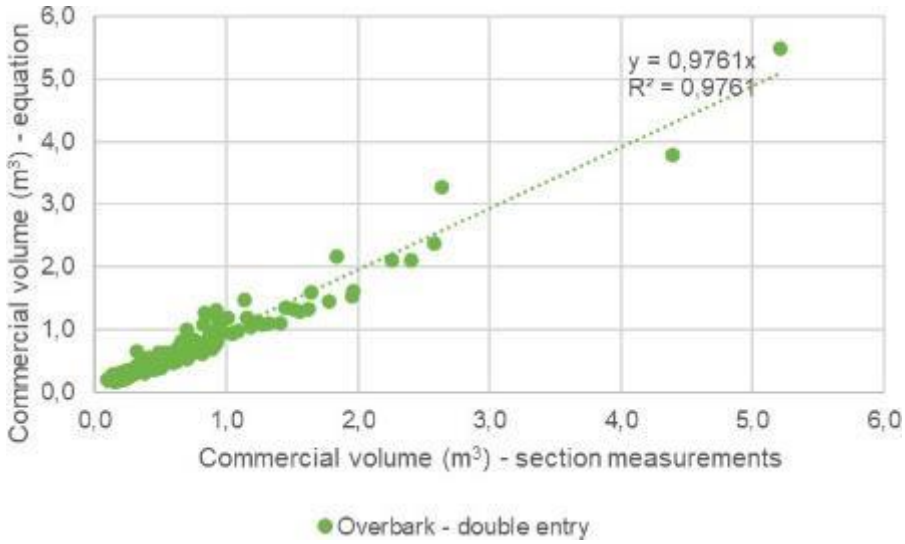


Figure 15: Performance of over-bark double-entry equation for Teak

The under-bark commercial volume can be estimated using the following single-entry equation [3]:

$$V_{comm,underback} = -0.26684 + 0.017119 * DBH + 0.00033576 * DBH^2$$

The under-bark commercial volume can also be estimated using the following double-entry equation [4], where *H* is merchantable height:

$$V_{comm,underback} = 0.00030523 * DBH^{1.74401} * H^{0.51052}$$

Figure 16 shows the predicted values using the under-bark single-entry equation against the observed commercial volume calculated using section measurements.

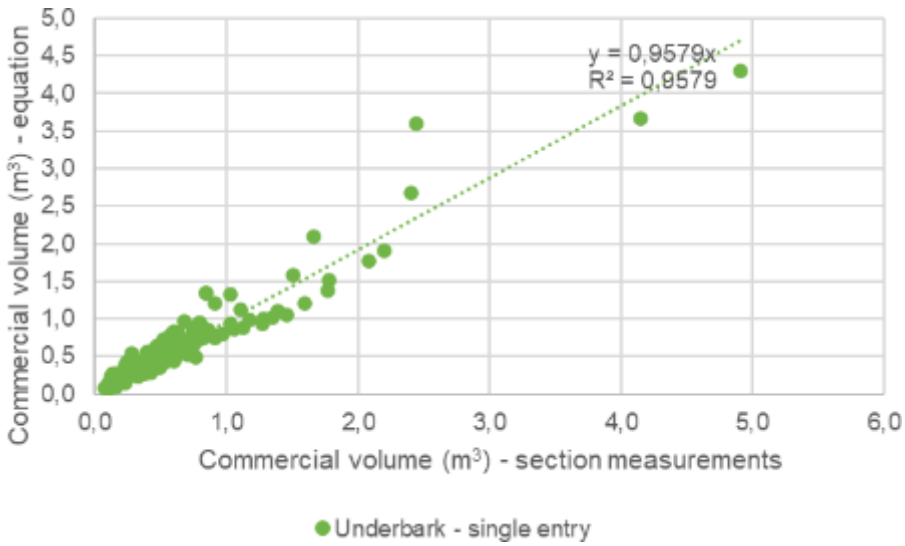


Figure 16: Performance of underbark single-entry equation for Teak

Figure 17 shows the predicted values using the double-entry under-bark equation against the observed commercial volume calculated using section measurements.

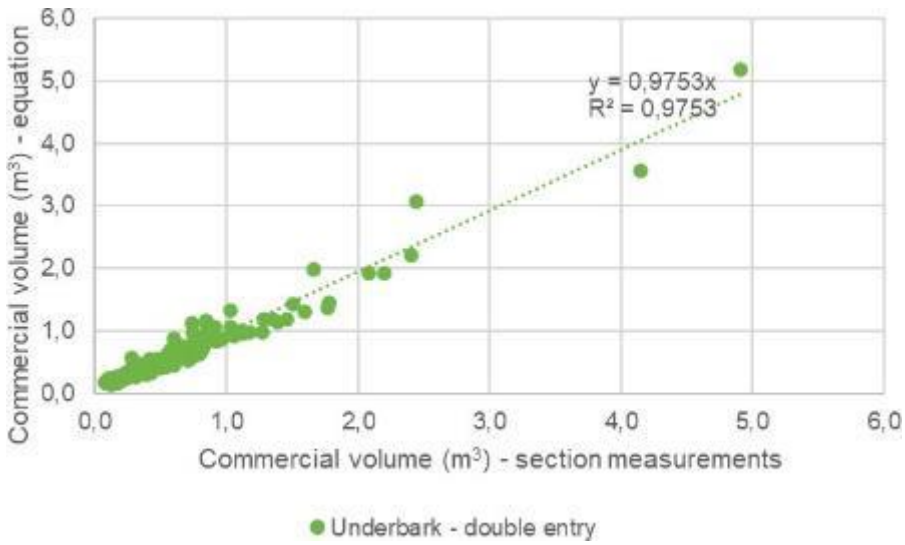


Figure 17: Performance of under-bark double-entry equation for Teak

Table 13 shows the calculated form factor for the sampled trees per DBH class. As most of teak harvested and sold in Ghana falls within 20 – 30 DBH, form factors were developed for 10 – 19.9; 20 – 29.9; 30 – 39.9 and 40 – 49.9. For larger diameters, the last range should be used. In the entire data set 13 trees (out of 173) had a diameter larger than 50 cm, which would make the form factor for large classes unreliable. Coppice was excluded here as coppice cannot be compared with regular forest stands.

Table 13: Form factor for sampled Teak trees (excl. coppice)

DBH class	# trees	Form factor over bark	Form factor under bark
10-19.9	21	0.82	0.65
20-29.9	70	0.73	0.61
30-39.9	51	0.64	0.56
40-49.9	18	0.54	0.48

Instead of applying a form factor per diameter class, a generic form factor per species is usually applied. A distinction is made between over-bark and under-bark form factors. Currently a 2 cm bark deduction is applied for Teak with a form factor of 0.7857. Table 14 shows the form factor for Teak based on the dataset of this study.

Table 14: Generic form factor for Teak

	Form factor
Over-bark	0.6759
Under-bark	0.5724
Under-bark – 2cm bark deduction	0.6682

For the primary timber product recovery (e.g., billets, poles) from the commercial log, an average conversion factor was estimated. For the study, the commercial log length for Teak was the full length of a felled tree up to the commercially utilizable top-end diameter (or up to a minimum diameter of about 12 cm). The estimated conversion factor can be multiplied with the commercial log volume to estimate the volume of the primary Teak product (i.e., billets and poles). For Teak this factor is:

90.6% based on over-bark figures.

90.6% based on under-bark figures.

For lumber recovery, measurements were undertaken at three (3) sawmills. These sawmills rely on the use of portable mobile wood processing equipment (Wood-Mizer). The estimated conversion factor for Teak products are as follows:

Table 15: Estimated Teak Recovery from various sites

Site	Company Name	Type of Product	Recovery (%)
Josanwi Sawmill, Abofour	Josanwi Company Limited	Clean Square Lumber	32.9
Portable Wood Processing Equipment located outside the Bosomoa FR	Morricom Company Limited	Rough Square Lumber	56.6
Portable Wood Processing Equipment located outside the Kwamisa FR	Asuboa Company Limited	Rough Square Lumber	50.7

7.10 Summary of results: Cedrela

Table 16 shows the summary of sampled *Cedrela* trees in the different ecological zones and with different management. For the Wet Evergreen Zone, only *Cedrela* from poorly management stands was included in the sample. One should take into account that the well managed stand in the moist semi-deciduous zone had a much higher average diameter (74.4cm) compared to the other areas (43.1cm and 45.2cm respectively). This implies that the ecological zones are not equally represented in the different diameter classes.

Table 16: Summary of Cedrela sampling

Species	Zone	Management	# trees	Average DBH (cm)
Cedrela	Wet evergreen	Poorly managed	20	43.1
Cedrela	Moist Semi-deciduous	Poorly managed	30	45.2
Cedrela	Moist Semi-	Well managed	20	74.4

	deciduous			

Based on section measurements the commercial log volume can be estimated using the following single-entry equation [3]:

$$V_{comm\_overba} = -0.45523 + 0.018251 * DBH + 0.00048638 * DBH^2$$

The commercial log volume can also be estimated using the following double-entry equation [4], where H is merchantable height:

$$V_{comm\_overba} = 0.00041253 * DBH^{1.76549} * H^{0.47424}$$

Figure 18 shows the predicted values using the over-bark equation against the observed commercial volume calculated using section measurements.

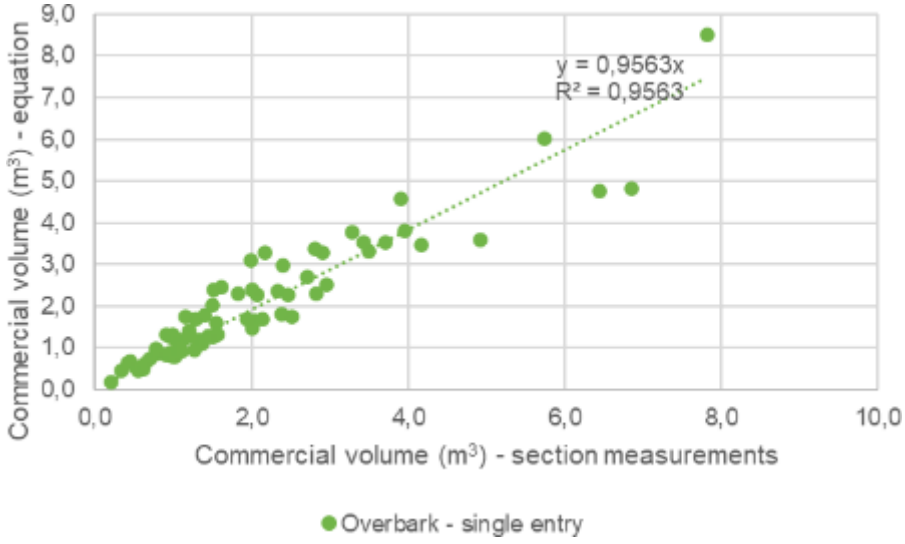


Figure 18: Performance of overbark single-entry equation for Cedrela

Figure 19 shows the predicted values using the double-entry over-bark equation against the observed commercial volume calculated using section measurements.

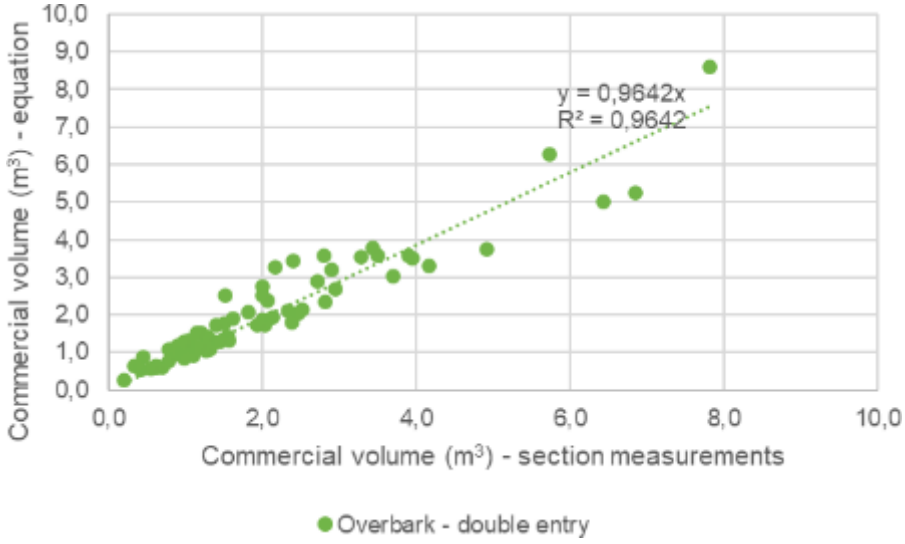


Figure 19: Performance of overbark double-entry equation for Cedrela

The under-bark commercial volume can be estimated using the following single-entry equation [3]:

$$V_{comm\_underba} = -0.40486 + 0.013909 * DBH + 0.00048635 * DBH^2$$

The under-bark commercial volume can also be estimated using the following double-entry equation [4], where H is merchantable height:

$$V_{comm\_underba} = 0.00030240 * DBH^{1.82422} * H^{0.46665}$$

Figure 20 shows the predicted values using the under-bark single-entry equation against the observed commercial volume calculated using section measurements.

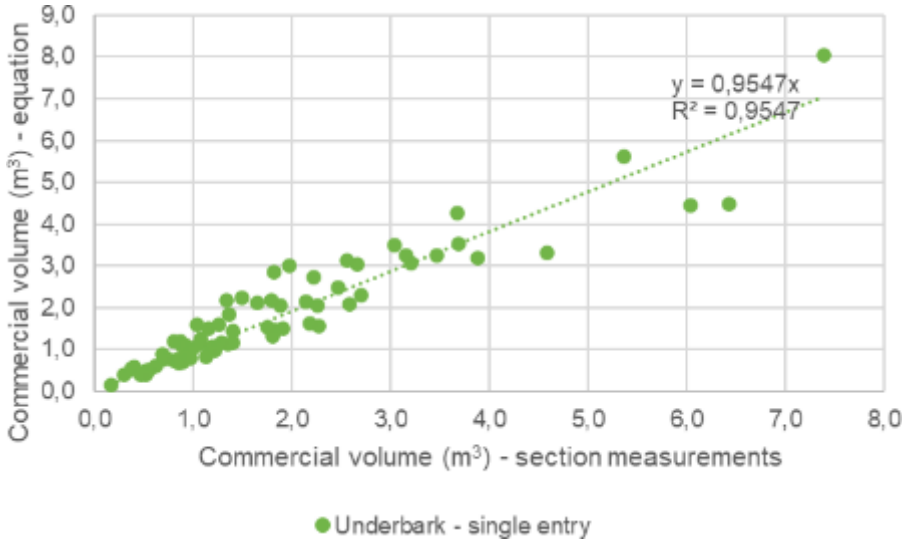


Figure 20: Performance of underbark single-entry equation for Cedrela

Figure 21 shows the predicted values using the double-entry underbark equation against the observed commercial volume calculated using section measurements.

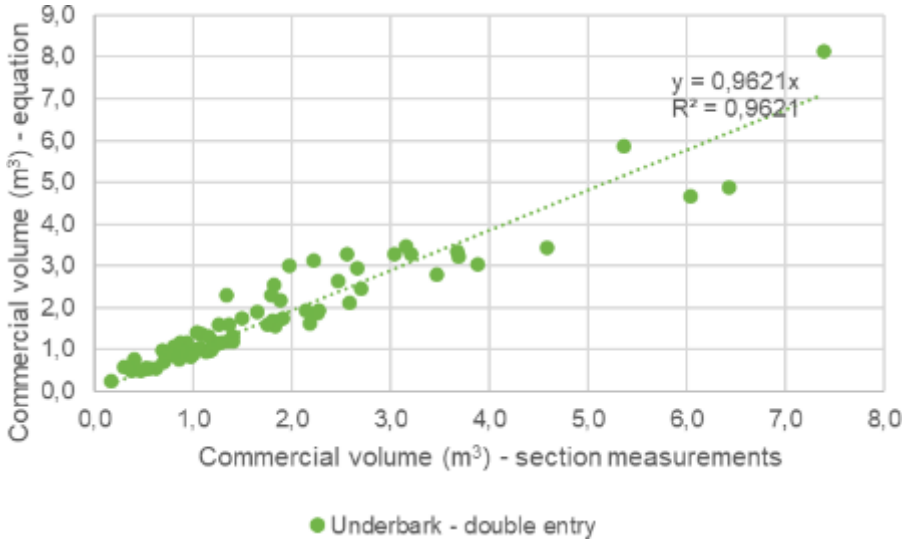


Figure 21: Performance of underbark double-entry equation for Cedrela

Table 17 shows the calculated form factor for the sampled trees per DBH class. Form factors were

developed for the diameter classes 20 – 29.9, 30 – 39.9, 40 – 49.9 and 50 – 59.9. For larger diameters the last range is used. As the number of trees is relatively low per diameter class, the calculated form factor is not very reliable.

Table 17: Form Factor for sampled Cedrela trees

DBH class	# trees	Form factor over bark	Form factor under bark
20-29.9	4	0.82	0.69
30-39.9	14	0.74	0.65
40-49.9	17	0.67	0.60
50-59.9	13	0.66	0.59

Instead of applying a form factor per diameter class, a generic form factor per species is usually applied. A distinction is made between over-bark and under-bark form factors. Currently a 1.5 cm bark deduction is applied for Cedrela with a form factor of 0.6779.

Table 18 shows the form factor for Cedrela based on the dataset of this study.

Table 18: Generic form factor for Cedrela

	Form factor
Over-bark	0.6556
Under-bark	0.5860
Under-bark – 1.5cm bark deduction	0.6264

For the primary timber product recovery (e.g., log, bolts) from the commercial log, an average conversion factor was estimated. For the study, the commercial log length for Cedrela was the full length of a felled tree up to the commercially utilizable top-end diameter (or up to a minimum diameter of about 20 cm). The estimated conversion factor can be multiplied with the commercial log volume to estimate the volume of the primary Cedrela product. For Cedrela, this factor is:

78.0% based on over-bark figures.
77.9% based on under-bark figures.

For lumber recovery, the estimated conversion factor for sawn Cedrela products are as follows:

Table 19: Estimated conversion factor for Cedrela at Ayipah Sawmill

Site	Type of Product	Recovery (%)
Ayipah Sawmill	Export Quality	11.9

7.11 Summary of results: Gmelina

Table 20 shows the summary of sampled Gmelina trees. The sampling included only two ecological zones and one type of management. This implies that care must be taken when applying the outcomes to different growing conditions.

Table 20: Summary of Gmelina Sampling

Species	Zone	Management	# trees	Average DBH (cm)
Gmelina	Moist Semi-deciduous	Poorly managed	40	36.5
Gmelina	Moist evergreen	Poorly managed	56	38.1

Based on section measurements the commercial log volume can be estimated using the following single-entry equation [3]:

$$V_{comm\_overba} = 1.07186 - 0.055694 * DBH + 0.0012225 * DBH^2$$

The commercial log volume can also be estimated using the following double-entry equation [5], where H is merchantable height:

$$V_{comm\_overba} = 0.34921 - 0.00097872 * DBH * H + 0.000043450 * DBH^2 * H$$

Figure 22 shows the predicted values using the over-bark equation against the observed commercial volume calculated using section measurements.

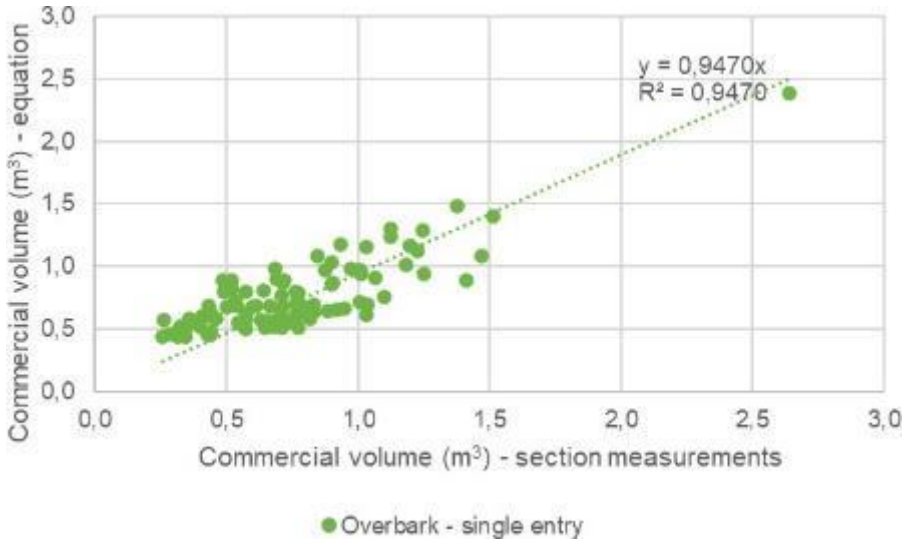


Figure 22: Performance of overbark single-entry equation for Gmelina

Figure 23 shows the predicted values using the double-entry over-bark equation against the observed commercial volume calculated using section measurements.

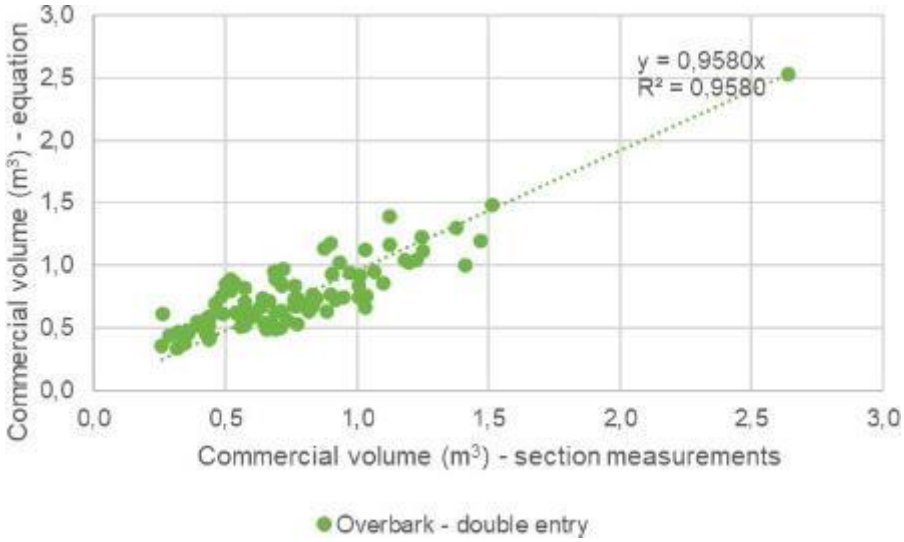


Figure 23: Performance of over-bark double-entry equation for Gmelina

The under-bark commercial volume can be estimated using the following single-entry equation [3]:

$$V_{comm\_underba} = 0.98860 - 0.053059 * DBH + 0.0011601 * DBH^2$$

The under-bark commercial volume can also be estimated using the following double-entry equation [5], where H is merchantable height:

$$V_{comm\_underba} = 0.32113 - 0.0010066 * DBH * H + 0.000042073 * DBH^2 * H$$

Figure 24 shows the predicted values using the under-bark single-entry equation against the observed commercial volume calculated using section measurements.

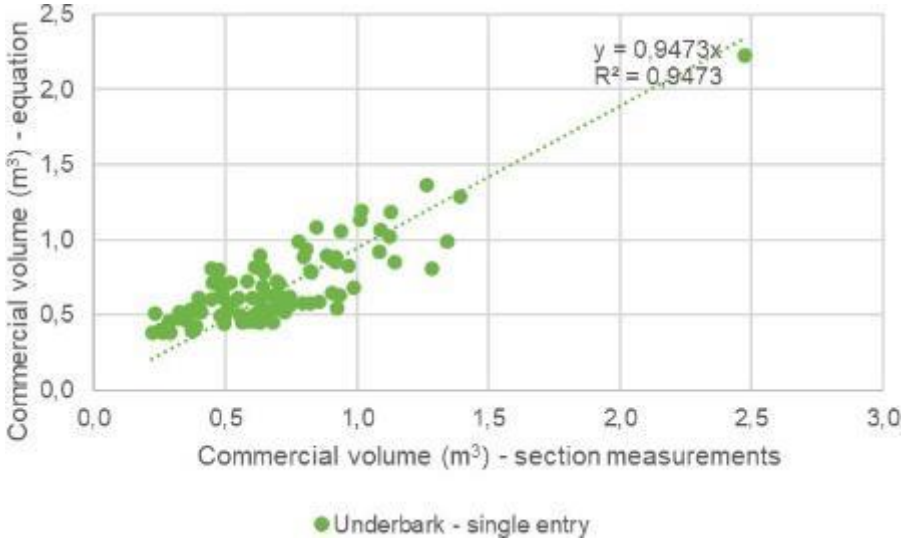


Figure 24: Performance of underbark single-entry equation for Gmelina

Figure 25 shows the predicted values using the double-entry under-bark equation against the observed commercial volume calculated using section measurements.

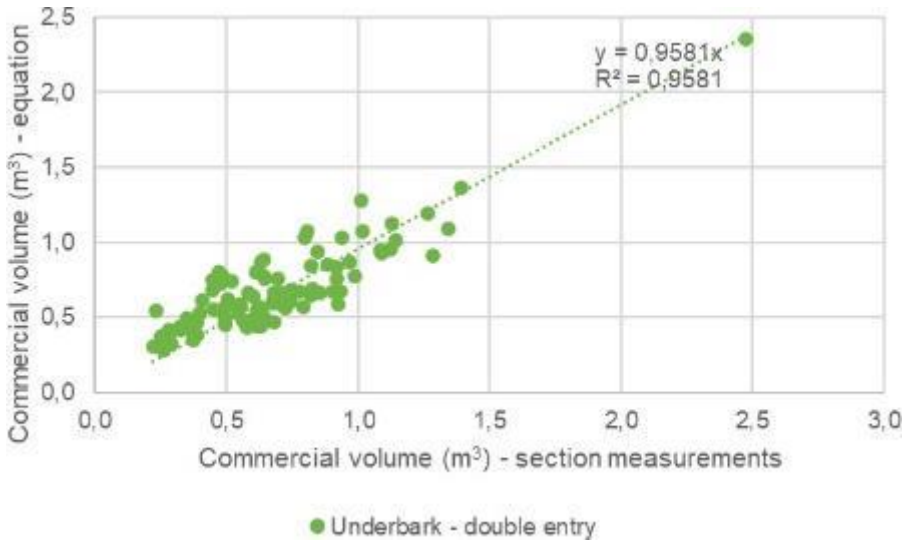


Figure 25: Performance of under-bark double-entry equation for Gmelina

Table 21 shows the calculated form factor for the sampled trees per DBH class. The number of trees included in the sample is relatively low and only a narrow range of diameter classes is included in the sample.

Table 21: Form Factor for Sampled Gmelina Trees

DBH class	# trees	Form factor over bark	Form factor under bark
20-29.9	8	0.82	0.71
30-39.9	56	0.76	0.68
40-49.9	29	0.67	0.61

Instead of applying a form factor per diameter class, a generic form factor per species is usually applied. A distinction is made between over-bark and under-bark form factors. Currently a 2 cm bark deduction is applied for Gmelina from the moist- deciduous zone with a form factor of 0.7764. Table 22 shows the form factor for Gmelina based on the dataset of this study.

Table 22: Generic form factor for Gmelina

	Form factor
Over-bark	0.7312
Under-bark	0.6551
Under-bark – 2cm bark deduction	0.7352

For the primary timber product recovery (e.g., billets) from the commercial log, an average conversion factor was estimated. For the study, the commercial log length for Gmelina was the full length of a felled tree up to the commercially utilizable top-end diameter (or up to a minimum diameter of about 15 cm).

The estimated conversion factor can be multiplied with the commercial log volume to estimate the volume of the primary Gmelina product. For Gmelina, this factor is:

84.5% based on over-bark figures.
84.7% based on under-bark figures.

The estimated conversion factor for Gmelina Billets to veneer is as follows:

Table 23: Conversion Factor for Gmelina at Miro's Veneer/ Ply Mill

Site	**Type of Product**	**Recovery (%)**
Miro Veneer/Ply Mill at Drobonso	Veneer	47.76

7.12 Summary of results: Eucalyptus

Table 24 shows the summary of sampled Eucalyptus trees. The sampling included only one ecological zone and one type of management. This implies that care must be taken when applying the outcomes to different growing conditions.

Table 24: Summary of Eucalyptus sampling

Species	Zone	Management	# trees	Average DBH (cm)
Eucalyptus	Dry Semi-deciduous	Well managed	44	23.0

Based on section measurements the commercial log volume can be estimated using the following single-entry equation [3]:

$$V_{comm\_overba} = -0.15930 + 0.011662 * DBH + 0.00050663 * DBH^2$$

The commercial log volume can also be estimated using the following double-entry equation [4], where H is merchantable height:

$$V_{comm\_overba} = 0.000056553 * DBH^{1.91293} * H^{0.91803}$$

Figure 26 shows the predicted values using the over-bark equation against the observed commercial volume calculated using section measurements.

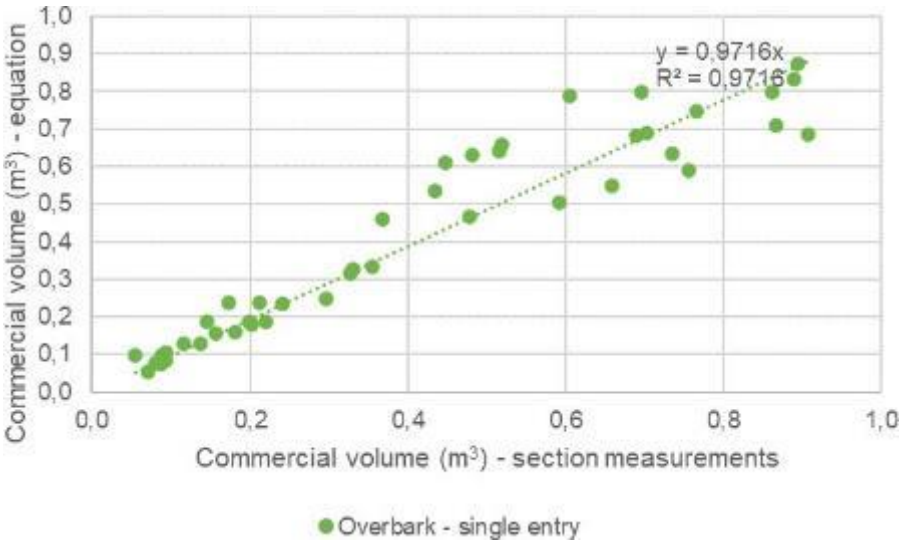


Figure 26: Performance of overbark single-entry equation for Eucalyptus

Figure 27 shows the predicted values using the double-entry over-bark equation against the observed commercial volume calculated using section measurements.

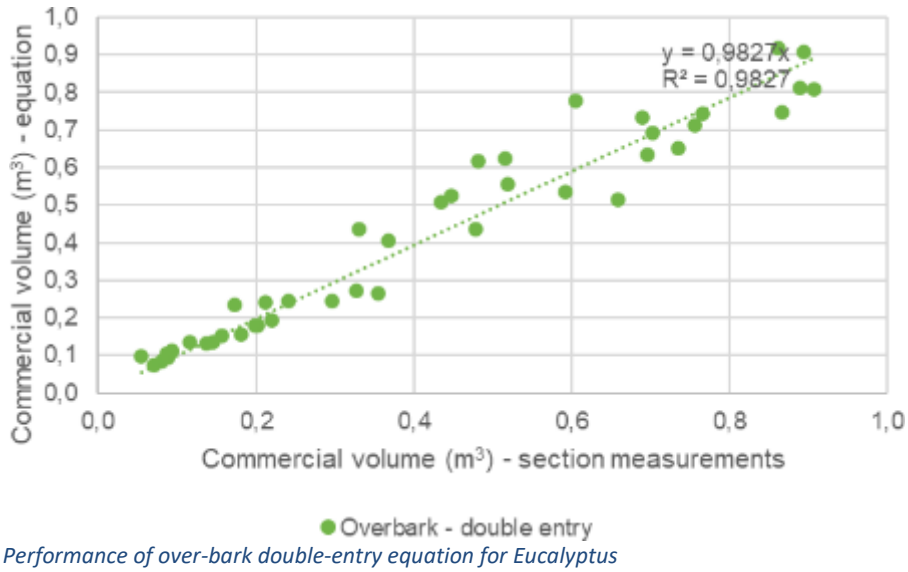


Figure 27: Performance of over-bark double-entry equation for Eucalyptus

The under-bark commercial volume can be estimated using the following single-entry equation [3]:

$$V_{comm\_underba} = -0.11238 + 0.0060459 * DBH + 0.00055393 * DBH^2$$

The under-bark commercial volume can also be estimated using the following double-entry equation [4], where H is merchantable height:

$$V_{comm\_underba} = 0.000031003 * DBH^{2.04082} * H^{0.92941}$$

Figure 28 shows the predicted values using the under-bark equation against the observed commercial volume calculated using section measurements.

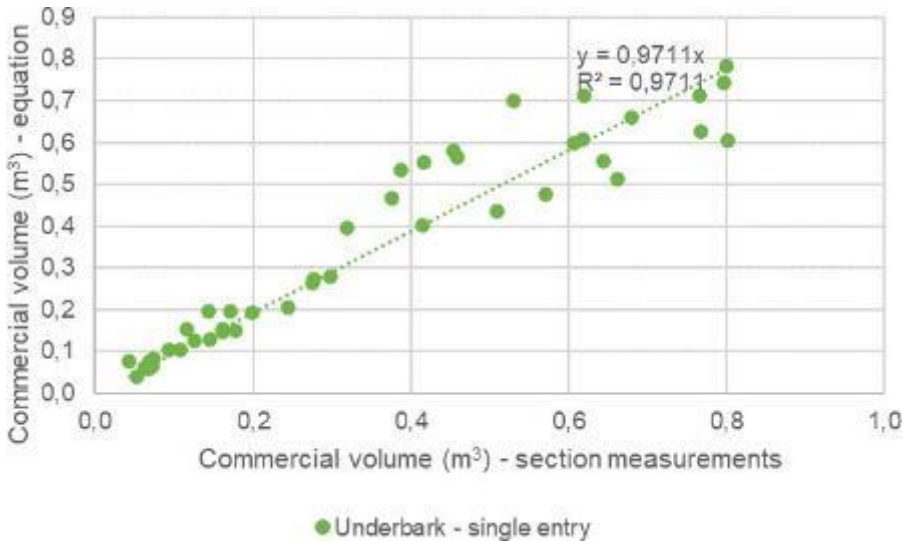


Figure 28: Performance of underbark single-entry equation for Eucalyptus

Figure 29 shows the predicted values using the double-entry under-bark equation against the observed commercial volume calculated using section measurements.

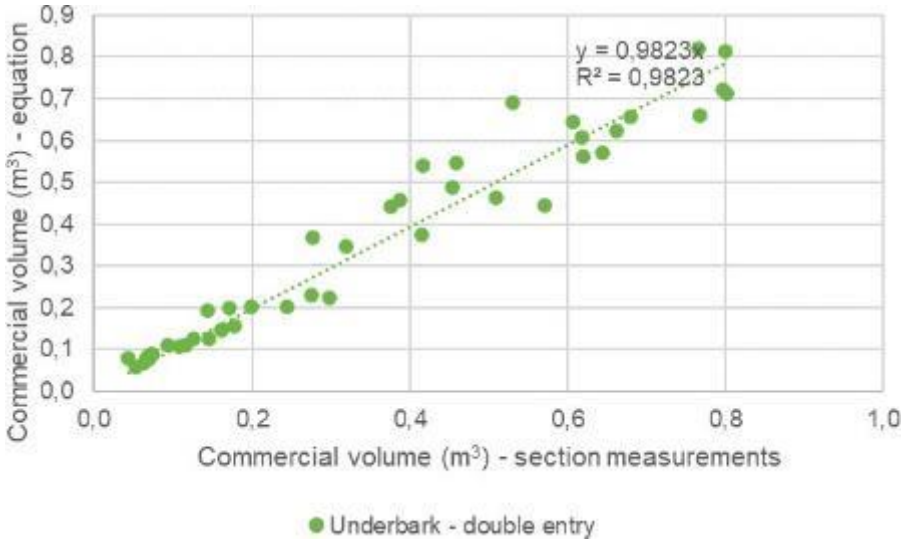


Figure 29: Performance of underbark double-entry equation for Eucalyptus

Table 25 shows the calculated form factor for the sampled trees per DBH class. The number of trees included in the sample is relatively low and only a narrow range of diameter classes is included in the sample.

Table 25: Form Factor for Sampled Eucalyptus Trees

DBH class	# trees	Form factor over bark	Form factor under bark
10-19.9	20	0.71	0.56
20-29.9	13	0.56	0.48
30-39.9	11	0.52	0.46

Instead of applying a form factor per diameter class, a generic form factor per species is usually applied. A distinction is made between over bark and under-bark form factors. Currently a 1cm bark deduction is applied for Eucalyptus with a form factor of 0.8. Table 26 shows the form factor for Eucalyptus based on the dataset of this study.

Table 26: Generic Form Factor for Eucalyptus

	Form factor
Over-bark	0.6162
Under-bark	0.5194
Under-bark – 2cm bark deduction	0.5694

For the primary timber product recovery (e.g., billets) from the commercial log, an average conversion factor was estimated. For the study, the commercial log length for Eucalyptus was the full length of a felled tree up to the commercially utilizable top-end diameter (or up to a minimum diameter of about 9 cm). The estimated conversion factor can be multiplied with the commercial log volume to estimate the volume of the primary Eucalyptus product. For Eucalyptus, this factor is:

93.3% based on over-bark figures.
93.2% based on under-bark figures.

The estimated conversion factor for Eucalyptus logs to veneer are as follows:

Table 27: Conversion Factor for Eucalyptus at Miro's Veneer/Ply Mill

Site	**Type of Product**	**Recovery (%)**
Miro Veneer/Ply Mill at Drobonso	Veneer (smaller diameters)	45.3
Miro Veneer/Ply Mill at Drobonso	Veneer (bigger diameters)	55.9

8 CONCLUSION

The field assessment indicates that the data collected from the PSPs within the commercial forest plantations visited can be adopted to estimate the Standing Tree Volume (STV) of plantation timber earmarked for harvesting from these stands. This approach represents a cost-effective and efficient method for estimation of STV to enable issuance of harvesting permits. After harvesting of the earmarked trees, actual volume of the trees will be estimated and the necessary reconciliation of tree volumes made.

The estimated volume of the truck consignments of logs and lumber will also provide a critical monitoring mechanism for the Forestry Commission in the estimation of volumes of plantation timber harvested and exported. For example, the Forestry Commission should be able to estimate, to a higher degree of accuracy, the volume of teak harvested by determining the number of containers of teak products shipped and applying the relevant conversion factor for teak trees to the exported products (i.e. billets/ rough square lumber). This approach will further enable the Forestry Commission to enforce legality standards and ensure that the companies pay the requisite statutory charges and fees for harvested plantation products.

9 RECOMMENDATIONS

I. PSP Assessment

a. Private plantation developers that intend to utilise their PSP data for estimation of STV should be required to submit their PSP data to FSD biannually, with a copy to RMSC.

b. FSD/ RMSC should undertake periodic monitoring visits to the PSPs to validate data received from the companies. The validated PSP data will be incorporated in the National PSP Database at RMSC.

II. Volume Assessment

a. The sample size for estimation of volumes of plantation materials conveyed per container (for Teak) and specialized vehicles (for Gmelina and Eucalyptus at Miro's site) is inadequate. Although it is a good guide in the interim, the Forestry Commission (FC) should provide resources to further increase the number of containers/ trucks sampled for more robust estimates.

b. Further field work should also be undertaken by FC to determine volume of clean sawn teak lumber loaded in 20ft containers.

c. If a company installs a weighbridge, FC should undertake field measurements to determine the weight-to-volume factor for estimation of PLMCC volume per truck load of the plantation material.

d. The applicable volume which should be entered on PLMCCs for Gmelina conveyed by Miro Forestry Gh. Limited to their veneer/ply mill should be as follows:

Vehicle Type	**Vehicle Dimensions**	**Volume of billets (m^3) - Overbark**	**Volume of billets (m^3) - Underbark**	**Conversion Factor (billets to commercial log)**	**PLMCC Volume per Truck (m^3)**
Log Carrier Truck (Leyland DAF - Main Body)	4.2m long x 2.7m wide x 0.9m high	7.496	6.299	1.181	7.437
Log Carrier Truck (Leyland DAF - Trailer)	6m long x 2.7m wide x 0.9m high	12.065	10.094	1.181	11.917
Log Carrier Truck (Leyland DAF 4 x4 LHD - Bucket Type)	4.46m long x 2.4m wide x 1.6m high	9.346	8.049	1.181	9.503

e. The applicable volume which should be entered on PLMCCs for Eucalyptus conveyed by Miro Forestry Gh. Limited should be as follows:

Vehicle Type	Vehicle Dimensions	Volume of billets (m^3) - Overbark	Volume of billets (m^3) - Underbark	Conversion Factor (billets to commercial log)	PLMCC Volume per Truck (m^3)
Log Carrier Truck (Leyland DAF - Main Body)	4.2m long x 2.7m wide x 0.9m high	11.318	9.288	1.073	9.966
Log Carrier Truck (Leyland DAF - Trailer)	6m long x 2.7m wide x 0.9m high	12.670	10.375	1.073	11.132
Log Carrier Truck (Leyland DAF 4 x4 LHD - Bucket Type)	4.46m long x 2.4m wide x 1.6m high	9.429	7.699	1.073	8.260

III. Form and Conversion Factor Estimation

a. FSD should pilot the use of the recommended double-entry equations for estimation of STV of the major plantation timber species.

b. Staff of FSD should be trained and provided the necessary height measuring equipment to enable them accurately estimate the height of the tree up to the point of the minimum commercially utilizable top end diameter. If height estimation is not done accurately, the use of the recommended equations and/ or form factors to estimate Standing Tree Volume will be associated with errors.

IV. Cross-cutting Issue

Essentially, the recommendations in this report would be effectively implemented when the human resource and logistics exist to put them to meaningful use. It is strongly recommended that the Forestry Commission engages additional staff with the requisite technical capacity to support tree inventory and demarcation-related tasks, in order to ensure that these tasks are undertaken more efficiently and effectively.

APPENDIX I: COMPOSITION OF FIELD TEAM CONSTITUTED FOR PILOT TESTING OF DRAFT GPTH

NAME	ORGANISATION
1. Hugh C. A. Brown	Forest Services Division of the Forestry Commission (FSD)
2. Chris Beeko	Timber Validation Department of the Forestry Commission (TVD)
3. Valerie Fumey-Nassah	Resource Management Support Centre of the Forestry Commission (RMSC)
4. Kwame Agyei	FSD
5. John Appah	FSD
6. Bright Owusu Sekyere	TVD
7. Jones Agyei Kumi	RMSC
8. Eric Asuka	Timber Industry Development Division of Forestry Commission (TIDD)
9. Eric Obiaw	TIDD
10. Harrison Mante	RMSC
11. Eloi Nketsiah	FSD
12. Baffour Nti Brempong	FSD (National Service Personnel)
13. Gustav Adu	Kumasi Wood Cluster (KWC)
14. Esi Banful	KWC
15. Representatives (3)	FSD Offinso District
16. Representatives (5)	FSD Mampong District
17. Representatives (5)	FSD Kumawu Forest District
18. Inventory Team	Form Ghana Limited
19. Inventory Team	Miro Forestry Gh. Limited

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