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LOGGING RESIDUE FROM THE TROPICAL HIGH FORESTS IN THE WESTERN REGION OF GHANA

By

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A Graduate Thesis Submitted

In Partial Fulfillment of the Requirements

For the Degree Of Master of Science in Forestry

Faculty of Forestry and the Forest Environment

Lakehead University

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ABSTRACT

Eshun, A. A. 2000. Logging residue from the tropical high forests in the Western Region of Ghana. 161 pp. M.Sc.F. thesis, Faculty of Forestry and the Forest Environment, Lakehead University, Thunder Bay, Ontario, Canada. Major Advisor: Dr. H. Gary Murchison.

Key words: Western Region of Ghana, logging residue, volume estimation, harvesting efficiencies, sample size, biomass equations, volume equations, residue utilization.

In the face of increasing demand for industrial wood and the serious reduction of the forest resource base in Ghana, logging is reported to be wasteful. However, the level of wastage or residue generation has not been well quantified and described in regard to its potential uses and/or effects on the resource base. Data were collected from 100 sample trees during normal commercial harvesting operations in five logging sites within four forest districts in the Western Region of Ghana. The data were analysed in order to assess the extent of logging residue. On average, 79 percent of the total bole volume and 68 percent of the measured above-ground total tree volume was extracted as logs. Thus, 32 percent of the measured above-ground total tree volume was left in the forest as residue. Branch wood was the highest average proportion of logging residue followed by crown-end offcuts, butt-end offcuts and stump wood. Logging residue may be attributed to a variety of causes including natural defects, and human errors and/or inefficiencies of machine operators. This study indicated significant differences in harvesting efficiencies among timber species and among logging companies. Efficiencies were highest in the two large-scale companies followed by the medium-scale and the small-scale companies. These differences emanated from the level of integration of the companies, equipment and machinery available, the competence of the workforce, terrain conditions, bole shape and form, bole length, occurrence and extent of natural defects, and rarity and commercial value of the species.

The study further showed that for a combination of various species, 56 sample trees will be required at an allowable error of ±10 percent and a confidence level of 95 percent in order to estimate the proportions of the various identified logging residue (or tree sections). Provisional biomass models were developed for predicting the measured above-ground total tree volume and thereby the measured above-ground total residue volume. Also, provisional local and standard volume equations were developed for forest resource management. Generally, the species-specific models were more precise than the generalised equations.

In order to increase recovery and utilization of harvested trees, potential types of forest products which might be converted from logging residue were identified. These products include small-size solid products (e.g., scantlings, strips, squares, narrows, shorts, parquet and strip floorings, broomsticks, profile boards, mirror and picture frames), chips for wood-based panel products, pulp and paper, charcoal, fuelwood and other potential commercial uses.

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DEDICATION

Posthumously to:

Stephanie, my first child, who died in 1995.

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1.0 INTRODUCTION

1.1 BACKGROUND

Ghana's forestry sector, of which timber is a key commodity, ranks third after cocoa and minerals in foreign exchange earnings. It contributes about 6 to 8 percent of the total Gross Domestic Product (GDP) and about 11 to 18 percent of the country's total export earnings. The sector also contributes to government revenues in the form of fees and taxes and employs over 75 000 people while providing direct livelihood to about 2 million people out of a total population of over 15 million (MLF 1996a, 1996b; TEDB 1996). In addition, the forests provide fuel, food and drinks, medicines, shelter and environmental benefits (Nolan 1989). Further, the forests effectively control agricultural production (both food and export crops) and thereby effectively control the entire national economy (Chachu 1989).

The availability of timber resources in Ghana has been established by forest inventory (Ghartey 1989). However, the greatest problem facing the Ghana Timber Trade and Industry is that of securing sufficient resource base to meet the ever increasing demands for present and perpetual use. This problem may be solved by:

1. Making more efficient use of the available timber resources, including such logging residue as branch wood, crown-end offcuts and butt-end offcuts which are almost invariably left to rot in the forests or rarely used as fuelwood and/or for making charcoal; and

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2. Increasing commercial tree plantations in Ghana in order to broaden the sources for timber and thereby reduce the pressure on the tropical natural forests.

Indeed, wood residue utilization, industrial tree plantation establishment and rubber-wood processing have been identified (by Ghana's Ministry of Lands and Forestry) as priority areas for development and investment in Ghana. Commercial tree plantations can be relied on to expand forest resources and thereby produce sustainable raw material supplies if the Ghana timber industry and related jobs are to be sustained in the long run. Rubber-wood development and processing have been identified as a potential project to promote economic utilization of mature rubber-trees from managed rubber estates (MLF 1996a, 1996c; TEDB 1996).

It is regrettable that mills in Ghana deal mainly with large diameter logs and allow small diameter logs, branch wood and other logging residue to go to waste. Technologies already exist in developed countries for processing small diameter logs many of which are about the same size as tropical timber branches and plantation grown timber. Malaysia has also developed technology for processing rubber-wood from plantation-grown rubber-trees (MTIB 1986; Smith *et al.* 1990). It was, therefore, against this background that this research topic was proposed.

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1.2 OBJECTIVES OF THE STUDY

The main objective of this research was to provide information which overall could contribute towards Ghana sustaining its wood supply for both the domestic and export markets. The specific objectives were:

1) To identify the sources and causes of logging residue in the tropical forests in the Western Region of Ghana;
2) To assess the extent (or amount) of logging residue occurring at the various stages of harvesting and primary conversion in the Western Region of Ghana;
3) To compare harvesting efficiencies among the various timber species harvested;
4) To compare harvesting efficiencies among selected large-scale, medium-scale, and small-scale logging companies operating in the Western Region of Ghana;
5) To determine the number of samples required to estimate the proportions of the various sources of logging residue;
6) To develop provisional biomass models for predicting logging residue generation in the tropical forests in the Western Region of Ghana; and,
7) To develop appropriate volume functions for management of tropical forests in the Western Region of Ghana.

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1.3 JUSTIFICATION FOR THE STUDY

The current demand for industrial round logs in Ghana is estimated at about 2.5 million m^3 per annum (TEDB 1995; Amankwah 1996), whereas the prescribed Annual Allowable Cut (AAC) is 1.0 million m^3 (Aninakwa 1996; MLF 1996b). Woodfuel, which is the main source of domestic energy for the vast majority of Ghanaians, also consumes over 25 million m^3 of wood annually (FAO 1997). Woodfuel (which is defined to include fuelwood and charcoal) supply, however, comes mostly from Savanna (non-forest) trees (MLF 1996a). Thus, it is evident that the total log requirement for primary processing in Ghana far exceeds the supply.

If the Ghana timber industry is to be sustained and further expanded, the annual log requirement deficit would have to be made up through imports and/or supplements from industrial plantations (Amankwah 1996), tree breeding (or tree improvement), and increased utilization of mill and logging residue.

While there have recently been some imports of Afrormosia (*Pericopsis elata* [Harms] Van Meeuwen {syn. *Afrormosia elata* Harms}) wood from Gabon (Duah, pers. comm. 1998), Pines (*Pinus sp.*) from South Africa and transmission poles from USA (Ofori, pers. comm. 1998); imports do not seem to be an attractive alternative. Also, even though tree breeding generates greater volumes of wood (Yang 1987a) and/or improves wood quality, Ghana's current developmental status cannot support any meaningful tree breeding programmes at this point of time. Presently, some 60 000 ha of plantations have been established within forest reserves, while private interests and communities are planting trees on an increasing scale around the

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country (MLF 1994, 1996a, 1996b). Clearly, Ghana will have to turn more to plantation-grown timber in the years ahead in order to meet rising demand for wood from both domestic and export markets. However, short rotations of fast growing plantation trees tend to produce inferior quality sawlogs. The lower quality of plantation sawlogs, when compared to trees grown in natural or semi-natural forests, can partly be attributed to the inclusion of a high proportion of juvenile wood (Yang 1987a, 1987b).

Meanwhile, mill residue is increasingly being utilized for production of a number of products (e.g., furniture, squares, strips, blockboards, beds, toys, door and window frames, mouldings, boxes, charcoal, firewood) and also to fire boilers for generation of steam for sawmill and veneermill dry-kilns and steaming pits (Chryssides 1974; Ofori *et al.* 1993; Ofosu-Asiedu *et al* 1996). The same, however, cannot be said for logging residue.

Against the background of increasing demand for industrial wood and the serious reduction of the forest resource base in Ghana (Chryssides 1974; Avatofo 1975; MLF 1994, 1996a, 1996c), logging is reported to be wasteful (Chryssides 1974; Ababio 1975; Armstrong-Mensah 1975; Avatofo 1975). However, the level of wastage or residue generation has not been well quantified and described in regard to its potential uses and/or effects on the resource base. Studies on felled trees and extracted volumes will help to estimate the extent of logging residue, and identify the level of inefficiencies in timber harvesting and the areas that require improvement to

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increase logging recovery. Such studies will also provide estimates of additional wood material that could be obtained from harvested timber trees (Adam 1998a).

Previous studies undertaken by Otoo (1978) and Faakye (1988) gave estimates of logging residue in Ghana from only the bole. Residue with respect to the total tree was not adequately covered. For instance, while Otoo (1978) did not estimate branch wood at all, Faakye (1988) measured 10 branches down to a 60 cm diameter limit from only nine trees. Two recent studies by Nketiah (1992) and Ofori *et al.* (1993) estimated above-ground total tree volumes down to 10 cm and 20 cm branch diameter limits, respectively. In all of these studies, data analyses were generalised due to the small sample sizes (30 to 40 sample trees) and the limited number of individual timber species. Most of these studies also took place in the Moist Semi-deciduous and the Dry Semi-deciduous forest types of the Ashanti and the Brong Ahafo Regions of Ghana.

It is hoped that the results of this study will provide a basis for optimizing logging and harvesting operations thereby minimizing the pressure on Ghana's forest resources. The study could also provide a data base for further research on logging practices and more efficient wood utilization in Ghana. Furthermore, the study is expected to provide information which will be of use to forest managers, planners, policy-makers, researchers and industry.

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2.0 LITERATURE REVIEW

2.1 LOGGING RESIDUE

Generally, logging residue comprises logging refuse and wastewood (or woodwaste). *Refuse* describes those portions of a tree or log whose removal from the forest or utilization at the mill cannot be justified economically; that is, the currently worthless residue. *Wastewood* is a loose synonym of *residue*, and refers to wood left over from any conversion process, whether true refuse, true wastewood or destined for further conversion. In a strict sense, however, *wastewood* describes those portions of a tree or log that could be profitably utilized but are not (Ford-Robertson 1971). This latter definition would seem to agree with that of Kantola (1966) who defined logging waste as any portion of a tree which, under the current highest stage of technological development, could be used in manufacturing but is left in the forest or lost in the course of logging. This means that in some countries some wood may be considered as waste wood and in some other countries not, depending on the current national economic conditions (Kantola 1966).

2.1.1 Sources of Logging Residue

Logging residue may result from high stumps, felling above buttresses, long butts of felled trees, merchantable sections in large top offcuts, unused bole sections, felled trees that are never found, limbs or branches, and residual trees

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(Jenkins 1953; Chappell and Beltz 1973; Balachandra 1988; Gerwing *et al.* 1996). Logging residue is also produced by poor felling and bucking techniques which result in the splitting and/or breaking of felled trees (Hendrison 1989; Gerwing *et al.* 1996). Besides, splits and/or breakage in wood due to poor felling and bucking techniques may render wood unsuitable for secondary and subsequent conversion (Wackerman *et al.* 1966).

Kantola (1966) expands the list and notes that the forms of logging residue include: wood remaining in roots, stumps, tops and branches; bark and leaves; substandard wood cut, rejected and left in the forest; trees cleared for silvicultural purposes; breakage of boles during felling, cross-cutting and other handling; losses through improper log lengths and cutting diameter; loss of growth and quality of the growing trees during felling and transport; wood losses during storing and transport; decay through insects and fungi in storage; and other losses in manufacturing owing to improper logging methods. These many forms of logging residue show that residue is inevitable during logging. However, the nature and degree of residue depends upon the circumstances in which logging is performed (Kantola 1966).

2.1.2 Factors Influencing the Amount of Logging Residue

The amount of residue generation is dependent on many factors which are often quite different in different countries. Factors which influence the amount of logging residue include the price of ordinary wood and of residue from the point of manufacturing or use, as well as the stumpage price; the methods and cost of

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conversion, storing and transport; the skill and carefulness of tree fellers, buckers, and skidder operators; the size (i.e., the height and diameter) and quality of the trees in the forest; the tree species of the forest; the standard lengths and minimum cutting diameter of the assortments used in logging; the quality requirements for the manufacturing assortments; the possibilities of using different tree species for different purposes in integrated manufacturing; the ownership and location of the forest as well as the degree of intensity of forestry; and the prevailing laws in the country concerned (Kantola 1966). Hakkila (1971) also indicates that stump height is affected by the butt swell (or buttress flanges) of the tree, the evenness of the terrain and the care of logging. The amount of obstacles also affects stump height.

2.1.3 Logging Residue and the Sustainability of Forestry

Most forest and forest industry operations produce varying amounts of residue depending on the efficiency of the operations. At less intensive logging levels, simple and inexpensive extraction and secondary transport systems are often combined with relatively wasteful felling, debranching and cross-cutting techniques, to leave as waste or residue as much as 45 percent of the standing tree volume. Whether the residue becomes waste depends on the availability of uses for it. Residue which requires attention in tropical countries results from the operations based on natural forests and first thinnings of plantations. Due to heterogeneity, such residue often becomes waste unless action to develop use for it is taken (FAO 1985). In many cases, logging residue left in the forest is suitable for supplying

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domestic markets through small-scale sawmilling (Quiros *et al.* 1997). According to Noack (1995), greater wood utilization efficiency in both harvesting and mill processing can greatly enhance the sustainability of the tropical timber industry.

In recent years, there has been considerable effort to reduce waste in processing the portion of the tree removed from the forest. At the same time, there has been relatively little effort to establish methods and techniques to utilize logging residue primarily because of the awesome problem of harvesting such material (Young 1964). Logging residue offers greater opportunities for increasing wood supply if systems can be found to profitably handle the material. Thus, utilization of logging residue is dependent upon residue values exceeding the costs of collection and hauling (Chappell and Beltz 1973).

Complete utilization of the tree would eliminate the present enormous amount of logging residue. It would also reduce the fire hazard following a harvesting operation. Moreover, better utilization should make it possible to conserve our truly limited natural resource, the forest which serves us in many ways (Young 1964). Without such planned conservation we will be unable to meet the future demands placed on the forests of the world.

2.2 TREE VOLUME ESTIMATION

The most accurate way to measure tree volume is by water displacement (Husch *et al.* 1982; Martin 1984). Where accurate volume information is required, such as for developing tree volume equations, the water displacement technique is

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an alternative to stem analysis. Though these methods produce accurate tree volume data, they require extensive destructive sampling (Maurer 1993).

Since it is not possible to measure individual tree volumes directly in the field, they must be estimated from more easily measured auxillary variables such as diameter and height (Murchison 1984; Maurer 1993). Several formulae have been developed for estimating tree volume using diameter and height data. Though Newton's and Huber's formulae are known to be more accurate for tree volume estimation (Husch *et al.* 1982; Philip 1994), Ghana's Forest Services Division (formerly known as the Forestry Department) has adopted Smalian's formula for calculating bole and log volumes (FD 1997). The Smalian's formula is based on the assumption that tree (or bole) sections, except tree stumps, are frustrums of a paraboloid (Husch *et al.* 1982; Philip 1994). Husch *et al.* (1982) noted that the cylindrical formula is normally used to compute the volume of the stump.

2.2.1 Volume Functions

The use of volume functions (i.e., volume equations and tables) which relate diameter and height to tree volume offers speed and convenience in estimating tree volume. Volume functions may be constructed on the basis of a single tree or stand volume. Single tree volume functions predict volume per tree while stand volume functions predict volume per unit area, usually per hectare (Philip 1994).

Single tree volume functions can be categorised into local (single parameter), standard (double parameters) and form class (multiple parameters) volume

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functions. Local volume functions give tree volume in terms of diameter at breast height (dbh) only (Husch *et al.* 1982). Standard volume functions give tree volume in terms of dbh and merchantable or total height. These are normally prepared for individual species or groups of species within specific localities (Husch *et al.* 1982). Form class volume functions give volume in terms of dbh, merchantable or total height, and some measure of form such as Girard form class or absolute form quotient (Spurr 1952; Husch *et al.* 1982; Avery and Burkhart 1994).

Single tree volume functions are generally prepared by three methods (Spurr 1952): viz, the graphical, the alignment chart and regression methods. The graphical and the alignment chart methods have been generally discarded in favour of the regression method (i.e., mathematical functions or models) (Husch *et al.* 1982). The regression method consists of measuring the volumes of selected trees in a representative sample, establishing relationships between the measurements taken on the tree and its volume, choosing the best model and verifying the accuracy of models constructed (Philip 1994).

Many different equations have been proposed for volume table construction, but considerable difficulty may arise in attempting to decide which equation is most appropriate for a particular data set (Furnival 1961). Considerable difference of opinion also persists regarding not only the function to be used but the proper criterion of comparison (Spurr 1952). The choice of appropriate model(s) is based on adequacy of fit as dictated by least squares regression assumptions (Philip 1994): viz, normality of regression residuals, homogeneity of variance across all

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predictor variables, and the independence of the predictor variables and regression residuals. A fourth assumption is that the sample is a simple random sample (Cunia 1964).

These assumptions are hardly met in practice and often, some form of transformation is necessary (Norusis 1993; Philip 1994). The most commonly used transformations are the square root, square, cube, reciprocal, reciprocal of the square root and logarithmic transformations of variables (Norusis 1993). Frequently, the logarithmic transformation is used (Philip 1994), though it has been shown to have some bias in prediction (Meyer 1938; Satchell *et al.* 1971; Baskerville 1972; Beauchamp and Olson 1973). Baskerville (1972) and Alder (1980) proposed correction factors for this logarithmic bias. The most common problem in volume function construction has been heteroscedasticity of residuals. This is due to the fact that larger tree volumes tend to deviate more from the regression line than do smaller ones. Cunia (1964) proposed the use of weighted least squares to correct for heteroscedasticity in volume function construction. Theoretically, weights should be employed that are inversely proportional to the variance of the residuals in order to achieve the homogeneity of variance assumption (Furnival 1961).

2.2.2 Residual Analysis

The residual is defined as the difference between the observed value of the dependent variable and the corresponding fitted (or predicted) value from the regression model. The residual may be regarded as the observed error, in

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distinction to the unknown true error in the regression model. Residuals are highly useful for studying whether a given regression model is appropriate for the data at hand. For a model to be considered as appropriate or adequate, the observed residuals should be assessed to be normally and independently distributed, with mean zero (0) and constant variance σ^2. Thus, residual analysis is a highly useful means of examining the aptness of a statistical model (Neter *et al.* 1996).

2.2.3 Model Evaluation and Selection Criteria

Once two or more models demonstrate adequacy of fit in terms of the regression assumptions, a number of criteria exist for evaluating goodness of fit. The common ones are the coefficient of determination (r^2), the standard error of the mean (SE), the Furnival index (FI), and the mean squared differences between predicted and observed volumes (Furnival 1961; Schlaegel 1981; Philip 1994).

Probably, the most commonly used model selection criterion is the coefficient of determination, r^2, value. This statistic indicates the proportion of the total sum of squares of the dependent variable explained by the linear regression. A major disadvantage of this statistic is that it can be used to compare two or more models only if the units of the dependent variable are the same for the models. Secondly, inclusion of additional independent variables never decreases the r^2 value, even though they may not be statistically significant (Schlaegel 1981).

The use of the standard error of the estimate as a selection criterion for models is second only to the coefficient of determination (Schlaegel 1981). The

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standard error is a measure of the variation in the observed dependent variable values not accounted for by the linear relationship with the independent variables (Husch 1963). It is a function of the number of coefficients estimated from the model since it is dependent on the sample size and the number of regression coefficients in the model. Transforming the dependent variable changes the magnitude of the standard error for the same equation, thus making the standard error inappropriate for comparing equations with different units or with different dependent variables. The standard error is difficult to interpret without additional information such as the distribution of the data, the mean and the range of the dependent variable (Schlaegel 1981).

The standard error and the coefficient of determination can only be used to compare equations that have the same dependent variable, and are not suitable when the dependent variables differ or when transformations of the dependent variables are involved (Furnival 1961; Crow 1971). Furnival (1961), proposed an index (based on the maximum likelihood principle) for comparing equations with different dependent variables. The Furnival index (FI) is calculated as:

$$FI = \frac{SE}{GM_Y} \qquad [1]$$

Where:

FI = the Furnival index,

SE = the standard error of the fitted regression, and

GM_Y = the geometric mean of the dependent variable.

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For the common transformations, the corresponding inverse of the geometric means are as follows (Furnival 1961; Alder 1980; Unnikrishnan and Singh 1984):

Transformation	Inverse of Geometric Mean
V (i.e., no transformation)	1
Log V	antilog $\frac{2.3026 \Sigma \log V}{n}$
Ln V	antilog $\frac{\Sigma \log V}{n}$
V/D^2	antilog $\frac{\Sigma \log D^2}{n}$
V/D^2H	antilog $\frac{\Sigma \log (D^2H)}{n}$
$1/V$	antilog $\frac{\Sigma \log V^2}{n}$
V^k	antilog $\frac{\Sigma \log 1/(KV^{K-1})}{n}$

Where:

D = the diameter at breast height (dbh),

H = total bole height,

V = total bole volume,

k = power transformation, and

n = the number of observations or the sample size.

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The equation with the smallest FI is selected as the model that gives the best fit to the data. Where there is no transformation (i.e., where the dependent variable is volume alone), the Furnival index reduces to the usual standard error.

The Furnival index has the advantage of reflecting both the size of the residuals and possible departures from the assumptions of linearity, normality, and homoscedasticity (Furnival 1961). Consequently, the FI is regarded as the best criterion for model selection (Furnival 1961; Alder 1980; Unnikrishnan and Singh 1984; Philip 1994).

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3.0 MATERIALS AND METHODS

3.1 THE STUDY AREA

Ghana is situated in West Africa and lies approximately between latitudes 4^0 45' N and 11^0 10' N, and longitudes 1^0 12' E and 3^0 15' W. Much of the country is gently undulating with some marked escarpments, but no great elevational differences (Prah 1994). The country has a total surface area of about 238 540 km^2. It is bordered on the east by Togo, on the west by Côte d'Ivoire, on the north by Burkina Faso, and on the south by the Atlantic Ocean (Borota 1991). From the coast, the country extends to a distance of about 710 km northward and 538 km from the east to the west.

3.1.1 Natural Vegetation Zones of Ghana

There are two broad vegetation zones in Ghana; namely, the Closed-canopy Tropical High Forest in the southwest, and the Open Savanna Woodland in the north (Taylor 1960). The Tropical Rainforest and the Semi-deciduous forests are broadly classified as the Tropical High Forest zone. This zone occupies the southwestern third of the country and covers an area of about 81 342 km^2. The remaining 157 198 km^2, which constitutes two-thirds of the country is mainly the Savannas (Lawson 1968).

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3.1.2 The Tropical High Forest Zone

The High Forest zone of Ghana is divided into ecological types, each with distinct associations of plant species and corresponding rainfall and soil conditions. Four broad ecological types have been identified in the High Forest zone. These are the Wet Evergreen (WE), the Moist Evergreen (ME), the Moist Semi-deciduous (MSD), and the Dry Semi-deciduous (DSD) (Hall and Swaine 1981; Figure 1). Floristically, these are synonymous with the *Cynometra-Lophira-Tarrietia* (i.e., *Heritiera*), the *Lophira-Triplochiton,* the *Celtis-Triplochiton* and the *Antiaris-Chlorophora* (i.e., *Milicia*) associations recognised by Taylor (1960). The MSD is further divided into the North-West (MSNW) and the South-East (MSSE) subtypes, while the DSD is subdivided into the Fire Zone and the Inner zone subtypes (Hall and Swaine 1976, 1981). There is, however, no distinct line of demarcation between these associations as one association imperceptibly merges into another. The general pattern is of wetter forest in the south and west turning to increasingly drier forest zones towards the north and east (Prah 1994).

The Moist Semi-deciduous forest is the most extensive forest type in Ghana. It is also the most productive forest zone. It is especially rich in economic timber species and it contributes the major proportion of forest produce from Ghana. The Dry Semi-deciduous forest exists under a wider range of environmental conditions than does any other forest type. It forms a peripheral band around the moister forest types and is adjacent , in the north, to the Guinea Savanna zone. It is characterised by several important timber species (Hall and Swaine 1981).

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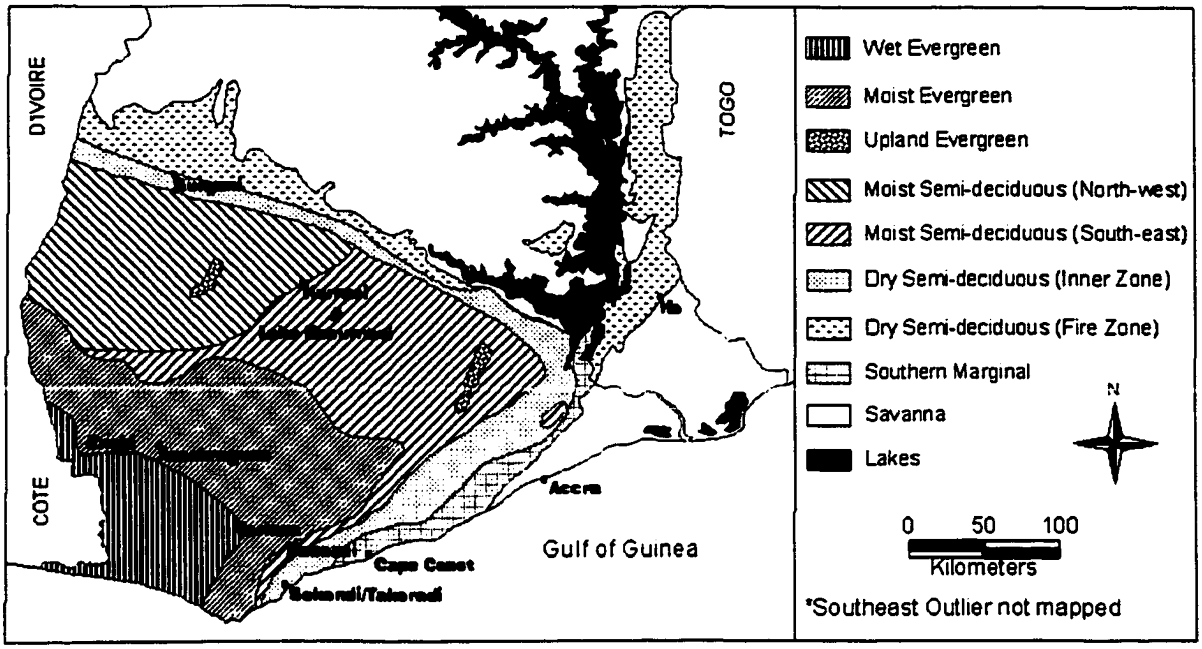

Figure 1. The study area and the distribution of forest types in southern Ghana (adapted from Hall and Swaine 1981).

3.1.3 The Wet Evergreen (WE) Zone

This forest type is restricted to the highest rainfall zone of Ghana. Mean annual rainfall is in excess of 1 750 mm and in some places higher than 2 000 mm. As a result, the soils show the most severe effects of leaching; total exchangeable bases (cations) are very low and never exceed 2m-equiv/100g soil and base saturation is low, rarely greater than 15 percent, giving low pH values almost entirely within the range 3.8 to 4.3. Scarcity of free nutrients may well explain the reduced stature of the forest. Most of this forest type is underlain by basement complex rocks, but a small area of land is formed of tertiary sediments. This forest contains more characteristic species than any other type. As a consequence of high diversity, the density of individual species tends to be low. The structure of this

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forest is essentially the same as that of the MSD type, but vertically compressed; canopy trees rarely exceeding 40 m. However, the largest trees may have massive boles and the basal area per hectare is not significantly different from that in more productive areas (Hall and Swaine 1981).

The forest is termed evergreen because of the relative scarcity of deciduous trees in the canopy (< 20 percent). The characteristic valuable timber species include *Lophira alata* Banks ex Gaertn. F., *Heritiera utilis* (Sprague) Sprague (syn. *Tarrietia utilis* [Sprague] Sprague), *Lovoa trichilioides* Harms, and *Guarea cedrata* (A. Chev.) Pellegr. Other economic timber species are *Milicia excelsa* (syn. *Chlorophora excelsa* Benth. & Hook. F.) and *Milicia regia* (syn. *Chlorophora regia* A. Chev.). However, there is a notable absence of Ghana's chief export timber species *Triplochiton scleroxylon* K. Schum. Moreover, the useable bole length of most exploitable timber trees is relatively short (Hall and Swaine 1981).

3.1.4 The Moist Evergreen (ME) Zone

This forest type is somewhat intermediate between the Wet Evergreen (WE) and the Moist Semi-deciduous (MSD) types. Although the Moist Evergreen (ME) type has fewer species than in the Wet Evergreen forest, there are more species than in the Moist Semi-deciduous forest. Even though very similar to the MSD in appearance, the tallest trees in ME forests are slightly shorter on average (43 m). Deciduous trees form only a small proportion (< 20 percent), hence the application of the term "evergreen". Annual rainfall is approximately 1 500 to 1 750 mm. The

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soil is poorer in nutrients than the MSSE forest subtype. The Subri River Forest Reserve (approximately 60 000 ha), Ghana's largest forest reserve, lies entirely within this forest type. The ME forest contributes greatly to Ghana's timber production. Valuable timber species of the ME forest include *Triplochiton scleroxylon* K. Schum., *Milicia excelsa* (syn. *Chlorophora excelsa* Benth. & Hook. F.), *Milicia regia* (syn. *Chlorophora regia* A. Chev.) and *Khaya ivorensis* A. Chev. (Hall and Swaine 1981).

3.1.5 Study Sites

The study for this thesis was carried out in the Western Region of the Republic of Ghana. The Region's constituent Wet Evergreen (WE) and Moist Evergreen (ME) forests are noted to contain the greatest floristic diversity in Ghana. In particular, the ME forest is very rich in economic timber species, being second only to the Moist Semi-deciduous forest type of the Ashanti Region. The Western Region, therefore, accounts for a greater proportion of log production in Ghana (Hall and Swaine 1981). Indeed, the greatest proportion of productive forest land in Ghana is located in the Western Region. The Western Region boasts stocking levels of 88 million m^3 out of the estimated gross national standing volume of 188 million m^3 (Ghartey 1989).

The study sites comprised four forest reserves and two off-forest reserves. These were the Boi Tano, Totua Shelterbelt, Bonsa River and Subri River forest reserves, and the Owurakese and Sekyere Krobo off-forest reserves. Due to time

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and budgetary constraints, the study was limited to five logging sites, comprising six compartments and two coupes. Selection of the five logging sites was made after consultations with officials of Ghana's Forest Services Division and some of the logging companies operating in the Western Region. An important prerequisite was the willingness of the concessionaires or logging companies to permit the study in their logging sites. Details of the study sites are provided in Table 1.

Table 1. Summary of information on study sites.

Forest Reserve	Forest District	Location Of Compt.	Area Of Reserve	Compt Number	Area Of Cpt or Coupe
Boi Tano	Enchi	Via Enchi	128.50 km^2	35	128.79 ha
Boi Tano	Enchi	Via Enchi	128.50 km^2	36	128.79 ha
Totua Shelterbelt	Asankragwa	Via Asankragwa	63.50 km^2	35	189.00 ha
Bonsa River	Tarkwa	Via Tarkwa	160.60 km^2	36	126.00 ha
Owurakese	Tarkwa	Via Oppon Valley	24.27 km^2	N/A	*500.00 ha
Subri River	Takoradi	Via Daboase	587.90 km^2	240	116.64 ha
Subri River	Takoradi	Via Daboase	587.90 km^2	241	144.32 ha
Sekyere Krobo	Takoradi	Via Daboase	N/A	N/A	*500.00 ha

* These refer to the sizes of coupes that were being logged in the two off-forest reserves.

3.2 SURVEY PROCEDURES

The basic sampling unit was the single felled tree. Sample trees were selected from four forest districts in the Western Region between June and September 1998. The four districts were randomly selected from the seven forest districts in the Region. The selected districts were the Asankragwa, Enchi, Takoradi

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and Tarkwa forest districts. Logging companies actively operating in these districts were stratified into large-, medium- and small-scale firms based on their production and export capacities. Two companies were randomly chosen from each stratum to afford data on harvesting efficiencies among the different scales of operators. However, at the time of the field surveys, two out of the six selected companies were no longer engaged in felling operations; while one company had temporarily ceased harvesting operations, the second company was then engaged in pre-felling activities in a newly acquired concession. Therefore, data from the felling operations of only four timber companies could be obtained.

3.3 DATA COLLECTION

Sources and causes of logging residue were identified through on-site surveys and critical observations at the selected felling sites. Causes of logging residue in the study area were also identified through an evaluation of harvesting methods and forest policy, including logging legislation and enforcement of logging legislation in Ghana. Observations on felling and skidding damage (including damage to residual stands, damage to the forest floor, and canopy openings due to harvesting) were also made. Due to time and budgetary constraints, only a qualitative assessment of forest disturbance and logging damage was made. As no measurements were made, this may well be described as a subjective assessment of forest disturbance and logging damage. Additional information was gathered from

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interviews and discussions with stakeholders, and from felling and work-plan records of the selected logging sites.

Principally, data collection involved on-site evaluation and measurement of felled trees at the selected logging sites. All diameter measurements were taken over-bark using a diameter tape or, where necessary, a linear tape. In all cases (except with stumps), two diameter measurements were taken; one each at the top end and at the bottom end of each tree section. Where the section was irregular-shaped, as a result of protrusions caused by buttress flanges or forks, two or more diameter measurements (each passing through a marked center) were taken at each end or cut surface, using a linear tape. The average of the diameter measurements at each end or cut surface was computed as the diameter of that end of the section. Length (or height) measurements were also taken with a linear tape. Logging residue included stumps, butt-end offcuts, crown-end offcuts (top-end offcuts), branch wood (i.e., tree branches) and other rejects deemed to be of potential commercial sizes (Figure 2).

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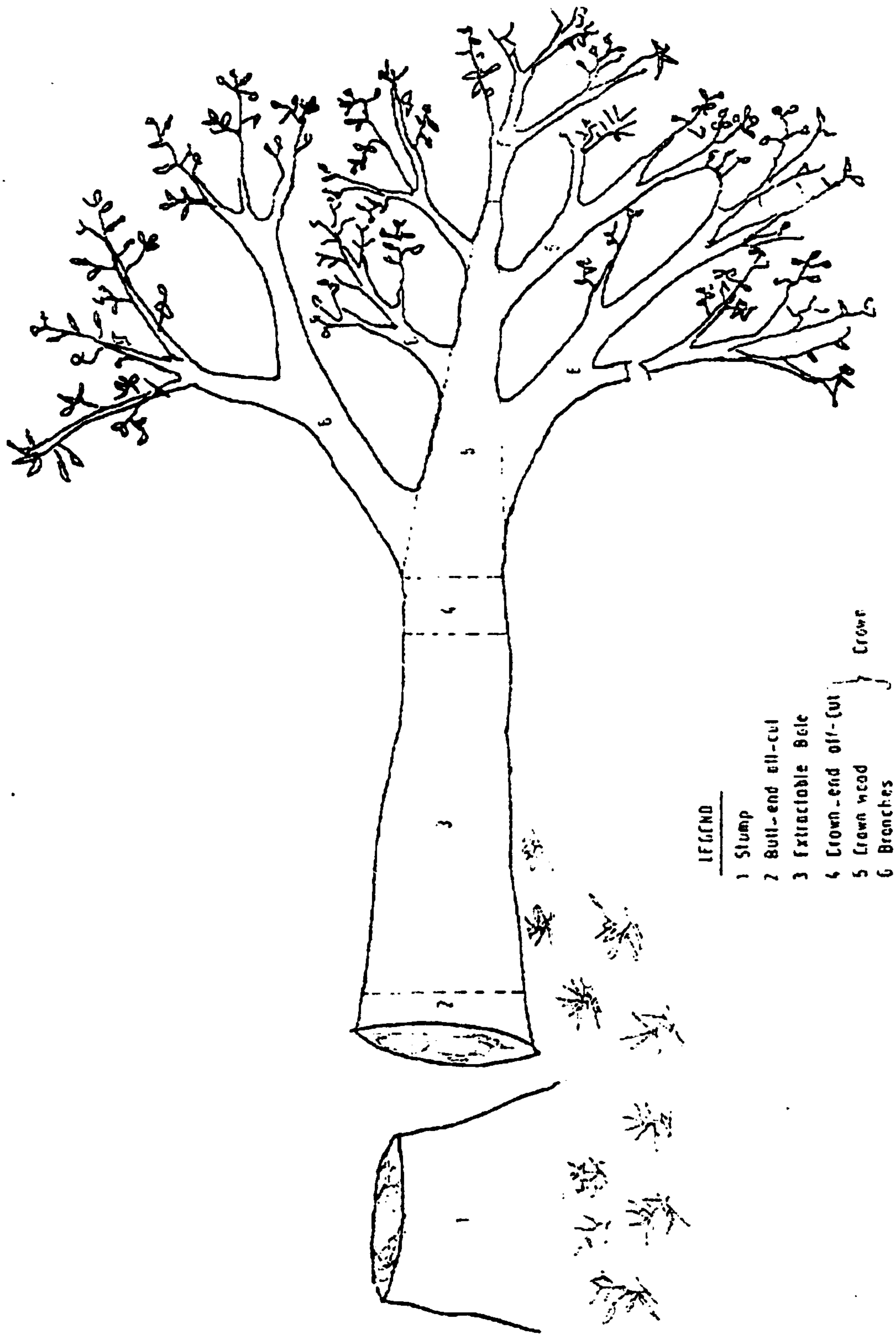

Figure 2. Schematic representation of a felled tree showing the various sections (adapted from Nketiah 1992).

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3.3.1 Stumps Identification and Measurement

Stumps were located and identified with the assistance of felling clerks, forest guards and technical officers responsible for felling checks. Heights and only top diameters of stumps were measured. Stump height was measured as the vertical distance between the top of a stump and the ground level. On slopes, the ground level was taken as the point where the tree (stump) touched the ground on the up-hill side (Aldred and Alemdag 1988).

3.3.2 Butt-end Offcuts Measurement

Diameter measurements were taken at the top end where the first log was cut and at the bottom end where the tree was cut from the stump. The distance between the two ends was measured as the total length of each butt-end offcut.

3.3.3 Measurement of Extracted Boles

Length, and bottom and top diameter measurements of extracted boles (i.e., extracted logs) were taken at the stump sites, primary landings and/or loading bays. Where necessary, these measurements were obtained from felling records of the respective logging areas since each bole (or log) bears identification marks (stock survey number, species, log number, locality mark, compartment number and reserve code). Where necessary, extracted boles were marked into short lengths (or billets) for easy measurement. This helped to reduce the influence of sweep or curvature.

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3.3.4 Measurement of Rejected Boles in Slash and at Loading Bays

Length and diameter measurements, as above, were also taken on all rejected boles (or bole offcuts) deemed to be of potential commercial sizes. Where possible, the reasons for rejection were determined.

3.3.5 Crown-end Offcuts (Top-end Offcuts) Measurement

Diameter measurements were taken at the bottom-end where the last log was cut and at the crown point where the first crown-forming branch was located. Irrespective of minor side branches, if any, the distance between the two ends was measured as the total length of each crown-end offcut.

3.3.6 Measurement of Branch Wood

For each sample tree, all branches with diameters equal to or greater than 20 cm were measured. However, rotted or severely crooked branches were not included in the assessment of branch wood. Also, branches which were crushed due to impact of falling were not measured. For each branch, diameter measurements were taken at the base of the branch just above the fork and at the top, just before the next branching. In all cases, the distance between the two diameter measurements was recorded as the length of the branch. Where necessary, branches were marked into short lengths (or billets) for easy measurement. This helped to reduce the influence of sweep or curvature.

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3.4 DATA ANALYSES

Altogether, data on 104 sample trees were captured during the surveys. Prior to data analyses, four sample trees were discarded since they did not have the full complement of measurements for all tree sections. The remaining 100 sample trees, comprising 26 different species, were then used for the analyses. Since the study followed normal commercial logging operations, the species composition of the sample trees was influenced by the loggers' choice of species during felling. The loggers' choice of species were dependent on their contractual obligations to buyers at that time.

3.4.1 Volume Estimation

The volume of each tree section was computed using the corresponding diameter and length (or height) measurements. Smalian's formula was used to estimate volumes in all sections (except tree stumps). Thin buttress protrusions were disregarded in the estimation of stump and butt-end offcut volumes since such thin protrusions were not considered merchantable, except as woodfuel. Thus, the central core of each stump was treated as a cylindrical log with the same diameters at both the base and the top. Consequently, volumes of stumps were estimated as if they were cylindrical solids.

Residue was considered as any wood material in the stump, main bole, crown, and branch wood down to 20 cm diameter that was not extracted during normal commercial logging operations. The volume of saw-dust produced during

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felling and bucking was not considered since it was not practicable to have done so. For each sample tree, residue volume was estimated for the stump, butt-end offcut(s), crown-end offcut(s) and branch wood. Above-ground total residue volume was calculated as the sum of residue in the stump, butt-end offcut(s), crown-end offcut(s) and branch wood. The above-ground total residue volume was estimated for each sample tree, average for individual timber species, average for each logging company and average for the overall data set.

Above-ground total tree volume was determined for all components down to a 20 cm diameter limit. The above-ground total tree volume was calculated as the sum of the above-ground total residue and extracted bole(s) volumes. Total bole volume was computed as the sum of the stump, butt-end offcut(s), extracted bole(s) and crown-end offcut(s) volumes. The proportion of the bole volume extracted was calculated as the ratio of extracted bole volume to total bole volume. The proportion of the bole volume extracted (expressed as a percentage), the total bole volume and the above-ground total tree volume were estimated for each sample tree. Also, the averages for individual timber species, each logging company and for the overall data set were calculated.

In order to increase recovery and utilization of harvested trees, potential types of forest products which might be converted from logging residue were identified. This necessitated visits to some wood processing mills, and woodworking shops where carvings and handicrafts are made, in order to observe utilization of wood

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residue. The study also looked at the technical feasibility of utilizing existing plants and machinery in Ghana to develop the identified products.

3.5 STATISTICAL ANALYSES

Statistical treatment of the data sets included computations of sample means ($\bar{x}$), 95 percent confidence intervals (CI) of the sample means, standard errors (SE), standard deviations (Std Dev.), and the coefficients of variation (CV%) of the means of diameters, heights (or lengths) and estimated volumes of the sample trees. The minimum and maximum values for each parameter were also noted in order to demonstrate the range in values found for each parameter for the overall data set, for the data set of individual timber species and for the data set of each logging company.

Statistical analyses comprised *F*-tests for comparing data sets derived from different logging sites, one-way analysis of variance (ANOVA) for comparing group means, sample size determinations and modeling (using regression analyses) to predict logging residue volume.

3.5.1 *F*-Tests for Comparing Data Sets Derived from Different Logging Sites

F-tests, based on the use of dummy variable analysis using regression, were used for comparing data sets derived from the five logging sites in order to determine if the tree data could be combined for further analyses (Alder 1980; Weisberg 1980). The dependent variable was total bole volume, while total bole height and diameter (of the top end of butt-end offcuts) were the independent

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variables. The dummy variables were used in combination with the independent variables to generate new variables.

3.5.2 One-way Analysis of Variance for Comparing Group Means

One-way analysis of variance (ANOVA) was used to compare the group means of the proportions of bole volumes that were extracted. This was done in order to test for significance in harvesting efficiencies among the different logging companies, and among the different harvested timber species with at least two observations. For the purpose of this study, harvesting efficiency for each logging company or individual timber species was determined by the mean of the proportions of bole volumes extracted for that particular logging company or individual timber species.

3.5.3 Sample Size Determinations

The data sets were further analyzed to determine the number of samples required to obtain the mean value of a parameter within a specified allowable error and confidence level. Diameter and length measurements were the parameters upon which sample size determinations were based. This is explained by the fact that volume estimation was carried out using diameter and length measurements. Sample size calculations were executed using the iterative method given by Freese (1962) and outlined in Husch *et al.* (1982).

An allowable error of ±10 percent at the 95 percent confidence level is considered acceptable for most inventory and biomass studies (Maurer 1993).

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Since it may not always be practical or economical to obtain a sample size at this precision and confidence level, the sample size calculations were replicated at 95 percent confidence level and at an allowable error of ±15 percent. The sample sizes were determined for all the sub-sample tree sections (or logging residue) except branches. Since branches were marked into short lengths (or billets) to facilitate measurement, and no distinction was made between billets of a particular branch, it was not possible to determine sample sizes for branch wood. Optimum sample sizes were determined for the overall data set and then replicated for each timber species with a frequency of at least six observations.

3.5.4 Modeling Total Tree Volume to Predict Total Residue Volume

Simple linear regression models were developed for predicting the measured above-ground total tree volumes, using extracted bole volumes as the independent variable. Attainment of homoscedasticity and the other regression assumptions were facilitated by transformations. The regression model that produced the best fit for each data set was selected for predicting the measured above-ground total tree volume and thereby the measured above-ground total residue volume. The criterion for selecting the best model was the Furnival Index (Furnival 1961). Models were developed for the overall data set and then replicated for individual species with at least eight observations.

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3.5.5 Local and Standard Volume Equations

Using simple linear regression and multiple regression analysis, local and standard volume equations were constructed with the individual total bole height, top diameter of butt-end offcut and total bole volume data. The 15 most commonly used volume equations (Appendix I) presented in Unnikrishnan and Singh (1984) were tested in order to determine the most appropriate model. Independent variables were either diameter, height, combinations of diameter and height, or transformations of these variables. The dependent variable was total bole volume.

Heteroscedasticity of the residuals, based on models of the constructed volume equations, were corrected by weighting. Using SPSS, appropriate weighting variables were determined as functions of diameter (D) or the product of diameter and height (DH): i.e., $(D^2)^{-x}$, $(D^2H)^{-x}$ and $(DH)^{-x}$. Yet again, the criterion for selecting the best equation was the Furnival Index (Furnival 1961). Models were developed for the overall data set and then replicated for individual timber species with at least six observations.

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4.0 RESULTS

The preliminary analysis involved *F*-tests for comparing data sets derived from the five logging sites. The null hypothesis was accepted for all the *F*-tests. Thus, the tree data from the different sites can be assumed to come from the same super populations. This also implied that the data sets could be pooled together for further analyses without a consequent loss of accuracy. Data analyses, therefore, were based on the overall data from the five logging sites.

4.1 FOREST DISTURBANCE AND LOGGING DAMAGE

During the survey, it was realized that many trees were destroyed as a result of felling and tree fall, skidding of felled trees and boles, and construction of access roads and loading bays (or landings). In particular, large-sized trees (e.g., dbh > 150 cm) and large-crowned species caused the greatest damage to residual trees. Such species include Guarea (*Guarea cedreta* [A. Chev.] Pellegr.), Antrocaryon (*Antrocaryon micraster* A. Chev. & Guill.), Ogea (*Daniellia thurifera* Benn.), Bompagya (*Mammea africana* Sabine), Abura (*Mitragyna ciliata* Aubrev. & Pellegr.), Wawa (*Triplochiton scleroxylon* K. Schum.), Dahoma (*Piptadeniastrum africanum* [Hook. F.] Brenan), Ekki (*Lophira alata* Banks ex Gaertn. F.), Ceiba (*Ceiba pentandra* [Linn.] Gaertn.), Mahogany (*Khaya ivorensis* A. Chev.) and Makore (*Tieghemella heckelii* Pierre ex A. Chev.). In addition, felling trees whose crowns are interconnected with climbers (i.e., lianas) results in larger canopy openings and

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more severe damage to residual trees. A list of the scientific names (and the trade names) of Ghana's export timber species is given in Appendix II.

By far, the greatest damage to residual trees and the forest floor appeared to have been caused during skidding of felled trees. Damage caused by skidding included crown breakage, wounds to bark, stems and roots of residual trees, push-over and sometimes complete uprooting of trees. Worst still, some skidder operators were not sticking to the official skid tracks but resorted to taking the shortest possible routes at any point in time. Of the Caterpillar D6, D7 and D8 tractors being used, the heavier D7 and D8 skidders seemed to be causing the greatest damage to residual trees, wider skid tracks and greater soil compaction. Soil disturbance, due to skidding, appeared to be worse under wet conditions. Unskilled skidder operators were the worst offenders in causing damage to residual trees and the forest floor. In all cases, saplings and seedlings appeared to have suffered the greatest damage. Loading bays and access roads had been cleared of virtually all vegetation. Margins of access roads exhibited a preponderance of secondary species such as *Musanga cecropioides* (R. Br.) J. Léonard and *Elaeis guineensis* Jacq. (Oil Palms).

4.2 SOURCES AND CAUSES OF LOGGING RESIDUE

Sources of logging residue, identified during the survey, included high stumps, butt-end offcuts, rejected boles (or bole offcuts), crown-end offcuts and

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branchwood (i.e., tree branches) (Figures 3 to 6). Rejected boles, however, appeared to constitute an insignificant proportion of the sources of logging residue.

Figure 3. The stump of a harvested tree showing splinters caused by poor felling.

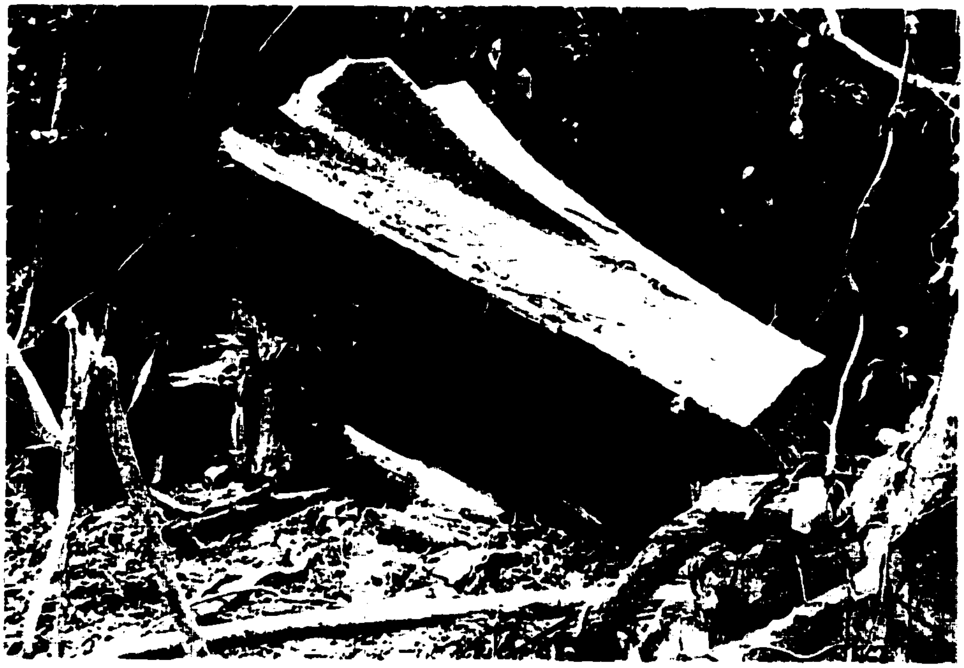

Figure 4. Butt-end offcut left at the stump site showing buttress flanges.

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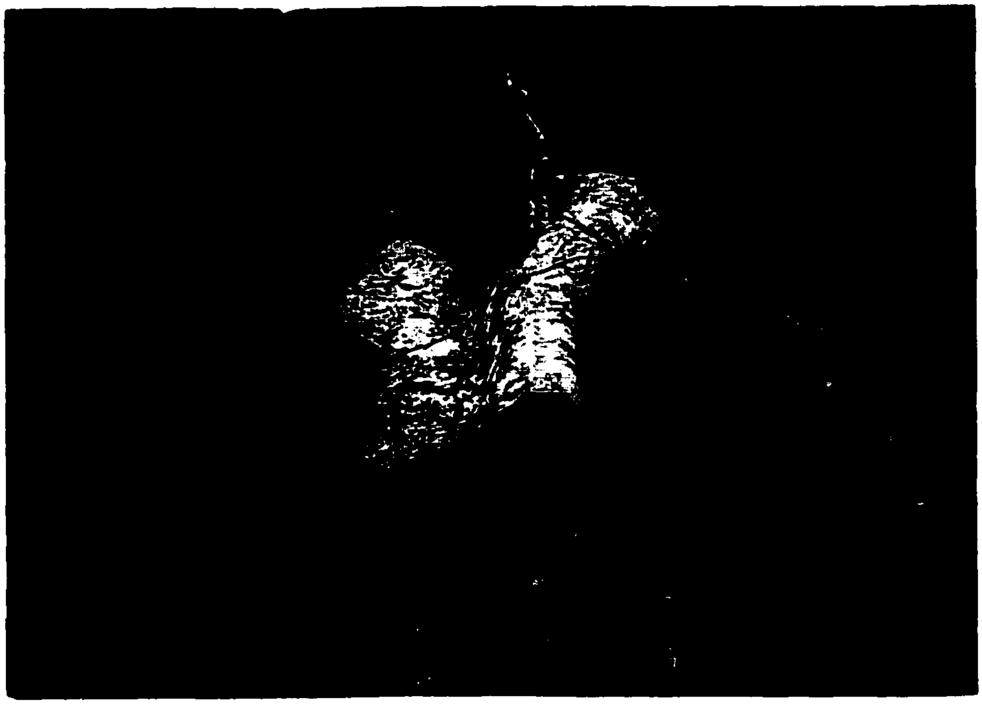

Figure 5. Crown-end offcut left in slash showing a split caused by impact of falling.

Figure 6. Rejected bole with a cup shake defect lying close to the landing.

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Logging residue may be attributed to a variety of causes. These causes included huge buttresses, fluted boles, stump rot and/or heart rot (Figure 7) resulting in high stumps and long butt-end offcuts. Huge buttresses are characteristic of large-sized timber species. Such species include Dahoma, Walnut (*Lovoa trichiliodes* Harms), Ofram (*Terminalia superba* Engl. & Diels), Ceiba, Wawa, Mahogany, Pterygota (*Pterygota macrocarpa* K. Schum.), Danta (*Nesogordonia papaverifera* [A. Chev.] R. Capuron and Niangon (*Heritiera utilis* [Sprague] Sprague) (Appendices III and IV). Incidentally, Hall and Swaine (1981) reported that some of these species can have buttresses stretching as high as 10 m or more up the bole. Heart rot was especially prevalent in Wawa and Ofram species. Heart rot and/or decay also led to bole rejects, crown-end offcuts and sometimes discarding of entire trees.

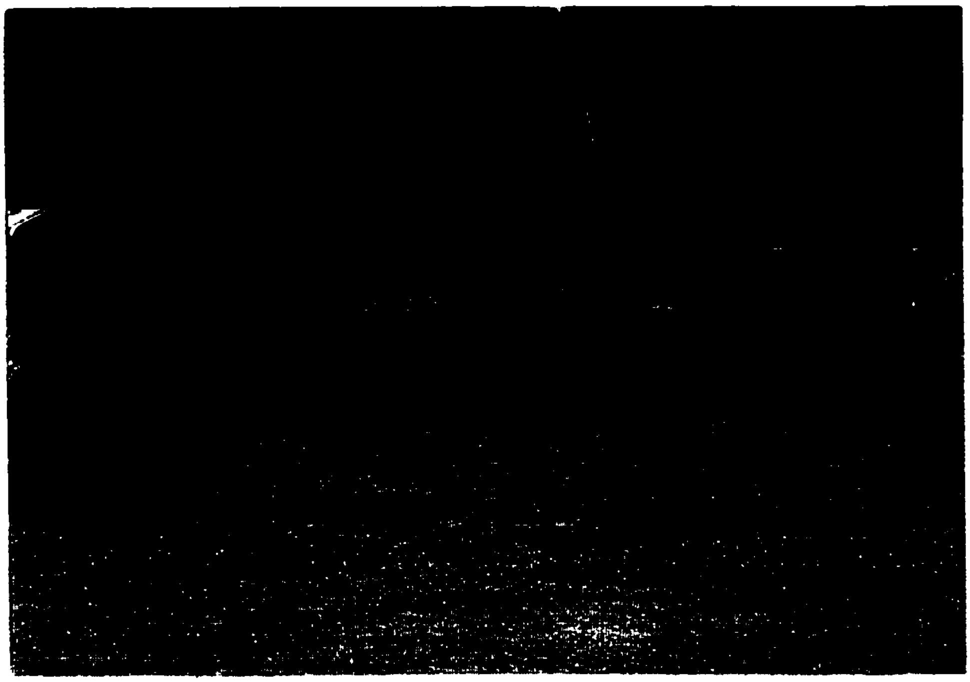

Figure 7. Crown-end offcut with a heart rot defect.

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Undulating or hilly terrain made felling difficult and thus resulted in high stumps. In particular, logging sites where most of the Wawa, Pterygota and Niangon trees were felled were characterized by hilly terrain.

Other causes of logging residue were splits, heart checks, heart shakes, cup shakes, ring shakes, huge knots and bumps, sweep and crook, sap stains and higher sapwood proportion especially towards the crown-end of the bole. All of these natural defects resulted in high stumps, offcuts and/or bole rejects. Indeed, Wong (1989) reported a mean defect per tree of 8 percent of the bole volume in Ghanaian tropical high forests. Wider sapwood was especially common and distinct in the crown wood of Dahoma, Niangon, Ogea, Danta, Abura and Makore (Appendix VI). Generally, the loggers were disinterested in wood with greater sapwood proportion since the sapwood content is slabbed away in the mills.

Unskilled chain saw operators (tree fellers and bole buckers) created more wastage through faulty or careless cutting operations, leading to breakages and splits in felled trees and more damage to residual trees.

4.3 VOLUME ESTIMATION

Summary statistics of volume estimates by species are given in Tables 2 to 6. Parameters of the component sections of individual sample trees and other details are provided in Appendices III to XII. Results presented include the averages of the above-ground total tree volumes, total extracted bole volumes, proportions of bole volumes extracted and the above-ground total residue volumes for individual timber

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species. Also presented are data on boles (or bole offcuts) discarded in slash or loading bays, but which were considered to be potentially useful.

Table 2. Sectional volumes (m^3) of sample trees by species.

No.	Timber Species	Stump Wood Volume (m^3)	Butt-End Offcut Volume (m^3)	Extracted Bole Volume (m^3)	Crown-End Offcut Volume (m^3)	Branch Wood Volume (m^3)	Total Tree Volume (m^3)	Proportion of Bole Volume Extracted (%)
1	Niangon	0.32	1.13	11.19	0.88	1.13	14.65	82.91
2	Dahoma	0.58	2.73	12.63	1.24	7.16	24.34	73.01
3	Ayan	0.43	0.90	6.93	1.59	1.71	11.57	71.10
4	Ceiba	2.39	18.40	45.30	5.12	3.60	74.81	63.61
5	Guarea	2.15	5.51	27.33	5.95	8.39	49.33	66.76
6	Mahogany	0.76	0.70	16.63	0.33	2.52	20.93	90.90
7	Edinam	0.65	0.00	13.46	0.00	1.40	15.51	95.38
8	Adasema	0.18	1.74	14.30	2.11	2.65	20.98	77.99
9	Aningeria	0.35	0.80	4.65	1.39	0.44	7.64	64.71
10	Antrocaryon	3.65	0.00	31.94	0.00	9.40	44.98	89.75
11	Walnut	0.64	0.44	10.53	0.60	2.85	15.05	86.92
12	Ogea	1.11	0.00	26.29	1.71	4.80	33.92	88.63
13	Makore	1.96	0.00	57.53	2.08	9.58	71.15	90.96
14	Kusia	0.68	0.00	16.30	1.71	1.41	20.10	87.23
15	Bompagya	1.12	0.00	22.01	1.65	0.26	25.04	88.82
16	Afzelia	0.57	0.00	11.06	0.47	3.14	15.24	91.24
17	Fotie	0.60	0.00	12.72	1.22	1.59	16.13	87.35
18	Ilomba	0.55	0.00	12.92	0.79	0.14	14.40	90.37
19	Abura	0.65	0.00	21.68	2.25	6.75	31.33	88.18
20	Potrodom	0.75	0.00	10.46	0.37	3.99	15.57	90.33
21	Ekki	0.82	0.00	25.24	2.05	15.12	43.23	89.77
22	Pterygota	0.21	1.49	10.49	2.63	1.16	15.99	70.17
23	Wawa	0.59	3.74	12.92	1.71	2.51	21.46	69.37
24	Avodire	0.24	0.02	3.51	0.71	1.57	6.05	77.99
25	Ofram	0.47	2.31	10.04	2.00	0.34	15.16	66.77
26	Danta	0.28	0.44	9.76	0.74	0.42	11.64	84.13
	Mean	**0.59**	**1.50**	**13.30**	**1.28**	**2.82**	**19.50**	**79.39**

For the individual sample trees, bole diameters (top diameters of butt-end offcuts) ranged from 61 cm (Avodire {*Turraeanthus africanus* [Welw. ex C. DC.] Pellegr.}) to 219 cm (Makore) and averaged 98 cm. Similarly, total bole lengths

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varied from 8.85 m (Avodire) to 47.93 m (Danta) and averaged 27.74 m. Total bole volumes of individual sample trees ranged from 3.02 m^3 (Avodire) to 84.02 m^3 (Makore) and averaged 16.68 m^3.

Table 3. Percentage (%) distribution of sectional volumes by species.

No.	Timber Species	Stump Wood Volume (%)	Butt-End Offcut Volume (%)	Extracted Bole Volume (%)	Crown-End Offcut Volume (%)	Branch Wood Volume (%)	Total Tree Volume (%)	Proportion of Bole Volume Extracted (%)
1	Niangon	2.57	7.49	76.43	5.67	7.84	100.00	82.91
2	Dahoma	2.42	11.13	51.83	5.09	29.53	100.00	73.01
3	Ayan	3.81	6.18	60.80	14.68	14.52	100.00	71.10
4	Ceiba	3.19	24.60	60.56	6.84	4.81	100.00	63.61
5	Guarea	4.36	11.17	55.40	12.06	17.02	100.00	66.76
6	Mahogany	3.66	2.79	79.21	1.64	12.70	100.00	90.90
7	Edinam	4.20	0.00	86.76	0.00	9.04	100.00	95.38
8	Adasema	0.87	8.31	68.15	10.05	12.61	100.00	77.99
9	Aningeria	4.61	10.44	60.94	18.19	5.82	100.00	64.71
10	Antrocaryon	8.11	0.00	71.00	0.00	20.89	100.00	89.75
11	Walnut	4.39	2.35	70.51	3.82	18.93	100.00	86.92
12	Ogea	3.31	0.00	75.53	6.21	14.95	100.00	88.63
13	Makore	3.31	0.00	79.47	4.79	12.44	100.00	90.96
14	Kusia	3.38	0.00	81.10	8.50	7.03	100.00	87.23
15	Bompagya	4.49	0.00	87.90	6.57	1.04	100.00	88.82
16	Afzelia	3.89	0.00	72.57	3.08	20.46	100.00	91.24
17	Fotie	3.80	0.00	78.91	7.71	9.58	100.00	87.35
18	Ilomba	3.74	0.00	89.82	5.82	0.62	100.00	90.37
19	Abura	2.08	0.00	69.20	7.19	21.53	100.00	88.18
20	Potrodom	4.79	0.00	67.17	2.40	25.64	100.00	90.33
21	Ekki	1.91	0.00	58.38	4.74	34.98	100.00	89.77
22	Pterygota	1.37	9.20	65.24	16.81	7.39	100.00	70.17
23	Wawa	3.19	15.39	60.94	8.90	11.58	100.00	69.37
24	Avodire	3.92	0.31	59.26	13.09	23.42	100.00	77.99
25	Ofram	3.29	15.02	65.41	14.31	1.96	100.00	66.77
26	Danta	2.96	2.62	80.02	9.28	5.11	100.00	84.13
	Mean	**3.20**	**6.56**	**68.18**	**7.96**	**14.11**	**100.00**	**79.39**

For individual sample trees, above-ground total tree volumes ranged from 3.97 m^3 (Avodire) to 98.91 m^3 (Makore) and averaged 19.50 m^3. For the group

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(species) means, above-ground total tree volumes varied from 6.05 m^3 (Avodire) to 71.15 m^3 (Makore). For the group (species) means, extracted bole volumes ranged from 3.51 m^3 (Avodire) to 57.53 m^3 (Makore). For individual sample trees, extracted bole volumes varied from 2.33 m^3 (Avodire) to 82.13 m^3 (Makore) and averaged 13.30 m^3 (Table 2, Appendices V and IX).

For individual sample trees, extracted bole volumes constituted 31 percent (Dahoma) to 94 percent (Ilomba) and averaged 68 percent of the above-ground total tree volumes. Proportions of bole volumes that were extracted ranged from 43 percent (Wawa) to 98 percent (Makore) and averaged 79 percent of total bole volumes. Thus, in each case, only a portion of the total bole volume was extracted (Appendix X). For the sample (species) means, extracted bole volumes constituted 52 percent (Dahoma) to 90 percent (Ilomba {*Pycnanthus angolensis* [Welw.] Warb.}) of above-ground total tree volumes (Table 3).

Volumes of rejected boles (and rejected bole offcuts) in slash ranged between 1.89 and 26.77 m^3, and averaged 10.15 m^3 (Table 4). In particular, the largest volume of 26.77 m^3 was contributed by a fluted Wawa tree, while the second largest volume of 26.74 m^3 was contributed by an Ofram tree with a heart rot cavity covering over 50 percent of the total bole volume. An Afzelia (*Afzelia bella* Harms) tree with a heart rot cavity of about 17 percent of the total bole volume of 6.88 m^3 was also rejected in slash. A Pterygota bole offcut (with total volume of 2.36 m^3) had been rejected because it did not meet the sales contract specification of a minimum diameter of 60 cm.

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Table 4. Parameters of boles and bole offcuts rejected in slash.

Timber Species	Bole Length (m)	Bottom Diameter (m)	Top Diameter (m)	Bole Volume (m^3)	Remarks
Afzelia	9.60	0.98	0.93	6.88	Heart rot volume = 1.20 m^3
Pterygota	8.30	0.65	0.55	2.36	Undersized veneer log!
Pterygota	4.40	0.74	0.74	1.89	Heart rot defect
Mahogany	5.80	0.75	0.58	2.05	Crooked and sweepy bole
Ofram	37.00	1.13	0.75	26.74	Heart rot vol. > 50 % of bole vol
Ofram	9.70	0.84	0.66	4.35	Heart rot volume = 0.35 m^3
Wawa	15.70	1.71	1.19	26.77	Fluted bole
Total				**71.04**	

Volumes of rejected boles (and rejected bole offcuts) at the loading bays ranged between 0.29 m^3 and 8.91 m^3, and averaged 2.38 m^3 (Table 5). A greater volume of boles were rejected in slash than at the loading bays. The total rejected boles (and bole offcuts) volume of approximately 90 m^3, at both the loading bays and in slash, is negligible when compared to the overall above-ground total tree volume of about 1 950 m^3. Indeed, the total volume of rejected boles represented less than 5 percent of the overall above-ground total tree volume. Incidentally, about 30 percent of the total volume of rejected boles (representing the Ofram bole with over 50 percent heart rot cavity) was of cull material. Since this Ofram bole was considered a cull, it was not included in the data which was analyzed. However, it is worthy of mention that heart rot and fluting were the causes contributing to a greater proportion of rejected boles in slash and at the loading bays. Other reasons for bole rejects were splits, shakes, sweep and crook, and the presence of large buttresses and prominent knots with bumps.

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Table 5. Parameters of boles and bole offcuts rejected at loading bays.

Timber Species	Bole Length (m)	Bottom Diameter (m)	Top Diameter (m)	Bole Volume (m^3)	Remarks
Dahoma	2.70	0.73	0.67	1.04	Split, huge knot and bump
Niangon	1.10	0.88	0.80	0.61	Heart rot volume = 0.01 m^3
Niangon	1.30	0.90	0.90	0.83	Large buttresses
Niangon	2.90	1.01	0.93	2.15	Sweep, huge knot and bump
Niangon	9.00	0.52	0.33	1.34	Crook and 3 sweeps
Niangon	1.50	0.51	0.48	0.29	Huge knot and split
Wawa	13.80	1.04	0.75	8.91	Splits and cup shake
Ofram	9.60	0.77	0.66	3.88	Heart rot
Total				**19.05**	

Of the major sources of logging residue, branch wood contributed the highest average proportion of 42 percent. This was followed by crown-end offcuts (26 percent), butt-end offcuts (19 percent) and stump wood (13 percent). Thus, total crown wood (comprising branch wood and crown-end offcuts) contributed a substantial proportion (68 percent) of the total logging residue (Table 6). In particular, the measured branch diameters ranged from 20 cm to 130 cm and averaged 39 cm. Further, branch lengths ranged from 1.0 m to 17.2 m and averaged 4.3 m. Generally, branch wood volumes were highest in large-crowned and/or huge timber species such as Dahoma, Guarea, Antrocaryon, Makore and Ekki. Conversely, branch wood volumes were lowest in narrow-crowned species like Ilomba, Ofram, Danta, Niangon, Pterygota, Avodire and Fotie (*Hannoa klaineana* Pierre & Engl.) (Table 2 and Appendices VII to XII).

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Table 6. Percentage (%) distribution of logging residue by species.

Number	Timber Species	Sample Size	Stump Wood (%)	Butt-End Offcuts (%)	Crown-End Offcuts (%)	Branch Wood (%)	Total Residue (%)
1	Niangon	15	12.64	31.52	23.50	32.34	100.00
2	Dahoma	11	5.38	24.58	10.32	59.72	100.00
3	Ayan	2	9.86	14.54	38.48	37.12	100.00
4	Ceiba	1	8.10	62.37	17.35	12.18	100.00
5	Guarea	1	9.77	25.04	27.03	38.16	100.00
6	Mahogany	8	19.37	9.82	8.11	62.70	100.00
7	Edinam	1	31.74	0.00	0.00	68.26	100.00
8	Adasema	1	2.74	26.09	31.56	39.60	100.00
9	Aningeria	1	11.80	26.73	46.56	14.90	100.00
10	Antrocaryon	1	27.97	0.00	0.00	72.03	100.00
11	Walnut	3	16.45	6.38	14.62	62.55	100.00
12	Ogea	2	14.62	0.00	22.42	62.95	100.00
13	Makore	2	15.39	0.00	19.85	64.76	100.00
14	Kusia	1	17.87	0.00	44.95	37.19	100.00
15	Bompagya	1	37.07	0.00	54.32	8.61	100.00
16	Afzelia	2	14.18	0.00	11.22	74.60	100.00
17	Fotie	3	18.42	0.00	34.32	47.26	100.00
18	Ilomba	4	37.76	0.00	57.46	4.78	100.00
19	Abura	1	6.76	0.00	23.34	69.90	100.00
20	Potrodom	1	14.60	0.00	7.30	78.09	100.00
21	Ekki	1	4.58	0.00	11.40	84.03	100.00
22	Pterygota	6	3.94	27.86	47.77	20.42	100.00
23	Wawa	13	8.09	38.31	23.87	29.73	100.00
24	Avodire	12	10.03	0.88	33.50	55.60	100.00
25	Ofram	4	9.47	43.95	40.68	5.90	100.00
26	Danta	2	14.63	22.60	40.02	22.74	100.00
	Mean		**12.57**	**19.07**	**25.97**	**42.39**	**100.00**

4.4 HARVESTING EFFICIENCIES AMONG DIFFERENT TIMBER SPECIES

A comparison of harvesting efficiencies among the different timber species is given in Figure 8 and Appendix XIII. As already noted, harvesting efficiencies were based on the proportions of bole volumes that were extracted. For the sample (species) means, these proportions ranged between 67 percent (Ofram) and 91

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percent (Afzelia, Makore and Mahogany). The standard errors of the sample means also ranged from 0.46 percent (Afzelia) to 6.80 percent (Makore) and averaged 1.18 percent.

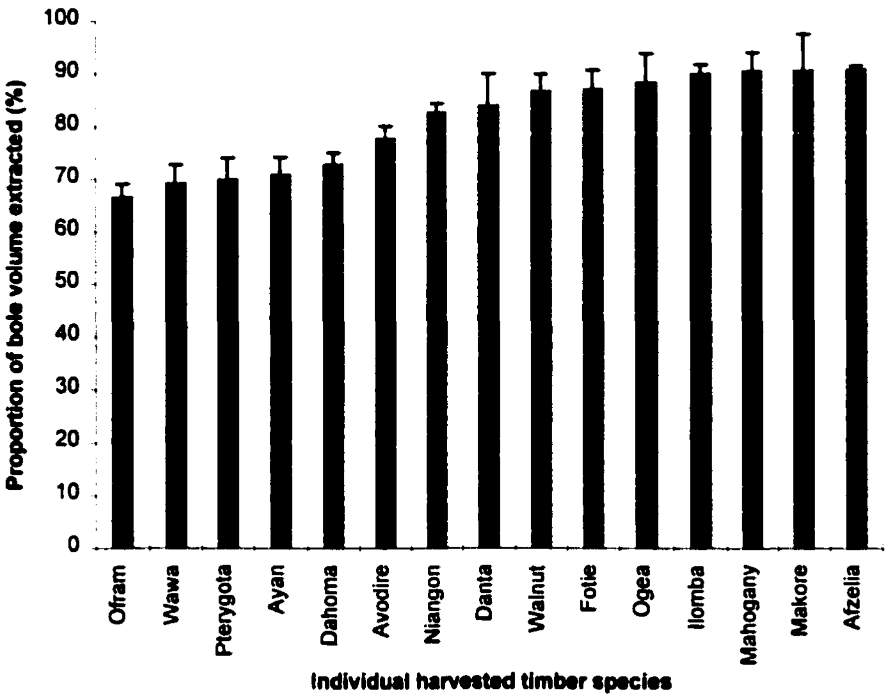

Figure 8. A comparison of harvesting efficiencies among different timber species.

Evidently, the sample means were highest (90 to 91 percent) in Afzelia, Makore, Mahogany and Ilomba and lowest (67 to 73 percent) in Ofram, Wawa, Pterygota, Ayan (*Distemonanthus benthamianus* Baill.) and Dahoma. The other sample means were somewhat in-between, with harvesting efficiencies in Avodire, Niangon and Danta being in the lower-middle group with 78 to 84 percent, and Walnut, Fotie and Ogea being in the upper-middle category with 87 to 89 percent.

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The question then is, can differences as large as these occur strictly by chance if there were actually no differences among the sample means?

Analysis of variance showed that there were significant differences in extraction efficiencies between Ofram, Wawa and Pterygota, on one hand, and Afzelia, Makore, Mahogany, Ilomba, Ogea, Fotie, Walnut, Danta and Niangon, on the other hand. There were also significant differences between sample means of Ayan and Dahoma, on one hand, and Afzelia, Makore, Mahogany, Ilomba, Ogea, Fotie and Walnut, on the other hand. Similarly, harvesting efficiency in Avodire was significantly lower than those in Afzelia, Makore, Mahogany and Ilomba. These differences in harvesting efficiencies were larger than would be expected by chance if there were actually no differences among the sample means. For instance, harvesting efficiency in Mahogany was significantly higher than that in Wawa ($P < 0.0005$). Furthermore, harvesting efficiency in Makore was significantly higher than that in Dahoma ($P < 0.008$).

Conversely, there were no significant differences in extraction efficiencies among Ofram, Wawa, Pterygota, Ayan and Dahoma. Similarly, there were no significant differences in harvesting efficiencies among Afzelia, Makore, Mahogany and Ilomba. That is, sample mean differences among these species could have occured by chance more than 1 time in 20 even if there were no real differences among the sample means. For example, there was no significant difference in harvesting efficiencies between Pterygota and Wawa ($P > 0.891$), and neither was there any significant difference between Makore and Mahogany ($P > 0.994$).

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While there were significant differences in harvesting efficiencies of member species among the groupings of lower, lower-middle, upper-middle and upper, there were no significant differences in sample means of timber species within a group or between some member-species from any two adjoining groups.

4.5 HARVESTING EFFICIENCIES AMONG INDIVIDUAL COMPANIES

A comparison of harvesting efficiencies among the four logging companies is given in Figure 9 and Appendices XIV to XVIII. Within the logging companies, harvesting efficiencies of sample trees varied from 58 to 86 percent for the small-scale company, 43 to 90 percent for the medium-scale company, 61 to 98 percent for the first large-scale company and 67 to 97 percent for the second large-scale company. The group means (of the proportions of bole volumes that were extracted) also varied from 71 percent for the small-scale logger, 74 percent for the medium-scale logger, 80 percent for the first large-scale logger and 87 percent for the second large-scale logger. The overall average for all four logging companies was 79 percent. The standard errors of the sample means also ranged from 1.45 percent (for the second large-scale logger) to 3.10 percent (for the small-scale logger) and averaged 1.12 percent.

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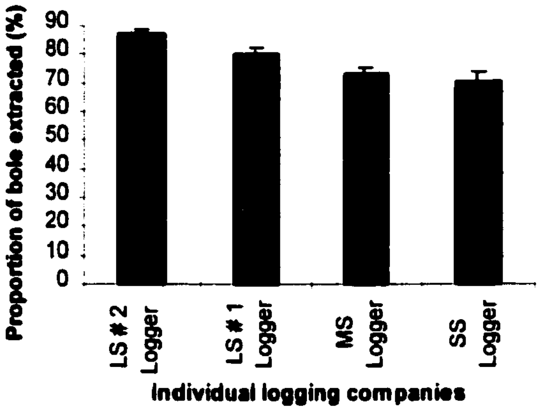

Figure 9. A comparison of harvesting efficiencies among the logging companies.

Clearly, harvesting efficiencies were highest in the second large-scale company, and followed by the first large-scale company, the medium-scale company and the small-scale company. Analysis of variance showed that there were significant differences in extraction efficiencies between the second large-scale company and the small-scale company ($P < 0.0005$), between the second large-scale company and the medium-scale company ($P < 0.0005$), and between the second large-scale company and the first large-scale company ($P < 0.005$). There were also significant differences between sample means of the first large-scale company and the small-scale company ($P < 0.009$), and the first large-scale company and the medium-scale company ($P < 0.013$). On the other hand, there was no significant difference in harvesting efficiencies between the medium-scale and the small-scale companies ($P > 0.427$).

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4.6 SAMPLE SIZE DETERMINATIONS

Estimates of optimum sample sizes and other ancillary details for the overall data set (with all sample trees pooled together) and for six individual species are presented in Table 7 and Appendices XIX to XXIV. For the overall data set, coefficients of variation (CV) ranged from 28 to 37 percent and 22 to 113 percent, respectively, for the mean diameters and mean lengths of the tree sections (or logging residue). This implies that 32 to 56 samples will be needed to estimate the means of the diameters of the tree sections, while 22 to 494 samples will be required to estimate the means of the lengths of the tree sections at an allowable error of ±10 percent and a confidence level of 95 percent.

For the individual species (Appendices XIX to XXIV), CV ranged from 19 to 28 percent, 13 to 24 percent, 12 to 21 percent, 10 to 22 percent, 24 to 36 percent and 13 to 32 percent, respectively, for the mean diameters of Niangon, Dahoma, Mahogany, Pterygota, Wawa and Avodire tree sections. This implies that 16 to 34, 9 to 25, 8 to 20, 7 to 22, 26 to 53 and 9 to 43 samples, respectively, will be needed to estimate the mean diameters of Niangon, Dahoma, Mahogany, Pterygota, Wawa and Avodire tree sections at an allowable error of ±10 percent and a confidence level of 95 percent. Furthermore, CV ranged from 16 to 72 percent, 18 to 47 percent, 14 to 216 percent, 16 to 53 percent, 20 to 79 percent and 20 to 245 percent, respectively, for the mean lengths of Niangon, Dahoma, Mahogany, Pterygota, Wawa and Avodire tree sections. This denotes that 13 to 200, 16 to 89, 11 to 1792, 13 to 113, 19 to 240 and 19 to 2308 samples, respectively, will be

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required to estimate the mean lengths of Niangon, Dahoma, Mahogany, Pterygota, Wawa and Avodire tree sections at an allowable error of ±10 percent and a confidence level of 95 percent. Generally, the results indicate greater sample size requirements based on mean lengths as compared to mean diameters of tree sections. This is a reflection of the substantially higher CV values associated with the estimation of the mean lengths of tree sections (or logging residue).

Table 7. Required sample sizes for the entire data set (inclusive of all sample trees).

Parameter	Summary Statistics			Number of	Samples Required	
	Mean (m)	SE (m)	CV (%)	Observations	$^*n_1$	$^*n_2$
Stumps						
Top diameter	0.91	0.03	35.52	100	51	25
Height	0.79	0.02	22.05	100	22	11
Butt-end offcuts						
Bottom diameter	0.91	0.03	35.52	100	51	25
Top diameter	0.98	0.03	27.62	100	32	16
Length	1.89	0.21	113.38	100	494	220
Extracted boles						
Bottom diameter	0.99	0.03	28.03	100	33	16
Top diameter	0.68	0.02	31.32	100	41	20
Length	21.10	0.67	31.71	100	42	20
Top-end offcuts						
Bottom diameter	0.68	0.02	31.32	100	41	20
Top diameter	0.69	0.03	37.35	100	56	27
Length	3.95	0.36	91.43	100	322	143

* n_1 = required sample sizes estimated at ±10 % allowable error and 95 % confidence level; and,
* n_2 = required sample sizes estimated at ±15 % allowable error and 95 % confidence level.

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4.7 MODELING TOTAL TREE VOLUME TO PREDICT TOTAL RESIDUE VOLUME

On the basis of the Furnival Index (FI), the best above-ground total tree volume model for the overall data set, was:

$$\mathrm{Ln}\,(TTV) = 0.625 + 0.903\,\mathrm{Ln}\,(EBV) \qquad [2]$$

($FI = 2.95$; $r = 0.96$; $r^2 = 0.91$; $SE = 0.19$; $n = 99$; $CF = 1.19$; $P < 0.00005$)

Where:

TTV = the above-ground total tree volume down to a 20 cm branch diameter limit,

EBV = the extracted bole volume,

Ln = natural (base *e*) logarithms,

0.625, and 0.903 are regression coefficients,

CF = correction factor for log-normal bias,

P = the observed significance *F* (probability) level,

r = correlation coefficient,

r^2 = coefficient of determination, and

all other variables are as previously defined.

Extracted Bole Volume (EBV) was selected over above-ground Total Residue Volume (TRV) as the independent variable because it had a higher partial correlation coefficient to above-ground Total Tree Volume (TTV). The partial correlation coefficient of EBV was 0.96 while that for TRV was 0.82. Norusis (1993) notes that the larger the absolute value of the correlation coefficient, the stronger the linear association. Thus, EBV correlates more highly with TTV than does TRV.

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The high correlation coefficient, r, value of +0.96 (close to +1) indicates a very strong, positive linear association between TTV and EBV. The very low significance *F* probability level ($P < 0.00005$) indicates that the regression is highly significant (i.e., not due to chance). The very low regression standard error value of 0.19 (close to zero) denotes that the above biomass model predicts the measured above-ground total tree volumes quite precisely.

Figure 10 presents the scatterplot of the residuals of the natural logarithm of the above-ground total tree volume equation for the full range of data. The plot shows that no systematic variations are exhibited by the residuals' variances. Thus, there is no sign of serious bias. The sample size was large enough to adequately define the above-ground total tree volume equation.

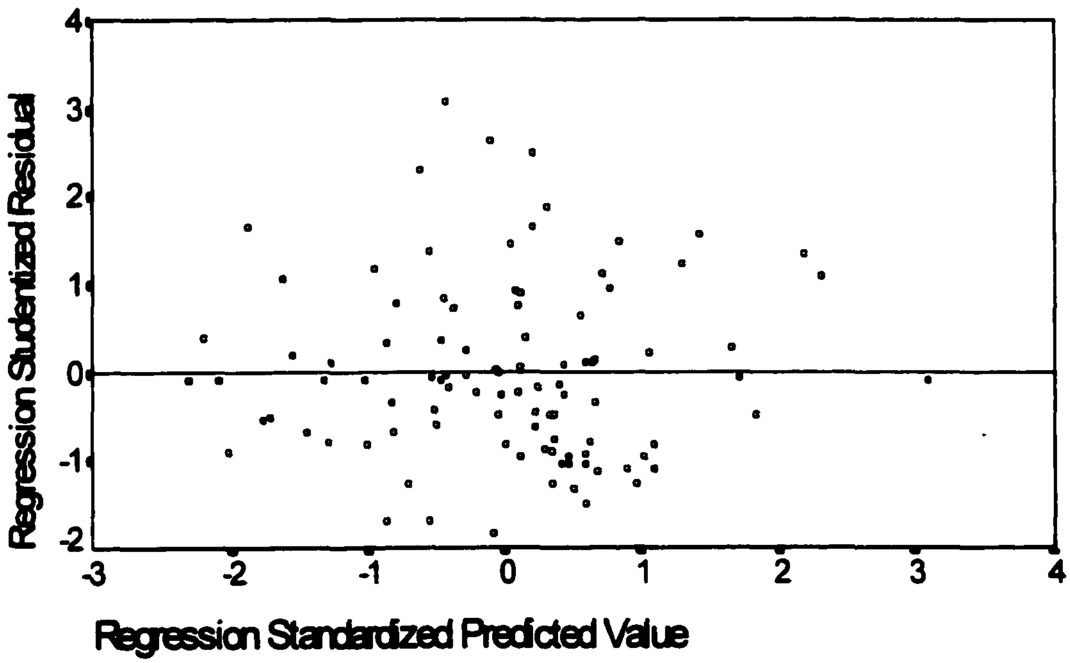

Figure 10. Scatterplot of the studentized residuals from the natural logarithm of the above-ground total tree volume equation against predicted values.

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Based on the Furnival Index, the best above-ground total tree volume models for individual species are presented below. No systematic variations were exhibited by the residuals' variances of these models. Hence, no signs of serious biases are associated with these biomass models.

Niangon:

$$\text{Ln (TTV)} = 0.399 + 0.946 \text{ Ln (EBV)} \qquad [3]$$

(FI = 1.29; r = 0.97; $r^2 = 0.94$; SE = 0.09; n = 15; CF = 1.07; $P < 0.00005$)

Dahoma:

$$\text{TTV} = 19.569 + 0.002 \text{ (EBV)}^3 \qquad [4]$$

(FI = 3.64; r = 0.76; $r^2 = 0.57$; SE = 3.64; n = 11; $P < 0.0071$)

Mahogany:

$$\text{TTV} = 14.359 + 0.001 \text{ (EBV)}^3 \qquad [5]$$

(FI = 0.52; r = 0.99; $r^2 = 0.99$; SE = 0.52; n = 7; $P < 0.00005$)

Wawa:

$$\text{TTV} = 1.782 + 1.524 \text{ EBV} \qquad [6]$$

(FI = 3.92; r = 0.98; $r^2 = 0.95$; SE = 3.92; n = 13; $P < 0.00005$)

Avodire:

$$\text{Ln (TTV)} = 0.499 + 1.027 \text{ Ln (EBV)} \qquad [7]$$

(FI = 0.86; r = 0.88; $r^2 = 0.78$; SE = 0.15; n = 12; CF = 1.04; $P < 0.0001$)

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4.8 LOCAL AND STANDARD VOLUME EQUATIONS

On the basis of the Furnival Index (FI), the best standard volume equation for the overall data set, was:

$$Ln (V) = 0.004 + 1.956\, Ln (D) + 0.828\, Ln (H) \qquad [8]$$

(FI = 2.17; R = 0.97; $R^2 = 0.94$; SE = 0.16; n = 100; CF = 1.21; $P < 0.00005$)

Where:

D = top diameter of butt-end offcut,

R = multiple correlation coefficient,

R^2 = multiple coefficient of determination, and

all other variables are as previously defined.

The top diameter of the butt-end offcut was selected over stump level diameter as an independent variable because it had a higher partial correlation coefficient to total bole volume. The partial correlation coefficient of the top diameter of the butt-end offcut was 0.88, while those for the stump level diameter and total bole height were 0.74 and 0.38, respectively.

The high multiple correlation coefficient (R) of 0.97 indicates an almost perfect positive linear association between the dependent and independent variables. The very low significance *F* probability level ($P < 0.00005$) indicates that the regression is highly significant. The very low regression standard error value of 0.16 (close to zero) denotes that the above regression model predicts total bole volume values quite precisely.

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Figure 11 presents the scatterplot of the residuals of the standard volume equation of the overall data set. The plot shows that no systematic variations are exhibited by the variances of the residuals. Thus, no sign of serious bias is associated with this model. The sample size (100 sample trees) was large enough to adequately define the standard volume equation.

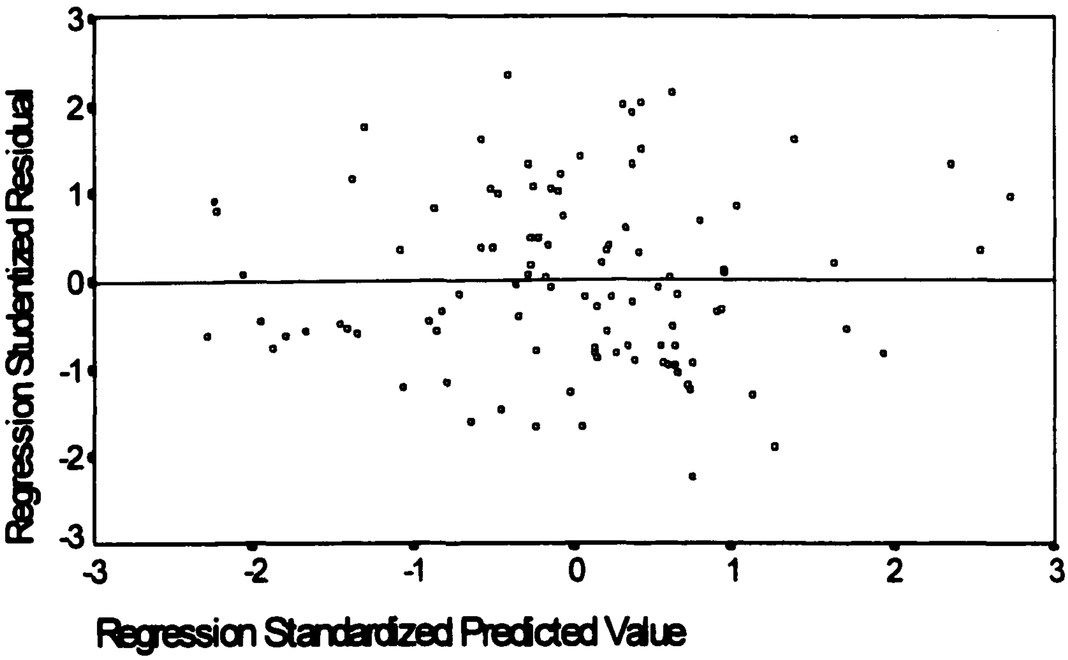

Figure 11. Scatterplot of the studentized residuals from the standard volume equation against predicted values.

The best local volume equation for the full range of data was determined to be:

$$V = 8.168 - 15.180\ D + 22.471\ D^2 \qquad [9]$$

(FI = 3.62; R = 0.97; $R^2 = 0.94$; SE = 4.17; n = 100; P < 0.00005)

Where the weight used in fitting the above model was D^{-2}.

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4.8.1 Local and Standard Volume Equations for Individual Species

Based on the Furnival Index, the best local and standard volume equations determined for the individual timber species are presented below. No systematic variations were exhibited by the residuals' variances of these models. Hence, no signs of serious biases are associated with these volume equations.

Niangon:

$$V = 2.600 + 0.402\ D^2H \qquad [10]$$

($FI = 0.49$; $r = 0.99$; $r^2 = 0.98$; $SE = 0.65$; $n = 15$; $P < 0.00005$)

Where the weight used in fitting the above model was D^{-4}.

$$V = -7.983 + 22.566\ D \qquad [11]$$

($FI = 1.52$; $r = 0.92$; $r^2 = 0.86$; $SE = 1.74$; $n = 15$; $P < 0.00005$)

Where the weight used in fitting the above model was D^{-2}.

Dahoma:

$$V = 4.551 + 0.465\ D^2H \qquad [12]$$

($FI = 1.50$; $r = 0.95$; $r^2 = 0.91$; $SE = 1.50$; $n = 11$; $P < 0.00005$)

$$V = 116.801 - 223.607\ D + 121.507\ D^2 \qquad [13]$$

($FI = 2.87$; $R = 0.83$; $R^2 = 0.69$; $SE = 2.87$; $n = 11$; $P < 0.0087$)

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Wawa:

$$V = 1.053 + 0.533\,D^2H \qquad [14]$$

($FI = 1.84$; $r = 0.998$; $r^2 = 0.996$; $SE = 2.22$; $n = 13$; $P < 0.00005$)

Where the weight used in fitting the above model was D^{-4}.

$$V = 28.152 - 59.350\,D + 48.404\,D^2 \qquad [15]$$

($FI = 4.66$; $R = 0.98$; $R^2 = 0.96$; $SE = 5.12$; $n = 13$; $P < 0.00005$)

Where the weight used in fitting the above model was D^{-2}.

Avodire:

$$V = 5.203 - 5.858\,D^2 - 0.298\,H + 0.909\,D^2H \qquad [16]$$

($FI = 3.18 \times 10^{-4}$; $R = 0.98$; $R^2 = 0.96$; $SE = 0.02$; $n = 11$; $P < 0.00005$)

Where the weight used in fitting the above model was D^{-12}.

$$V = 1.628 + 5.394\,D^2 \qquad [17]$$

($FI = 0.31$; $r = 0.72$; $r^2 = 0.52$; $SE = 0.60$; $n = 12$; $P < 0.0085$)

Where the weight used in fitting the above model was D^{-2}.

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Pterygota:

$$V = 38.976 - 32.583\,D^2 - 2.404\,DH + 2.788\,D^2H \qquad [18]$$

(FI = 0.027; R = 0.99; R^2 = 0.98; SE = 0.24; n = 6; P < 0.027)

Where the weight used in fitting the above model was D^{-12}.

$$V = -1.130 + 22.215\,D^2 \qquad [19]$$

(FI = 0.031; r = 0.98; r^2 = 0.95; SE = 0.27; n = 6; P < 0.0009)

Where the weight used in fitting the above model was D^{-12}.

Even though there were eight observations for Mahogany, models produced for this species proved to be statistically insignificant at the 95 percent confidence level. The observed significance probability level, in all 15 tested models for Mahogany, were more than 0.05. It appears that a larger sample size than eight observations are required to adequately define the relationships for the Mahogany sample trees.

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5.0 DISCUSSION

5.1 FOREST DISTURBANCE AND LOGGING DAMAGE

The survey indicated extensive logging (felling and skidding) damage to residual trees. Besides, tree felling, construction of access roads and loading bays resulted in large canopy openings. This appears to be a general trend. Armstrong-Mensah (1966) found about 10 percent of established trees to be damaged after normal selection felling in Ghana. Armstrong-Mensah (1966) and later, Ofori *et al.* (1993) reported that damage to residual trees was most severe in young trees of less than 50 cm diameter. Dawkins (1959) cites felling damage as a major constraint on the productivity of the selection system. The resultant large canopy gaps are rapidly covered by climbers, which tend to inhibit tree growth, and the remaining isolated trees are more liable to be blown down or to lose large branches during storms (Hall and Swaine 1981). Excessive canopy openings (e.g., forest roads, larger skid trails and loading bays) are detrimental to regeneration as they tend to have adverse effects on seed germination and seedling growth. It is also known that larger canopy openings promote rapid growth of relatively low-density timber, generally of low value (Swaine *et al.* 1997). Further, extensive canopy openings coupled with the creation of many dead trees and piles of slash make logged-over forests vulnerable to encroaching fires (Holdsworth and Uhl 1997; Swaine *et al.* 1997).

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Though logging appears quite destructive it has been shown that it could be used as a silvicultural treatment to induce forest increment (Maitre 1987). Some species (e.g., Wawa and Utile {*Entandrophragma utile* [Dawe & Sprague] Sprague}) actually regenerate better in logged forests than in undisturbed forests (Hawthorne 1989). Even though seedlings and saplings may recover from logging damage, larger trees often sustain permanent damage (Ofori *et al.* 1993).

Felling and/or skidding injury to residual trees are known to be the source of infection and fungous decay (Wright and Isaac 1956; Shigo 1966; Wallis *et al.* 1971; Aho *et al.* 1983) and ultimately a lowering of wood quality and thereby a decrease in wood value. This calls for formal training of chain saw and skidder operators. The foregoing also emphasizes the need for more closely controlled harvesting methods or the so-called Reduced Impact Logging (RIL). RIL embraces a host of improved road-building, felling and extraction practices. These practices include climber cutting and directional felling. Additional tools such as wedges and winches can be used to manipulate the fall of the tree in the desired direction. Directional felling facilitates log extraction, minimizes damage to the log and also minimizes damage to the residual stand (Klasson and Cedergren 1996). The RIL methods should include control of the distribution of felled trees, and increase an in the proportion of small skid trails relative to large skid trails and extraction roads. Swaine *et al.* (1997) argued for methods that distribute felling disturbance evenly over the forest so that more surviving trees can benefit from reduced competition and the detrimental effects of large openings are reduced.

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In 1992, Ghana's Forest Services Division introduced a logging manual as a statutory code of practice for planning and management of timber harvesting operations. This logging manual was issued to promote sound harvesting techniques which minimize environmental damage to the residual stand, reduce wastage during extraction and improve the regenerative capacity of the forest. Though the manual (which has since been revised in 1998) embraces many of the RIL methods, it is clear that its implementation and enforcement have not been thorough enough.

5.2 SOURCES AND CAUSES OF LOGGING RESIDUE

In terms of quantity, it would appear that efforts at residue reduction and/or residue utilization would have to be concentrated on crown wood. In terms of quality, however, efforts at residue reduction and/or residue utilization would have to be concentrated on butt-end offcuts and stump wood. In spite of their associated defects, butt-end offcuts and stumps contain the most mature wood and the greatest proportion of heartwood in the bole (Wackerman *et al.* 1966; Jozsa and Middleton 1994). Hence, good quality wood can still be recovered from these two sources of residue.

The term *defect*, as applied to wood, refers to any irregularity or deviation from the qualities that make wood suitable for a particular purpose. Normally, the presence of a defect in wood is a detriment and causes a loss in value (Panshin and de Zeeuw 1980). The preponderance of natural defects in logging residue is

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indicative that logging residue is of lower quality than normal extracted wood. The lower quality and the relatively small sizes of crown wood imply that lower rates of recovery would be achieved from logging residue. Nevertheless, logging residue is capable of being utilized for the manufacture of by-products for the domestic market, if not for the export market.

It was realized that some appreciable amount of wood could have been recovered from virtually all the logging residue except the Ofram tree in which the heart rot cavity constituted more than 50 percent of its bole volume. In Ontario, Canada, for instance, a log is considered a cull if and only if more than one-half of its volume is defective (OMNR 1976, 1995). Timber companies in Ghana will need to be re-orientated to adopt and implement such a viewpoint during their normal commercial harvesting and milling operations. Further, the companies must be obligated to have in place feasible plans for recovering and utilizing logging residue from their areas of operation. Thus, legislation could be enacted obliging loggers to extract all logs over 2 m long, over 20 to 30 cm diameter and of at least 50 percent sound volume. This is essential since most of the residue, especially that from perishable species (e.g., Wawa, Avodire, Pterygota, Ilomba and Ogea) deteriorates by the time other interest groups gain rights to logged-over forests. For instance, at the time of the survey some of the Wawa logging residue were already developing worm holes due to insect attacks. Meanwhile, Wawa alone contributes about 30 to 40 percent of the annual volume of log production in Ghana. Therefore, to wait for up to three years when an annual felling coupe would be closed and then re-

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allocating these logged-over compartments to those interested in wood residue would mean that over 40 percent of the logging residue would have deteriorated beyond recovery. In any case, two-stage operations (i.e., re-entry of logged-over forests before the beginning of the next rotation or felling cycle) has been noted to be particularly harmful (Fox 1969; Burgess 1971) and is therefore not recommended.

Implementation of the plan for recovering and utilizing logging residue must necessarily have to be enforced by Ghana's Forest Services Division and backed by prescribed sanctions, in order to ensure compliance by authorised logging companies. In the case of the Ofram tree which could genuinely be described as a cull, the tree should not have been felled in the first place since the heart rot cavity was clearly visible in the crown-end. Such trees could also be easily identified by the hollow sound that they produce upon the impact of a cutlass on the bole. Felling of such trees, which are eventually discarded enmasse, not only results in damage to the residual stand but also constitutes loss of potential seed trees. Similarly, felling of the fluted Wawa tree was uncalled for since almost 25 percent of the bole volume was discarded in the form of a long butt-end offcut. Felling of this tree not only constituted loss of a potential seed tree, but it also resulted in damage to the residual stand and a nearby cocoa farm.

Apart from natural defects, logging residue generation also resulted from inappropriate felling and bucking methods. It was realized that bucking was usually done over and beyond the convergence point of the buttresses. This often resulted

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in long butt-end offcuts and/or high stumps. For instance, butt-end offcut lengths ranged up to 10.10 m and averaged 1.89 m (Appendix IV). Besides, bucking frequently ended far from the crown point leaving behind long crown-end sections. Thus, crown-end offcut lengths ranged up to 14.90 m and averaged 3.95 m (Appendix VI).

It is known that felling causes sudden release of growth stresses in green trees resulting in heart shakes or cracks, brittle heart, compression failures, and end-splits in standing trees and felled trees (Panshin and de Zeeuw 1980; Kubler 1987; Mattheck and Walther 1992). If a tree is not notched during felling or if the felling notch is too small, the bending moments introduced by the small uncut ligament (hinge) into the falling tree also causes end-splits in the bole (Mattheck and Walther 1992). This demands that appropriate felling techniques must be used to minimize felling defects and thereby residue generation.

The forgoing shows the need for specialised training. This is emphasized by several studies which reported 73 to 300 percent reduction in residue associated with felling and bucking when well-trained operators were used in logging (Gerwing *et al.* 1996; Uhl *et al.* 1997; Winkler 1997). In addition to volume loss due to poor felling and bucking techniques, there can also be significant value and/or quality losses of felled trees (Wackerman *et al.* 1966; Vaughan and Biddle 1987; Pulkki 1998). Cross-cutting training programs have also shown that log values can be increased by 10 to 50 percent (Dykstra and Heinrich 1996). Thus, logger training is a key factor in reducing logging residue and value loss.

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5.2.1 Manpower and Training

In Ghana, just as in most tropical countries, a major constraint in the forestry sector is insufficient manpower training, especially at the vocational and technical levels of personnel. Formal training of forest workers (e.g., tree fellers, chain saw operators and skidder operators) is hardly done in Ghana. New operators learn from older ones thus perpetuating bad working methods and habits. Since the lack of trained manpower is one of the main constraints in logging operations in developing countries, special consideration will need to be given to training logging personnel at all levels (FAO 1985). Fortunately, the recently established Wood Industries Training Centre (WITC) has started offering short-term courses in *logging*.

5.3 VOLUME ESTIMATION

The sample average sectional volumes were 0.59 m^3 (stumps), 1.50 m^3 (butt-end offcuts), 13.30 m^3 (extracted boles), 1.28 m^3 (crown-end offcuts) and 2.82 m^3 (branch wood). The corresponding percentage distributions were 3.20 percent (stumps), 6.55 percent (butt-end offcuts), 68.18 percent (extracted boles), 7.96 percent (crown-end offcuts), and 14.11 percent (branch wood) (Tables 2 and 3 and Appendices IX and X). This indicates that for every 1 m^3 of extracted boles (or extracted logs), about 0.47 m^3 of residue was discarded in the forest in the form of stumps, offcuts and branches. If the volume of wood extracted per tree could be increased, it would mean harvesting fewer trees from the forest to meet a given market demand. This should result in reduced logging damage, increased reserve

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stock and enhance sustained yield management. At all the logging sites, only wood from boles were extracted during normal commercial harvesting operations. In particular, no branches were extracted even though many of these branches were of sawlog sizes. This appears to be the general logging practice in Ghana. Similar observations were made by Ofori *et al.* (1993). The foregoing is an indication of inefficient utilization of the timber resources of Ghana. This calls for improved logging practices to reduce residue generation and emphasizes the need for the adoption of enforceable and feasible plans to utilize the inevitable logging residue for other uses.

Comparing the manual and mechanical methods of logging, Armstrong-Mensah (1975) estimated that when using hand tools about 20 percent (sic) of the average standing tree volume was left in Ghanaian forests as residue, whereas with the introduction of chain saws, this residue was effectively reduced to about 10 to 15 percent (sic). However, this statement of opinion was not based on any quantitative data. These figures grossly underestimated logging residue generation in Ghana and they do not agree with the results of the present study. At the other extreme, Nketiah (1992) and Ofori *et al.* (1993) estimated logging residue generation in Ghana to be 50 percent and 52 percent of the above-ground total tree volume, respectively. Comparatively, these estimates are higher than the results of the present study. Otoo (1978), Faakye (1988) and Ofori *et al.* (1993) further estimated that on average 63 percent (small-scale logger), 78 percent (large-scale company), and 71 percent (3 medium-scale companies) of the total bole volume were extracted

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as logs during commercial harvesting operations. These results confirm that there are large differences in harvesting efficiencies among the different categories of logging companies.

Generally, these results and those of the present study indicate that recovery rates and harvesting efficiencies have been increasing over the years. This may be ascribed to the periodic upward reviews of royalty (stumpage) rates and other forestry levies. For instance in 1994, concession rents and royalties were increased with royalty rates being fixed as a percentage of the free-on-board (FOB) timber prices (Forest Fees [Amendment] Regulations, 1993 [L.I. 1576]; MLF 1996d). The new royalty rates (for the first time in the history of Ghana) reflected the market values of the species and thus they could be readily adjusted to take care of inflation, price and currency fluctuations. It is certain that the resultant increase in raw material costs has compelled the logging companies to increase their efficiencies considerably. Hence, the relatively low logging residue estimates indicated by the present study. It ought to be mentioned, however, that bole volume data from the previous studies were re-evaluated on the same scale in order to afford a uniform basis for comparison.

5.3.1 Stump Residue

For the individual sample trees, stump heights varied from 0.30 to 1.30 m and averaged 0.79 m (Appendix III). The minimum recorded stump height of 0.30 m is indicative that further efforts can be made to reduce stump heights to possibly lower

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than 0.30 m. It is worthy of mention that in North America, the standard maximum stump height is considered to be 0.30 m. Gerwing *et al.* (1996) suggested that for non-buttressed tropical timber trees, stump heights need not be higher than 0.20 m.

Stumps can be used to manufacture utility grade lumber (Chryssides 1974), highly figured and valuable veneer (Panshin and de Zeeuw 1980), fibreboard and pulp (Kantola 1966; Keays 1971), partition walls, drawing boards, doors and furniture (Balachandra 1988), carvings, fuelwood, and charcoal.

Though several equipment have been developed for extracting stumps (Kantola 1966; Hakkila 1971; Hakkila and Makela 1973; Koch 1974; Young 1978; Haygreen and Bowyer 1996), I do not advocate the adoption of this technology in Ghana. The stump-root system helps to maintain soil fertility by recycling nutrients through decomposition of dead wood. It also prevents erosion of topsoil due to excessive run-off. Though Ghana's tropical forest trees, in general, show little capacity for vegetative reproduction (Hall and Swaine 1981), some species such as Niangon and Abura have the capability to coppice from the stump-root system (Mbrayeh, pers. comm. 1998). Such re-sprouting is important as a means of vegetative reproduction, or at least replacement of harvested timber.

5.3.2 Butt-end Offcuts

Generally, the occurrence and extent of defects (e.g., high buttresses, heart rot and splits), the rarity and commercial value of species, and the skill of chain saw operators (tree fellers and bole buckers) determined the extent of offcuts. Individual

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butt-end offcut volumes ranged up to 18.40 m^3 and averaged 1.50 m^3 (Appendix IV). Therefore, the indication is that modest volumes of wood can be recovered from the resultant long butt-end offcuts. Chainsaws can be used to trim off the buttress flanges so that the remaining wood can be utilized. Apart from lumber, butt-end offcuts can also be utilized to produce wood-based panels, veneer, woodfuel and carvings. Species which are useful for producing carvings include Mahogany, Walnut, Odum (*Milicia excelsa* [syn. *Chlorophora excelsa* Benth. & Hook. F.]), Edinam (*Entandrophragma angolense* [Welw.] C. DC.), Niangon, Mansonia (*Mansonia altissima* [A. Chev.] A. Chev.) and Afrormosia.

5.3.3 Crown-end Offcuts and Branch Wood

Apart from some Mahogany and Makore trees, of which virtually all of the main bole up to and including the crotches were extracted, bucking usually ended far from the crotch thus leaving behind long crown-end offcuts. The crotches are normally utilized to produce curls from which decorative sliced veneers are manufactured. Panshin and de Zeeuw (1980) defined a crotch as the portion of the bole at the junction of a major fork. They further reported that the twisted grain in large crotches or forks, and stump swells, especially in trees that produce ornamental timber, yields highly figured and valuable veneers. The Ghana Gazette (1998) confirms that the decorative sliced veneers, produced from curls, are highly prized by furniture and panel manufacturers. Apart from Mahogany and Makore, other timber species in Ghana from which curls (and ultimately decorative sliced

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veneers) are produced are Avodire, Utile, Sapele (*Entandrophragma cylindricum* [Sprague] Sprague), Walnut and Aningeria (*Aningeria altissima/robusta* [A. Chev.] Aubrev. & Pellegr.).

Crown-end offcut volumes ranged up to 5.95 m^3 and averaged 1.28 m^3. Besides, most of the sample trees contained "merchantable" branches. Individual tree branch wood volumes ranged up to 15.12 m^3 and averaged 2.82 m^3. Indeed, some of these branches had diameters and lengths which were greater than some of the extracted logs (Appendices VIII and IX). For instance, some of the branches were over 100 cm in diameter and over 10 m in length.

Thus, greater use of crown wood will offer a substantial source of additional wood for pulping, wood-based panel products, lumber, veneer, fuelwood and charcoal production. However, crown wood is of inferior quality to the normal wood in most wood uses. This is ascribed to the increased amounts of tension wood and juvenile wood in crown wood. Generally, juvenile wood has structural characteristics and physical properties that are inferior to those in the mature wood of the same tree. This is evident in the chemical composition of the cell walls (i.e., lower cellulose and higher lignin contents), shorter cell lengths, larger fibril angle, lower density and lower tensile strength. The generally poor properties of juvenile wood in relation to normal mature wood makes such wood undesirable for structural uses and precludes their use for some other purposes. This is due primarily to the excessive longitudinal shrinkage with the consequent warping of lumber sawn from the juvenile wood portion of the tree. Generally, however, the low quality of juvenile

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wood and reaction wood (i.e., tension wood or compression wood) is more pronounced in conifers than in hardwoods (Bendtsen 1978; Panshin and de Zeeuw 1980; Yang 1987a, 1987b; Jozsa and Middleton 1994).

A further disadvantage of crown wood is the higher sapwood to heartwood proportion. Generally, sapwood is less durable than heartwood of the same species. The greater durability of heartwood is attributable largely to the presence of a wide variety of toxic extraneous materials such as essential oils, tannins and phenolic substances. When these materials are present in sufficient quantity or toxicity, they may prevent or at least considerably minimize the severity of the attack by destructive organisms. On the other hand, the presence of stored food in sapwood may increase its susceptibility to decay, and particularly to bacteria and fungal staining. Insects and fungi often attack sapwood because of the presence of reserve food in the parenchyma cells. Other factors that may also explain the greater durability of heartwood are its lower moisture content, its lower rate of diffusion, and the blocking of cell cavities by gums, resins, tyloses in vessels and tyloids in the resin canals. Any of these might adversely affect the balance between air and water necessary for the growth of fungi (Panshin and de Zeeuw 1980; Jozsa and Middleton 1994). Therefore, utilization of perishable wood in general, and sapwood in particular, demands preservative treatment prior to usage.

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5.4 HARVESTING EFFICIENCIES AMONG DIFFERENT TIMBER SPECIES

The observed differences in harvesting efficiencies among the timber species were not unexpected and may be attributed to a variety of reasons. Harvesting efficiencies were lowest in Ofram, Wawa, Pterygota and Dahoma, due to high stumps, and extremely long butt-end and crown-end offcuts. The presence of large buttresses (all four species), higher sapwood proportion in the crown wood (Wawa and Dahoma), heart rot (Ofram, Wawa and Pterygota), fluting and splits (Wawa), and contract restrictions (Pterygota), were some of the causes for the lower harvesting efficiencies. It is officially acknowledged by Ghana's Forest Services Division that Wawa, Dahoma, Pterygota and three other species have a high incidence of defects in over-mature trees and large-sized boles. Compared to the overall average stump height of 0.79 m, the average stump height in Ofram, Wawa, Pterygota and Dahoma were 0.78 m, 0.78 m, 0.83 m and 0.85 m, respectively. Similarly, the average butt-end offcuts length in these species were 4.06 m, 4.02 m, 3.82 m and 3.60 m, as compared to the overall average butt-end offcuts length of 1.89 m. Furthermore, compared to the overall average crown-end offcuts length of 3.95 m, the average crown-end offcuts length in Ofram, Wawa, Pterygota and Dahoma were 10.98 m, 5.51 m, 9.93 m and 1.93 m, respectively. Such large proportions of logging residue might have also been the consequences of the inefficiencies of the tree fellers and buckers (particularly those from the small-scale and medium-scale companies), and/or undulating terrain (Ofram, Wawa and Pterygota), resulting in high stumps and long offcuts.

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Due to quite different reasons, the harvesting efficiency in Ayan was among the lowest. As a result of minimal buttressing, stump heights in Ayan were relatively low and averaged 0.68 m. Further, due to minimal buttressing there was no butt-end offcut in one out of the two Ayan sample trees. Butt-end offcut in the other Ayan tree was occasioned by the presence of heart rot. However, due to the relatively short bole length of the Ayan sample trees only one to two logs per bole were extracted leaving behind quite long crown-end offcuts. The average of the total bole length of Ayan sample trees was 23.93 m, which was shorter than the overall average bole length of 27.74 m. Thus, the average crown-end offcuts length of 5.20 m, with a diameter range of 53 to 70 cm. This represented a substantial proportion (17 percent) of the bole volume of Ayan sample trees, hence the low harvesting efficiency.

The low harvesting efficiencies in Ofram, Wawa, Pterygota, Ayan and Dahoma, may also be ascribed to their relative abundance and/or low commercial value which were such that little attention was paid to residue reduction. Other abundant timber species in Ghana are Ceiba, Celtis (*Celtis mildbraedii/zenkeri* Engl.), Guarea, Avodire, Danta and Ilomba. Conversely, Makorẹ, Mahogany, Walnut, Odum, Afrormosia, Black Hyedua (*Guibourtia ehie* [A. Chev.] J. Leonard) and Edinam are among the rare timber species in Ghana. Other low value timber species in Ghana are Ogea, Ceiba and Ilomba. On the other hand, Pterygota, Avodire, Niangon, Danta, Walnut, Mahogany, Makore, Odum, Aningeria, Sapele,

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Afrormosia, Utile, Edinam and Afzelia are noted to be among the higher value timber species in Ghana (Alder 1989; Ghartey 1989; FPIB 1998).

Harvesting efficiencies in Avodire, Niangon and Danta were quite low due to a number of reasons. As a result of minimal buttressing and in some cases no buttresses, stump heights in Avodire were the shortest and averaged 0.56 m. Further, due to minimal buttressing or no buttresses, there were no butt-end offcuts in 10 out of the 12 Avodire sample trees. Butt-end offcuts in the remaining two Avodire sample trees were the shortest, thus making the average butt-end offcuts length to be as low as 0.05 m. This might have also been due to the fact that Avodire is among the commercially most expensive timber species in Ghana, thus considerable efforts were made to minimize residue generation. However, due to the short stature and therefore the short bole lengths of the Avodire trees, only one to two logs per bole were extracted, leaving behind relatively short crown-end offcuts. In particular, the average of the total bole lengths of Avodire sample trees was 13.86 m. This was the shortest average bole length among all the sample tree species. Thus, the relatively short average crown-end offcuts length of 3.02 m, with a diameter range of 42 to 114 cm, constituted a high proportion (16 percent) of the average bole volume of Avodire sample trees. Hence, the apparent quite low extraction efficiency of Avodire. It must be mentioned, though that the crotch of Avodire could have been utilized to produce highly-prized curls and ultimately decorative sliced veneer.

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The quite low harvesting efficiency in Niangon was due to a combination of factors. The presence of large buttresses in Niangon and hilly terrain resulted in high stumps and long butt-end offcuts. However, crown-end offcuts were relatively short probably because Niangon is among the commercially most valuable timber species in Ghana. Average stump height, average butt-end offcuts length and average crown-end offcuts length in Niangon were 0.88 m, 2.04 m and 3.06 m, respectively.

Despite the presence of large buttresses in Danta, stumps were moderately high (averaging 0.75 m) and butt-end offcuts were relatively short (averaging 1.0 m). These might have been due to the fact that Danta is among the most valuable commercial timber species in Ghana. Nonetheless, crown-end offcuts were quite long and averaged 5.85 m. The quite long crown-end offcuts in Danta might have been due to the wider sapwood proportion in the crown wood and/or the inefficiencies of the workers of the medium-scale company that harvested this species. All the above-stated factors probably contributed to the relatively low harvesting efficiency in Danta.

Large buttresses in Walnut resulted in high stumps. However, despite the presence of large buttresses, there was only one butt-end offcut out of three sample trees. Besides, crown-end offcuts were quite short. These might be attributable to the fact that Walnut is one of the rarest and commercially most valuable timber species in Ghana. Average stump height, average butt-end offcuts length and

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average crown-end offcuts length in Walnut were 0.86 m, 0.63 m and 1.93 m, respectively. Thus, harvesting efficiency in Walnut was quite high.

Though there are no buttresses in Fotie and no buttresses or minimal buttressing in Ogea, stumps were moderately high and averaged 0.78 m for Fotie and 0.75 m for Ogea. Further, due to the absence of buttresses or minimal buttressing, there were predictably no butt-end offcuts for these two species. Furthermore, crown-end offcuts were relatively short and averaged 3.17 m for Fotie and 2.75 m for Ogea. Thus, even though Fotie and Ogea are not among the rare and commercially most expensive timber species in Ghana, their harvesting efficiencies were quite high.

Harvesting efficiencies were highest in Ilomba, Mahogany, Makore and Afzelia. Though there is minimal buttressing in Ilomba, stumps were moderately high and averaged 0.74 m. Predictably, there were no butt-end offcuts in this species due to minimal buttressing. However, crown-end offcuts were relatively long and averaged 5.53 m. The moderately high stumps and the relatively long crown-end offcuts were perhaps due to Ilomba being of low value and one of the most abundant commercial timber species in Ghana. Nonetheless, the relatively long crown-end offcuts represented just 5.85 percent of the total bole volume. This was because of the extremely long total bole lengths (average of 35.44 m) and the small-sized crown-end diameters which ranged between 28 cm and 51 cm.

Owing to large buttresses, stumps in Mahogany were very high and averaged 0.89 m. However, despite the presence of large buttresses, there were no butt-end

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offcuts in six out of the eight Mahogany sample trees. This may be attributed to the fact that Mahogany is one of the rare and commercially most valuable timber species in Ghana. For this same reason, there were no crown-end offcuts in four out of the eight Mahogany sample trees. Even so, three out of the four crown-end offcuts were very short. Where there were no crown-end offcuts, the entire crown-end wood including the crotches were extracted. Thus, average butt-end and crown-end offcuts lengths in Mahogany were 0.63 m and 1.39 m, respectively.

As a result of minimal buttressing, stumps in Makore were relatively low and averaged 0.70 m. Further, due to minimal buttressing there were no butt-end offcuts. However, due to a serious heart rot defect (Figure 7), there was a crown-end offcut in one out of the two Makore sample trees. In the other sample tree, the entire crown-end wood including the crotch was extracted. Just as in the case of four of the Mahogany sample trees, the extracted crotch would be used to produce curls from which decorative sliced veneers would ultimately be manufactured. Another reason for less residue generation, and therefore the high harvesting efficiency in this species, is the fact that Makore is one of the rarest and commercially most valuable timber species in Ghana.

Although there is minimal buttressing in Afzelia, stumps were very high and averaged 0.90 m. Such high stumps in the face of minimal buttressing, might have been the result of inefficiencies of the tree fellers of the second large-scale company and/or the decision not to effect any butt-end offcuts. Thus, as a result of the minimal buttressing, there were no butt-end offcuts in this species. In addition,

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crown-end offcuts were very short and averaged 0.88 m, despite the relatively short average bole length of 22.78 m. The extremely short crown-end offcuts might have been due to the fact that Afzelia is among the most valuable timber species in Ghana. Thus, harvesting efficiency in Afzelia was among the highest in this study.

5.5 HARVESTING EFFICIENCIES AMONG INDIVIDUAL COMPANIES

The observed differences in harvesting efficiencies among the logging companies may be attributed to a number of reasons. Harvesting efficiencies were higher in the large-scale and the medium-scale companies because they had their own processing mills and therefore extracted as much wood as possible without being unduly concerned about the quality of logs. These companies also had adequate equipment and machinery holdings, including many haul trucks, to facilitate their logging operations.

On the other hand, the small-scale company did not own a processing mill and was therefore engaged solely in logging and log sales. Consequently, this company endeavoured to obtain higher quality logs and thereby premium log prices by offcutting most defects. Further, due to contract restrictions, this company was generating extremely long crown-end offcuts. For example, their forest operations manager indicated that their sales contract specified a minimum diameter of 60 cm for Pterygota veneer logs. The corollary of this contract restriction was that all Pterygota logs less than 60 cm diameter (in the crown-end) had to be discarded since the company did not have any use for them. These logs could have been

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extracted if the company possessed its own sawmill. Indeed, it took the prompting of the author before a Pterygota log (with dimensions 8.30 m x 0.65 m x 0.55 m) was extracted from the crown-end. Paradoxically, Pterygota is one of the high value timber species in Ghana (FPIB 1998). It is also one species in which there is little distinction between the sapwood and the heartwood (GTMB 1969; Chudnoff 1984). Thus, the long crown-end offcuts of Pterygota could have been utilized. At least, such logs from the crown-end could have been sub-contracted to a mill for customised production of lumber, veneer and/or profile boards. These products could have then been sold, at least on the domestic market, for housing construction, furniture and cabinet manufacture.

Further, the small-scale company lacked sufficient equipment and machinery holding. For instance, it did not have sufficient haul trucks or enough financial resources for transporting logs from the forest on a regular basis as was the case in the larger companies. This problem was compounded by higher transportation costs. Whereas logs of the small-scale company had to be transported over 160 km to the buyers, the other three companies had to transport their logs to their mills covering distances of just about 40 km, 60 km or 130 km. Hence, the small-scale logger tended to keep its extracted logs much longer in the forest before transporting them to the mills or market centres. Such logs, especially the perishable ones, left at the vagaries of the weather were liable to deterioration, and insect and fungal attacks. Moreover, all the larger companies owned front-end loaders (Figure 12), and thus could easily load logs with crook or sweep onto haul trucks. However, the

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small-scale company used ordinary tractors to roll logs on planks onto trucks (i.e., ramp loading). Consequently, this company often abandoned crooked logs in the bush due to difficulty of loading. It would seem that such inefficiencies could be averted if the Government of Ghana could assist timber companies to secure loans to enable them to acquire suitable equipment.

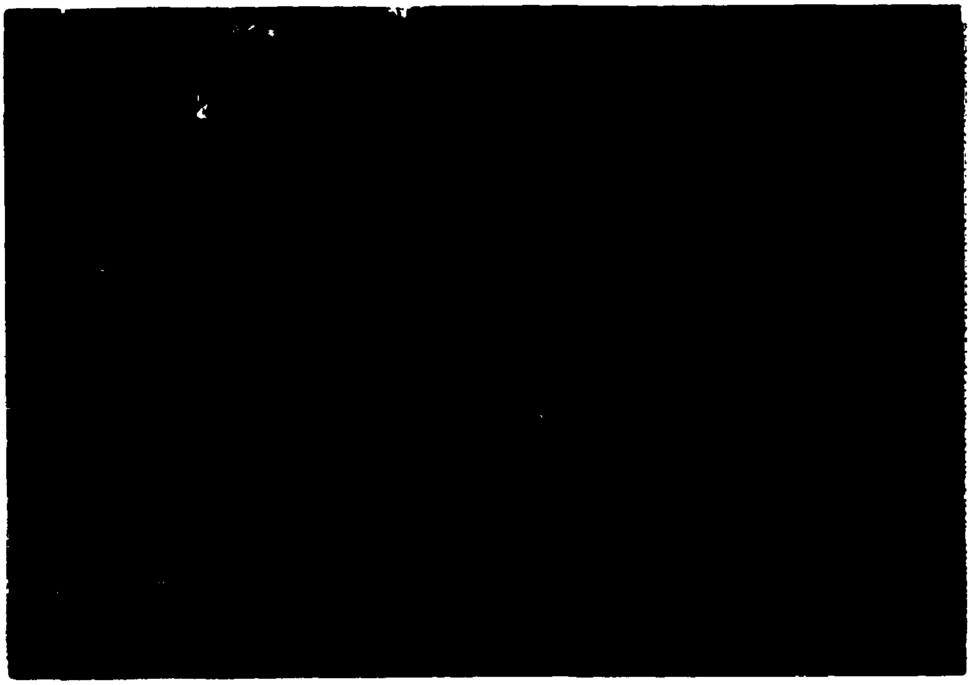

Figure 12. Front-end loader loading extracted boles onto a haul truck.

Moreover, the large-scale companies were more efficient than the medium-scale and the small-scale companies because they had more financial resources and therefore offered better remuneration packages to attract better qualified and more skillful manpower. Hence, their workers were more efficient.

However, in virtually all of the species which were commonly harvested by both companies, the second large-scale company was clearly more efficient than the

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first large-scale company. For instance, the harvesting efficiencies of the second large-scale company for Niangon, Dahoma and Mahogany were 87 percent, 75 percent and 94 percent, respectively. On the other hand, the harvesting efficiencies of the first large-scale company for these species were 81 percent, 69 percent and 81 percent, respectively. This outcome was very surprising since the first large-scale company is more highly integrated and it utilizes wood residue to generate its own electrical power. Perhaps, this company relies more on its sawmill and plymill residue for power generation. It would appear that the first large-scale company was less efficient because it had felling rights over such large forest concessions, that it probably had less incentive to improve its efficiency. In fact, the first large-scale company is reputed to possess timber rights over one of the largest forest concessions in Ghana. It is expected that such tendencies would be checked by the proposed competitive bidding of timber rights, under the soon to be implemented Timber Resources Management Act, 1997 (Act 547).

As previously noted, the results indicated a slight but statistically insignificant difference between the harvesting efficiencies of the medium-scale company and the small-scale logger. Probably, the medium-scale company is just as inefficient as the small-scale logger. This may be ascribed to the recent transition of the medium-scale company from the status of a small-scale logger into a logging and a sawmilling company. In particular, the medium-scale company was responsible for harvesting of the discarded Ofram tree in which over 50 percent of the bole volume was covered by heart rot cavity, the severely fluted Wawa tree and another Wawa

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tree with extensive heart rot. Indeed, the butt-end offcut lengths of 9.0 m (fluted Wawa tree) and 10.10 m (heart rotted Wawa tree) were the longest in the study. These two butt-end offcuts represented 23 percent and 41 percent, respectively, of the bole volumes of the fluted and heart rotted Wawa trees. Thus, the proportion of the extracted bole volume in this heart rotted Wawa tree (43 percent) was the lowest in the study. These two severely defective Wawa trees were removed from the analysis, but the result still indicated a non-significant difference in harvesting efficiencies between the medium-scale company and the small-scale logger.

Evidently, there were interactions between the harvesting efficiences of the timber species and the harvesting efficiences of the logging companies. For instance, all trees of Pterygota in the study were harvested by the small-scale logger. All species of Ofram and Danta were extracted by the medium-scale company. All trees of Wawa were harvested by the medium-scale company and the small-scale logger. Thus, it is probable that the inefficiencies of these two companies would have adversely impacted on the harvesting efficiencies of these species. On the other hand, all species of Ayan, Dahoma, Niangon, Walnut, Fotie, Ogea, Ilomba, Mahogany, Makore and Afzelia were harvested by the large-scale companies. Therefore, it is probable that the higher efficiencies of these companies would have positively impacted on the harvesting efficiencies of these species. The reverse could also have been true whereby the inefficiencies of some of the species (e.g., Ayan and Dahoma) could have adversely impacted on the harvesting efficiencies of these large-scale companies. The effects of such interactions could

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have been minimized by larger data sets of individual species across the full spectrum of logging companies.

5.6 SAMPLE SIZE DETERMINATIONS

The results in Table 8 and Appendices XIX to XXIV show that, for the estimated means of diameters of the tree sections, coefficients of variation (CV) ranged from 10 to 37 percent. Further, for the estimated means of the lengths of tree sections (or logging residue), CV ranged from 14 to 245 percent.

The coefficient of variation puts the degree of variability of parameters (e.g., diameter or length) on a comparable basis. Usually, the CV of forest trees is approximately 100 percent (Freese 1962). The higher CV values associated with lengths of tree sections is an indication of the high degree of variability in the lengths of the various offcuts (or residue) from the sample trees. These higher CV values emanate from zero values recorded in the butt-end and crown-end offcuts where no offcuts were made. They may also be attributed to greater variation in the lengths of actual offcuts (or residue) which in turn were dictated by the high degree of variability in the nature and extent of defects necessitating offcutting.

Results of sample surveys are always subject to some uncertainty because only part of the population has been measured and due to errors of measurement. This uncertainty can be reduced by taking larger samples and by using superior instruments of measurement. Since this usually costs time and money, the degree of precision desired in the results has to be specified (Cochran 1977). As in the

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case of this study, there is bound to be a problem when several measurements are taken from each sampling unit. Some parameters, and therefore some measurements, are bound to be more variable than others. The higher CV values, based on the mean lengths of the tree sections, necessitates the collection of more samples. In this case, the best basis for sample size determination will be sampling at an intensity high enough to estimate the mean of the most variable parameters at the desired precision. This is consistent with the findings of Freese (1962), that the reliability of sample estimates increases with increases in sample sizes.

In practice, the requirement of a larger sample size makes sampling surveys not only more costly but more difficult. However, Cochran (1977) notes that too small a sample size will result in a reduction of precision and thus diminish the utility of the results. Albeit, the number of samples may be reduced by decreasing the confidence level (e.g., from 99 percent to 90 percent) and/or increasing the desired allowable error from say ±10 percent to ±20 percent.

For practical purposes, it seems reasonable to ignore the higher coefficients of variation arising from the zero length values recorded in the butt-end and crown-end offcuts. In that case it can be conservatively estimated that 56 sample trees will be required at an allowable error of ±10 percent and a confidence level of 95 percent in order to estimate (from the overall data set) the proportions of the various logging residue. Alternatively, 27 sample trees will be needed at an allowable error of ±15 percent and a confidence level of 95 percent in order to estimate (from the overall data set) the proportions of the various logging residue. Similarly, 34, 34, 21, 41, 53

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and 43 sample trees will then be required at an allowable error of ±10 percent and a confidence level of 95 percent in order to estimate the proportions of the various logging residue for Niangon, Dahoma, Mahogany, Pterygota, Wawa and Avodire, respectively. On the other hand, 17, 17, 11, 20, 25 and 21 sample trees will be needed at an allowable error of ±15 percent and a confidence level of 95 percent in order to estimate the proportions of the various logging residue for these species, respectively. Differences in the sample size requirements of the different timber species are a reflection of inherent variabilities and therefore different levels of logging residue among the different timber species.

5.7 MODELLING TOTAL TREE VOLUME TO PREDICT TOTAL RESIDUE VOLUME

The above-ground total tree volume models are given by equations 2 to 7. For this study, Extracted Bole Volume (EBV) is more important than above-ground Total Residue Volume (TRV) in predicting the measured above-ground Total Tree Volume (TTV). The choice of EBV as an independent variable is also of more practical importance. During normal commercial harvesting operations in Ghana, data on only tree boles and extracted boles (or extracted logs) are captured on Tree Information Forms (TIFs), Log Information Forms (LIFs) and Log Measurement Certificates (LMCs). No such data (i.e., diameters, lengths and volumes) are captured on logging residue such as branches and stumps.

Volume data, from LIFs or LMCs, can be fed into the above-ground total tree volume equation(s) in order to estimate above-ground Total Tree Volumes (TTV).

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Thereupon, above-ground Total Residue Volumes (TRV) can be predicted from the simple mathematical equation:

$$TRV = TTV - EBV \qquad [20]$$

Where:

TRV = above-ground total residue volume down to a 20 cm diameter limit,

all other variables are as previously defined.

The results indicate that, in three out of five cases, the species-specific biomass models were better predictors of above-ground total tree volumes than the general biomass model (generated from the overall data set). The two exceptions were for Wawa and Dahoma. They had the lowest mean extraction intensities of total bole volume of 69 percent and 73 percent, respectively, compared to 78 percent, 83 percent and 91 percent for the three other species. Therefore, it is probable that the sample sizes for Wawa and Dahoma were not large enough to adequately estimate their respective above-ground total tree volumes. Thus, it may not be unreasonable to conclude that the species-specific biomass models were more precise estimators of above-ground total tree volumes and thereby above-ground total residue volumes, than the general biomass model. Therefore, it is recommended that the species-specific biomass models be used when estimates of higher precision are required. However, in view of the small sample sizes used in developing them, the species-specific biomass models should be used with caution.

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Alternatively, the general biomass model will be useful for quick volume estimation, if rough estimates are desired or in instances where species-specific biomass models are not available.

There is a need to validate these biomass models with independent (and preferably larger) data sets in order to establish the presence and nature of any prediction biases, and appropriate corrections made. Until this is done, the biomass models must be regarded as provisional and subject to future refinement. It is certain that the merchantability limit of 20 cm branch diameter, used in this study, tended to underestimate the above-ground total tree volumes and the above-ground total residue volumes. Therefore, the developed biomass models are only valid within the confines of this limitation.

5.8 LOCAL AND STANDARD VOLUME EQUATIONS

For this study, the top diameter of butt-end offcut and its square are more important than total bole height, stump level diameter and its square, in predicting total bole volume. Alder (1980) reports that for buttressed trees it is customary to measure diameter at a reference point about 1 m above the buttresses. It is worthy of note that the top diameter of the butt-end offcut coincides with this reference point. During normal commercial harvesting operations in Ghana, loggers seek to avoid buttress protrusions by cross-cutting the bole roughly at this point.

The single tree local and standard volume functions are given by equations 8 to 19. On the basis of the Furnival Index (FI), the best standard volume equations

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were more precise predictors of total bole volumes than the best local volume equations. However, the local volume equations can be used, if quick and rough estimates are desired. The results also indicated that in all cases, the species-specific volume functions were better predictors of total bole volumes than the general volume functions (generated from the overall data set). Therefore, it is recommended that species-specific volume functions be used when estimates of higher precision are required and in order to overcome inherent variabilities among the different timber species. However, in view of the small sample sizes used in developing them, the species-specific volume functions should be used with caution. It is further recommended that the standard volume equations (rather than local volume equations) be used when estimates of higher precision are required.

The ability to estimate the volume of trees and stands, and to predict wood supply, based on volume information derived from volume equations, is critical for planning the management of forest resources (Alder 1980; Maurer 1993). For planning and management purposes, diameter and height data can be fed into the volume equations (constructed in this study) in order to estimate total bole volumes for individual trees. In 1998, Ghana's Forest Services Division introduced a generalized Ready Reckoner for determining bole volumes and thereby stumpage prices. This Ready Reckoner or bole volume table was based on a generalized volume equation for all the different harvested timber species. Results of this study indicate that it may be advisable to use species-specific Ready Reckoners based on species-specific volume functions.

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The volume equations (constructed in this study) must be tested with independent (and preferably larger) data sets, in order to determine their validity and precision, and thereby make allowances for appropriate corrections. Until such validation is done, these volume functions must be regarded as provisional and subject to future adjustment. Freese (1962) and Alder (1980) cautioned that it is generally dangerous to extrapolate for volume measurements outside the range of data used in constructing volume functions. Therefore, such extrapolation is not recommended, particularly when the nature of any possible biases are not known. Hence, these volume equations are only valid over a diameter range of 61 to 219 cm and a total bole length range of 8.85 to 47.93 m.

5.9 UTILIZATION OF LOGGING RESIDUE

Modern timber processing technology has shown that with systematic planning, it is possible to use almost every part of a tree in some type of wood product. This applies more precisely to developed countries where all the advanced technology and machinery can be readily available for wood conversion. However, this is much less applicable in developing countries where such technology and equipment must be sought and bought with limited foreign exchange. In the light of the above statements, utilization of logging residue in the context of this study and with special reference to Ghana, implies maximum reduction of logging residue and optimal utilization of the inevitable residue. Logging residue is an essential source of organic matter for forest regeneration and growth. Consequently, complete

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removal of logging residue is not recommended. In particular, the complete-tree utilization concept will not be advocated for adoption in Ghana in view of its potential adverse impacts. Such potential consequences include increased nutrient export from the site (White 1974; Norton and Young 1976; Kimmins 1977, 1985; Martin 1988; Hendrickson *et al.* 1989) and increased soil damage during harvesting operations (Skinner *et al.* 1989; Senyk and Smith 1991).

There is only one timber company in Ghana which has the reputation and a long tradition of utilizing logging residue (Duah, pers. comm. 1998). This company had been using Afrormosia branches for the production of flooring and furniture up untill the 1980s. Afrormosia branches that were used had diameters in the range of 40 cm to over 90 cm (Andoh-Ampah, pers. comm. 1998). This company was able to utilize these branches since Afrormosia is characterized by very narrow sapwood. There are other timber species whose branches could also be utilized, since they have little or no distinction between sapwood and heartwood. Such species include Wawa, Pterygota, Antiaris (*Antiaris toxicaria* [Rumph. ex Pers.] Lesch.), Celtis, Avodire and Ilomba (Adam, pers. comm. 1998b). Also, it has been reported that large branches of other species such as Utile, Sapele, Mansonia, Odum and Makore are often extracted as logs by some logging companies (Chryssides 1974; Ghartey *et al.* 1997). It is worthy of mention that all these species are among the most rare and valuable timber species in Ghana. This may well explain the utilization of their branches. Indeed, Afrormosia is the rarest and the most valuable timber species in Ghana. Afrormosia has been listed by the Convention on International Trade in

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Endangered Species (CITES) as having become economically extinct in Ghana (MLF 1996a). Also, CITES recently considered listing Sapele, Utile and Mahogany as additional endangered species. Small quantities of logging residue are also reported to be utilized for fuelwood, charcoal production, carvings, and pit-sawing or chain-sawing into lumber (Otoo 1978; Faakye 1988; Nketiah 1992; Ofori *et al.* 1993).

Notable uses of logging residue encountered at the stump areas during the survey, were for fuelwood, production of carvings, and the construction of forest road bridges and culverts. Defective boles of durable and high density species were used for the construction of forest road bridges and culverts. Such species include Ekki, Dahoma, Asoma (*Parkia bicolor* A. Chev.), Kusia (*Nauclea diderrichii* [De Wild. & Th. Dur.] Merrill), Kokote (*Anopyxis klaineana* [Pierre] Engl.) and Denya (*Cylicodiscus gabunensis* [Taub.] Harms). Though charcoal was being produced in some nearby areas, it was not readily apparent whether logging residue was being utilized. Logging areas usually have adequate woodfuel resources. Therefore, logging residue is seldom harvested by local people for woodfuel. Commercialization of woodfuel from logging residue has also been limited due to accessibility and harvesting costs (Nketiah 1992). However, Subri Industrial Plantations Ltd. (SIPL) was known to be producing charcoal from logging residue during the mid 1980s.

It is obvious that logging residue can be used for the production of small dimension lumber, wood-based panels, woodfuel, briquettes, compost, animal fodder, and pulp and paper.

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5.9.1 Lumber Production from Logging Residue

It is apparent that collection and transportation of logging residue would be a major constraint in the utilization of logging residue in Ghana. Fortunately, mobile forest sawmills can be used *in situ* to convert logging residue into small dimension stock such as scantlings, strips, squares, narrows and shorts (i.e., short length lumber). Such lumber could have thicknesses ranging from 10 to 75 mm plus, widths of 25 to 110 mm plus, and lengths ranging from 8 mm to 1.80 m plus. Besides, finger-jointing and edge-gluing (i.e., glue-lamination) technology can be used to obtain longer, wider and thicker pieces of lumber. These small dimension stock can then be utilized for the manufacture of value-added products like furniture, cabinets, parquet and strip floorings, broomsticks, toys, handicrafts, tool handles, flushdoors, door frames and window frames. Other wood products that could be manufactured from small dimension stock are crates, boxes, pallets, and mouldings such as profile boards, picture frames, mirror frames, ceiling battens and corner battens.

Some companies in Ghana already have the machinery and equipment needed for the production of these value-added products. However, more of such machinery and equipment will be required to facilitate utilization of logging residue.

5.9.2 Production of Wood-based Panels from Logging Residue

Wood-based panel products that can be produced from logging residue include chipboards, particleboards, waferboards, flakeboards, oriented strand

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boards (OSB), hardboards, fibreboards and blockboards. These panel products can find numerous applications in construction, housing (e.g., ceilings, subflooring, partitions and wall claddings), and furniture industries (e.g., shelves, bookcases, cupboards, desktops and cabinets). Blockboard manufacture requires the use of strips of lumber for the inner core of the panel which is then overlaid with face veneer. These strips of lumber can easily be produced from logging residue. There are already 10 Plymills in Ghana and therefore it should not be difficult producing blockboards from logging residue. Indeed, some companies are already producing blockboards in Ghana, though not from logging residue.

Chipboards, particleboards, waferboards, fibreboards, hardboards, oriented strand boards (OSB) and flakeboards, however, are produced by breaking down wood into small chips, particles, wafers, fibres, strands or flakes and then gluing these wood substances together under heat and pressure to form sheets of reconstituted wood. Consequently, small diameter and/or low-quality logs from tree branches, crown-end offcuts and other logging residue can conveniently be utilized for the production of such panel products. However, mobile processors will be required to facilitate the break down of logging residue in the forest and their consequent bulk transportation to the premises of the only two chipboard and particleboard factories in Ghana. In particular, the sole particleboard factory in Ghana already utilizes mill residue such as slabs, edgings, residual peeler cores, offcuts, rejected lumber, bark and sawdust. Therefore, the use of logging residue in

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particleboard production should not be a problem once the issue of collection and transportation of logging residue is solved.

5.9.3 Pulp and Paper Production from Logging Residue

At the moment, there is only one small pulp mill in Ghana which is producing tissue paper and rough paper. This mill was designed for fibrous materials like grass and bagasse and therefore it cannot process chips from hardwoods (Nketiah 1992). However, the planned pulp and paper mill at Daboase (in the Western Region of Ghana) is intended to process a mixture of all timber species. This mill is also intended to have an annual capacity of 54 000 tonnes of paper pulp and will draw supplies from 10 000 ha, mainly plantations, in the nearby Subri River Forest Reserve (Hall and Swaine 1981).

Plantations of fast-growing species such as Gmelina (*Gmelina arborea* Roxb.) and Pines (*Pinus sp.*) have already been established for this purpose. Incidentally, a number of indigenous timber species have already been determined to be suitable for pulp and paper production. These species include Celtis (Twumasi 1989), Emire (*Terminalia ivorensis* A. Chev.), Wawa, Ceiba, Bombax (*Rhodognaphalon brevicuspe* [syn. *Bombax brevicuspe* Sprague]), Ilomba, Musanga (*Musanga cecropioides* [R. Br.] J. Léonard), Wawabima (*Sterculia rhinopetala* K. Schum.) and Alstonia (*Alstonia boonei* De Wild.). It would seem that until this second mill becomes operational, the use of logging residue for pulp production in Ghana is not likely in the near future.

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5.9.4 Wood Energy Production from Logging Residue

The lowest quality and/or the smallest sizes of logging residue can be used for the production of briquettes, fuelwood and charcoal for household and industrial purposes. The traditional earth-mound method and portable kilns can be used to carbonise logging residue into charcoal for domestic consumption and possibly for export to needy West African and North African countries.

Woodfuel plays a key role in Ghana's economy. It is the prime source of energy since it accounts for more than 80 percent of total energy consumed in the country. In rural communities, dependency on woodfuel exceeds 95 percent (MLF 1996a, 1996b). Also, it provides fuel for about 70 percent of urban households; some small-scale industries and other commercial activities (e.g., bakeries and traditional restaurants) also depend on it for cooking and heating (Nketiah 1992; MLF 1996a). Thus, utilization of logging residue for charcoal production should be an attractive proposition. However, existing forestry regulations against the setting of fires within forests will tend to preclude *in situ* carbonisation.

Since integrated timber companies require energy, it is logical that they use their own residue as boiler fuel for the generation of steam for their dry-kilns, veneer dryers and their steaming pits (or vats) for veneer logs. Logging residue can also be used as fuel in industrial plants and for generation of electrical power for the mills and nearby rural communities. Electricity so generated could be linked to the national grid, thus contributing to savings in foreign exchange currently spent on

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imported fossil fuels. This will help to alleviate the energy crisis currently facing Ghana.

Owing to their higher densities, branch woods of all species tend to have higher heat values than their corresponding bole woods (Yang 1981). Bark also tends to be high in heat value (Haygreen and Bowyer 1996). Thus, the bark of trees can be utilized to produce fuelwood. Additionally, bark can be used for the production of fibreboards, particleboards and hardboards. Bark (and foliage) can also be used to produce compost (Kantola 1966; Chappell and Beltz 1973).

Increased utilization of logging residue for the manufacture of the above-mentioned potential products will result in greater yields of timber per unit area of forest, reduced costs, higher quality processed products and greatly improved prospects for a sustainable forest industry. Other benefits will include improved utilization standards, development of cottage industries or rural enterprises, employment and income generation, and improved economic and social contributions of forestry as a component of sustainable development.

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6.0 CONCLUSIONS AND RECOMMENDATIONS

It has been established that Ghana has an industrial round logs deficit of about 1.5 million m^3 per annum. If the Ghana timber industry is to be sustained and further expanded, the deficiency in industrial timber supply will have to be made up through imports, tree breeding (or tree improvement), supplements from plantations, and increased utilization of mill and logging residue. Of these options, industrial tree plantation establishment and increased utilization of wood residue appear to be the most promising alternatives. However, limited information exists on the level of logging residue generation.

This study has shown that on average, about 32 percent of the measured above-ground total tree volume was left in the forest as residue during normal commercial logging operations in the Western Region of Ghana. The identified sources of logging residue included stumps, butt-end offcuts, crown-end offcuts and branch wood. Causes of logging residue include natural defects, and human errors and/or inefficiencies of machine operators.

The study indicated significant differences in harvesting efficiencies among timber species. Reasons for these differences were many and varied. They included competence (or otherwise) of machine operators, terrain conditions, bole shape and form, bole length, occurrence and extent of natural defects, and the rarity and commercial value of the species. The results also showed that there were significant differences in harvesting efficiencies among the logging companies. These differences

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emanated from the level of integration of the companies, equipment and machinery available, and the competence of the workforce especially the experience or inexperience of the machine operators.

The study further showed that for a combination of various species, 56 sample trees will be required at an allowable error of ±10 percent and a confidence level of 95 percent in order to estimate the proportions of the various sources of logging residue. However, it is suggested that any similar studies in future should cover at least 200 to 300 sample trees. This will help to incorporate more of the different timber species and also overcome their inherent variabilities.

The biomass models and volume equations developed in this study will need to be validated with larger data sets. Nonetheless, the study indicated that the species-specific biomass models and volume equations were better predictors of above-ground tree biomass and bole volumes, respectively, than their counterpart general biomass models and general volume equations. Also, the standard volume equations were better predictors of bole volumes than the local volume equations. The biomass models can be used to estimate above-ground total tree volumes and above-ground total residue volumes. Similarly, the volume equations can be applied as sets of volume tables or Ready Reckoners. These can be used by forest planners and managers for bole volume and therefore stumpage price determination. The volume equations can also be used for stand volume and forest yield prediction. This should help in the planning and management of the forest resource in Ghana.

In order to increase recovery and utilization of harvested trees, potential types of forest products which might be converted from logging residue were identified. These

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products include small dimension stock (e.g., scantlings, shorts, squares, narrows and strips), parquet and strip floorings, broomsticks, mouldings (e.g., profile boards, mirror and picture frames), compost, animal fodder, chips for producing flakeboards, chipboards, particleboards, blockboards, waferboards, fibreboards, hardboards, oriented strand boards (OSB), pulp and paper, charcoal, fuelwood, briquettes and other potential commercial uses.

6.1 RECOMMENDATIONS

Based on this study, the following recommendations are made:

1. The Ministry of Lands and Forestry will need to educate the Ghanaian public and the timber industry on the efficient utilization of forest resources. In particular, timber companies in Ghana will need to be re-orientated that wood can only be considered a cull if and only if more than one-half of its volume is defective;
2. The timber companies in Ghana must be obligated to have in place enforceable and feasible plans for recovering and utilizing logging residue from their areas of operation;
3. The timber companies must be encouraged to sponsor their employees to undergo specialised training in courses such as appropriate tree felling and bucking techniques, planning, design, lay out and construction of forest roads, management of logging operations, safety and ergonomics in forestry work, effects of logging on the environment, and management and utilization of logging residue; and

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4. The Government of Ghana must assist the timber companies to secure loans to enable them to acquire sufficient and suitable equipment. Emphasis would have to be placed on the acquisition of mobile chippers, mobile forest sawmills and re-conversion lines capable of utilizing logging residue and other small-size wood materials.

6.2 RECOMMENDATIONS FOR FURTHER STUDIES

As a result of this study, the following areas for further research are identified:

1. A pilot project on the production of small dimension stock from logging residue must be carried out in order to establish the technical and economic viability of utilizing logging residue for timber production;

2. Owing to the potential of greater juvenile wood and tension wood content, it is suggested that the strength properties and working qualities of Ghanaian timber tree branches must be determined in order to establish the suitability of utilizing such logging residue for timber production; and

3. An evaluation of Ghana's current forest policy with regard to logging operations and timber utilization standards will need to be conducted.

In conclusion, this study achieved its set objectives. It is hoped that forest planners, forest managers, policy-makers, industry personnel, researchers and others, will find the information therein to be useful.

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APPENDICES

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APPENDIX I

A LIST OF MODELS COMPARED FOR VOLUME EQUATIONS CONSTRUCTION

Number	Equation
1	$V = b_0 + b_1D$
2	$V = b_0 + b_1D + b_2D^2$
3	$V = b_0 + b_1D^2$
4	$V = b_0 + b_1D^2H$
5	$V = b_0 + b_1D^2 + b_2H + b_3D^2H$
6	$V = b_0 + b_1D^2 + b_2DH + b_3D^2H$
7	$LnV = b_0 + b_1LnD$
8	$LnV = b_0 + b_1LnD + b_2LnH$
9	$V/D^2 = b_0 + b_1(1/D) + b_2(1/D^2)$
10	$V/D^2 = b_0 + b_1(1/D^2)$
11	$V/D^2H = b_0 + b_1(1/D^2H)$
12	$V/D^2 = b_0 + b_1(1/D^2) + b_2(H/D^2) + b_3H$
13	$V/D^2H = b_0 + b_1(1/H) + b_2(1/D^2) + b_3(1/D^2H)$
14	$V/D^2 = b_0 + b_1(1/D^2) + b_2(H/D) + b_3H$
15	$V/D^2H = b_0 + b_1(1/H) + b_2(1/D) + b_3(1/D^2H)$

Where:

D = top end diameter of butt-end offcut in m;

H = total bole height in m;

V = total bole volume in m^3;

b_0 = regression constant or intercept; and,

b_1, b_2, b_3 = regression coefficients.

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APPENDIX II

A LIST OF GHANA'S EXPORT TIMBER SPECIES (CLASS 1 SPECIES)

No	Scientific Name	Std. Trade Name	Ghanaian Name
1	Afzelia species		
	a) *Afzelia africana* Smith	Afzelia	Papao
	*b) *Afzelia bella* Harms	Afzelia	Papaonua
2	*Albizia ferruginea* (Guill. & Perr.) Benth. (Syn. *Albizia angolensis* Welw. ex Oliv.)	Albizia, W. African	Awiemfo-samina
3	*Albizia zygia* (DC.) J. F. Macbr.	Okuro/Albizia	Okoro/Okuro
4	*Alstonia boonei* De Wild.	Alstonia	Sinuro/Nyamedua
5	*Amphimas pterocarpoides* Harms	Yaya	Yaya
6	Aningeria species		
	a) *Aningeria altissima* (A. Chev.) Aubrev. & Pellegr.	Aningeria	Asanfena/Asanfona
	*b) *Aningeria robusta* (A. Chev.) Aubrev. & Pellegr.	Aningeria	Asanfenanini
7	*Anopyxis klaineana* (Pierre) Engl. (Syn. *Anopyxis ealaensis* [De Wild.] Sprague)	Kokote	Kokote
8	*Antiaris toxicaria* (Rumph. ex Pers.) Lesch. (Syn. *Antiaris africana* Engl.)	Antiaris	Kyenkyen
9	**Antrocaryon micraster* A. Chev. & Guill.	Antrocaryon	Aprokuma
10	Berlinia species		
	a) *Berlinia confusa* Hoyle	Berlinia	Kwatafompaboa/
	b) *Berlinia tomentella* Keay	Berlinia	Samanta/Tetekon
11	*Bombax buonopozense* P. Beauv.	Akata/Bombax	Akonkodie/Akata
12	*Canarium sweinfurthii* Engl.	Canarium, African	Bediwonua
13	**Ceiba pentandra* (Linn.) Gaertn.	Ceiba	Onyina
14	*Celtis mildbraedii/zenkeri* Engl.	Celtis, African	Esa/Esakoko
15	*Cordia millenii/plathyrsa* Bak.	Cordia, African	Tweneboa
16	*Cylicodiscus gabunensis* (Taub.) Harms	Okan	Denya
17	*Cynometra ananta* Hutch. & Dalz.	Ananta	Ananta
18	Daniellia species		
	a) *Daniellia ogea* (Harms) Rolfe ex Holl.	Ogea	Hyedua/Ehyedua
	*b) *Daniellia thurifera* Benn.	Ogea	Sopi
19	*Dialium aubrevillei* Pellegr.	Duabankye	Duabankye
20	*Diospyros sanza-minika* A. Chev.	Ebony, African	Sanza-mulike
21	**Distemonanthus benthamianus* Baill.	Ayan	Bonsamdua
22	**Entandrophragma angolense* (Welw.) C. DC.	Gedu-Nohor	Edinam
23	*Entandrophragma candollei* Harms	Omu/Candollei	Penkwa-akowa
24	*Entandrophragma cylindricum* (Sprague) Sprague	Sapele	Penkwa
25	*Entandrophragma utile* (Dawe & Sprague) Sprague	Utile	Efuobrodedwo
26	*Erythrophleum spp.	Missanda	Potrodom
27	Gambeya spp. (Syn. Chrysophyllum spp.)		
	*a) *Gambeya giganta* (Syn. *C. giganteum*)	Longhi (Rouge)	Adesema
	b) *Gambeya albida* (Syn. *C. albidum* G. Don)	Longhi (Blanc)	Akasaa
	c) *Gambeya subnunda* Pierre (syn. *C. subnundum*)	Longhi (Rouge)	Kankabe
28	**Guarea cedrata* (A. Chev.) Pellegr.	Guarea (Scented)	Kwabohoro
29	*Guarea thompsonii* Sprague & Hutch.	Guarea (Black)	Kwadwuma
30	*Guibourtia ehie* (A. Chev.) J. Leonard	Ovangkol	Black Hyedua

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No	Scientific Name	Std. Trade Name	Ghanaian Name
31	*Guibourtia tessmannii* (Harms) J. Leonard (Syn. *Copaifera salikounda* Heckel)	Bubinga/Copaifera	Entedua
32	*†*Hannoa klaineana* Pierre & Engl.	Effeu/Fotie	Fotie
33	**Heritiera utilis* (Sprague) Sprague (Syn. *Tarrietia utilis* [Sprague] Sprague)	Niangon	Nyankom
34	a) *Khaya anthotheca* (Welw.) C. DC.	Anthotheca	Krumben
	b) *Khaya grandifoliola* C. DC.	Mahogany, African	Kruba/Odupon
35	**Khaya ivorensis* A. Chev. (Syn. *K. klainei*)	Mahogany, African	Dubini
36	*Klainedoxa gabonensis* Pierre ex Engl.	Kroma	Kroma
37	**Lophira alata* Banks ex Gaertn. F. (Syn. *Lophira procera* A. Chev.)	Ekki	Kaku
38	**Lovoa trichiliodes* Harms (Syn. *Lovoa klaineana* Pierre ex Prague)	Walnut, African	Dubini-biri
39	**Mammea africana* Sabine	African Apple	Bompagya
40	*Mansonia altissima* (A. Chev.) A. Chev.	Mansonia	Oprono
41	Milicia spp. (Syn. Chlorophora spp.)		
	a) *Milicia excelsa* (Syn. *C. excelsa* Benth. & Hook.F)	Iroko/Odum	Odum
	b) *Milicia regia* (Syn. *Chlorophora regia* A. Chev.)	Iroko/Odum	Odum
42	Mitragyna spp.		
	*a) *Mitragyna ciliata* Aubrev. & Pellegr.	Abura	Subaha
	b) *Mitragyna stipulosa* (DC.) O. Kuntze	Abura	Subaha
43	**Nauclea diderrichii* (De Wild. & Th. Dur.) Merrill (Syn. *Sarcocephalus diderrichii* De Wild. & Dur.)	Opepe	Kusia
44	**Nesogordonia papaverifera* (A. Chev.) R. Capuron (Syn. *Cistanthera papaverifera* A. Chev.)	Danta	Danta
45	*Parkia bicolor* A. Chev.	Asoma	Asoma
46	*Pericopsis elata* (Harms) Van Meeuwen (Syn. *Afrormosia elata* Harms)	Afrormosia	Kokrodua
47	*Petersianthus macrocarpus* (P. Beauv.) Liben	Esia	Esia
48	**Piptadeniastrum africanum* (Hook. F.) Brenan (Syn. *Piptadenia africana* Hook. F.)	Dahoma	Dahoma
49	**Pterygota macrocarpa* K. Schum.	Pterygota, African	Kyere/Kyereye
50	**Pycnanthus angolensis* (Welw.) Warb. (Syn. *Pycnanthus kombo* [Baill.] Warb.	Ilomba	Otie
51	*Rhodognaphalon brevicuspe* (Syn. *Bombax brevicuspe* Sprague)	Bombax	Onyina-koben
52	*Sterculia rhinopetala* K. Schum.	Sterculia (Brown)	Wawabima
53	*Strombosia pustulata* Oliv. (Syn. *Strombosia glaucescens* Engl.)	Afena	Afena
54	*Terminalia ivorensis* A. Chev.	Idigbo	Emire
55	**Terminalia superba* Engl. & Diels	Afara/Ofram	Ofram
56	**Tieghemella heckelii* Pierre ex A. Chev. (Syn. *Dumoria heckelii* [Hutch. & Dalz.] A. Chev.	Makore	Baku
57	**Triplochiton scleroxylon* K. Schum.	Obeche/Wawa	Wawa
58	**Turraeanthus africanus* (Welw. ex C. DC.) Pellegr.	Avodire	Apapaye

*Species marked with asteriks (*) represent the sample tree species used for this study.

†Though a Class 2 timber species in Ghana, *Hannoa klaineana* Pierre & Engl. (Fotie) was included in this list since it happened to be one of the sample tree species. It is usually used as a substitute for Ghana's most abundant timber species, *Triplochiton scleroxylon* K. Schum (Wawa).

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APPENDIX III

PARAMETERS OF STUMPS OF SAMPLE TREES

No.	Timber Species	Stock Survey Number	Stump Height (m)	Top Diameter (m)	Stump Volume (m^3)	Remarks
1	Niangon	1369	0.80	0.71	0.32	Large Buttresses
2	Niangon	1358	0.90	0.73	0.38	Large Buttresses
3	Niangon	1356	0.60	0.75	0.27	Buttresses
4	Niangon	1252	0.75	0.51	0.15	Large Buttresses
5	Niangon	1353	1.10	0.74	0.47	Large Buttresses
6	Niangon	*N/A	0.80	0.73	0.33	Buttresses
7	Niangon	3884	0.86	0.48	0.16	Large Buttresses
8	Niangon	685	1.00	0.90	0.64	Large Buttresses
9	Niangon	1005	1.10	0.67	0.39	Large Buttresses
10	Niangon	1701	1.00	0.84	0.55	Large Buttresses
11	Niangon	2105	0.90	0.49	0.17	Large Buttresses
12	Niangon	810	1.00	0.52	0.21	Large Buttresses
13	Niangon	854	0.94	0.50	0.18	Large Buttresses
14	Niangon	856	0.80	0.49	0.15	Large Buttresses
15	Niangon	1213	0.70	0.87	0.42	Large Buttresses
16	Dahoma	519	0.80	0.76	0.36	Large Buttresses
17	Dahoma	3927	1.00	1.15	1.04	Large Buttresses
18	Dahoma	913	1.10	0.72	0.45	Large Buttresses
19	Dahoma	2218	0.88	0.90	0.56	Large Buttresses
20	Dahoma	806	1.05	1.12	1.03	Large Buttresses
21	Dahoma	858	0.75	0.86	0.44	Large Buttresses
22	Dahoma	252	0.80	1.09	0.75	Large Buttresses
23	Dahoma	609	0.95	0.70	0.37	Large Buttresses
24	Dahoma	591	0.74	1.17	0.80	Large Buttresses
25	Dahoma	643	0.70	0.50	0.14	Large Buttresses
26	Dahoma	294	0.60	0.94	0.42	Large Buttresses
27	Ayan	2946	0.66	0.99	0.51	Minimal Buttresses
28	Ayan	2656	0.70	0.80	0.35	Minimal Buttresses
29	Ceiba	2617	0.80	1.95	2.39	Large Buttresses
30	Guarea	3821	1.03	1.63	2.15	Large Buttresses
31	Mahogany	2340	0.83	1.13	0.83	Large Buttresses
32	Mahogany	2100	1.08	1.38	1.62	Stump rot & L. buttresses
33	Mahogany	405	1.00	0.91	0.65	Large Buttresses
34	Mahogany	570	0.65	1.07	0.58	Large Buttresses
35	Mahogany	1165	0.85	0.93	0.58	Large Buttresses
36	Mahogany	916	0.90	0.95	0.64	Large Buttresses
37	Mahogany	1014	0.90	0.98	0.68	Large Buttresses
38	Mahogany	1003	0.90	0.87	0.54	Large Buttresses

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No.	Timber Species	Stock Survey Number	Stump Height (m)	Top Diameter (m)	Stump Volume (m^3)	Remarks
39	Edinam	2281	0.83	1.00	0.65	Buttresses
40	Adasema	2627	0.80	0.54	0.18	Large Buttresses
41	Aningeria	68	0.70	0.80	0.35	Minimal Buttresses
42	Antrocaryon	1624	1.30	1.89	3.65	Buttresses
43	Walnut	3883	0.90	0.98	0.68	Large Buttresses
44	Walnut	791	0.78	1.01	0.63	Minimal Buttresses
45	Walnut	2056	0.90	0.93	0.61	Large Buttresses
46	Ogea	*N/A	0.70	1.23	0.83	No Buttresses
47	Ogea	1858	0.80	1.49	1.40	Minimal Buttresses
48	Makore	232	0.90	1.70	2.04	Minimal Buttresses
49	Makore	2645	0.50	2.19	1.88	Minimal Buttresses
50	Kusia	254	0.60	1.20	0.68	Minimal Buttresses
51	Bompagya	2366	0.93	1.24	1.12	Buttresses
52	Afzelia	489	1.00	0.93	0.68	Minimal Buttresses
53	Afzelia	262	0.80	0.86	0.46	No Buttresses
54	Fotie	603	0.70	0.99	0.54	No Buttresses
55	Fotie	590	1.00	0.95	0.71	No Buttresses
56	Fotie	467	0.65	1.03	0.54	No Buttresses
57	Ilomba	1041	0.80	0.70	0.31	Minimal Buttresses
58	Ilomba	1029	0.65	1.00	0.51	Minimal Buttresses
59	Ilomba	940	0.50	0.87	0.30	Minimal Buttresses
60	Ilomba	792	1.00	1.18	1.09	Minimal Buttresses
61	Abura	657	0.65	1.13	0.65	Buttresses
62	Potrodom	1734	0.95	1.00	0.75	Minimal Buttresses
63	Ekki	1800	0.65	1.27	0.82	Minimal Buttresses
64	Pterygota	57	0.80	0.67	0.28	Large Buttresses
65	Pterygota	7	1.00	0.46	0.17	Large Buttresses
66	Pterygota	30	0.85	0.75	0.38	Buttresses
67	Pterygota	229	0.80	0.52	0.17	Large Buttresses
68	Pterygota	152	0.60	0.48	0.11	Large Buttresses
69	Pterygota	230	0.90	0.46	0.15	Large Buttresses
70	Wawa	247	0.85	0.63	0.27	Large Buttresses
71	Wawa	65	0.90	1.00	0.71	Large Buttresses
72	Wawa	242	0.80	0.5	0.16	Large Buttresses
73	Wawa	1808	0.60	0.65	0.20	Large Buttresses
74	Wawa	1332	0.90	0.85	0.51	Large Buttresses
75	Wawa	2298	0.70	0.69	0.26	Large Buttresses
76	Wawa	402	0.70	0.90	0.45	Large Buttresses
77	Wawa	403	0.75	1.00	0.59	Large Buttresses
78	Wawa	404	0.70	1.15	0.73	Large Buttresses
79	Wawa	413	0.70	1.20	0.79	Large Buttresses
80	Wawa	414	0.80	1.25	0.98	Large Buttresses
81	Wawa	1363	1.20	1.25	1.47	Large Buttresses
82	Wawa	1413	0.60	1.07	0.54	Large Buttresses
83	Avodire	1706	0.60	0.64	0.19	Minimal Buttresses

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No.	Timber Species	Stock Survey Number	Stump Height (m)	Top Diameter (m)	Stump Volume (m^3)	Remarks
84	Avodire	1069	0.50	0.86	0.29	Minimal Buttresses
85	Avodire	1481	0.60	0.67	0.21	No Buttresses
86	Avodire	2186	0.75	0.75	0.33	Minimal Buttresses
87	Avodire	2238	0.63	0.89	0.39	Minimal Buttresses
88	Avodire	13	0.60	0.69	0.22	No Buttresses
89	Avodire	180	0.61	0.67	0.22	Minimal Buttresses
90	Avodire	116	0.40	0.61	0.12	Minimal Buttresses
91	Avodire	119	0.30	0.72	0.12	Minimal Buttresses
92	Avodire	8118	0.50	0.64	0.16	Minimal Buttresses
93	Avodire	120	0.50	0.68	0.18	Minimal Buttresses
94	Avodire	2195	0.70	0.84	0.39	Minimal Buttresses
95	Ofram	2088	0.63	0.90	0.40	Large Buttresses
96	Ofram	209	0.90	0.80	0.45	Large Buttresses
97	Ofram	2059	0.77	0.87	0.46	Large Buttresses
98	Ofram	400	0.80	0.95	0.57	Large Buttresses
99	Danta	2161	0.70	0.71	0.28	Buttresses
100	Danta	152	0.80	0.66	0.27	Large Buttresses
	Total		**79.35**	**90.57**	**58.88**	
	Mean		**0.79**	**0.91**	**0.59**	
	Std Dev		**0.17**	**0.32**	**0.54**	
	S. E.		**0.02**	**0.03**	**0.05**	
	CV%		**22.05**	**35.52**	**91.06**	
	Minimum		**0.30**	**0.46**	**0.11**	
	Maximum		**1.30**	**2.19**	**3.65**	

* N/A Stock survey number was either not written on the stumps or it had been washed away by rains and/or tree exudates.

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APPENDIX IV

PARAMETERS OF BUTT-END OFFCUTS OF SAMPLE TREES

No.	Timber Species	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)	Remarks
1	Niangon	3.40	0.71	1.30	2.931	Large Buttresses
2	Niangon	1.80	0.73	1.17	1.345	Large Buttresses
3	Niangon	1.90	0.75	0.98	1.137	Buttresses
4	Niangon	2.30	0.51	1.04	1.212	Large Buttresses
5	Niangon	2.00	0.74	1.20	1.562	Large Buttresses
6	Niangon	2.20	0.73	0.67	0.849	Buttresses
7	Niangon	3.40	0.48	0.81	1.184	Large Buttresses
8	Niangon	1.20	0.90	1.05	0.902	Large Buttresses
9	Niangon	1.10	0.67	0.79	0.464	Large Buttresses
10	Niangon	0.00	0.84	0.84	0.000	L. buttresses but no offcut
11	Niangon	2.90	0.49	1.02	1.459	Large Buttresses
12	Niangon	2.60	0.52	1.00	1.298	Large Buttresses
13	Niangon	1.30	0.50	0.74	0.407	Large Buttresses
14	Niangon	1.90	0.49	1.06	1.018	Large Buttresses
15	Niangon	2.60	0.87	0.63	1.179	Large Buttresses
16	Dahoma	3.20	0.76	1.04	2.086	Large Buttresses
17	Dahoma	3.50	1.15	1.08	3.422	Large Buttresses
18	Dahoma	4.40	0.72	1.18	3.303	Large Buttresses
19	Dahoma	3.90	0.90	1.00	2.773	Large Buttresses
20	Dahoma	2.20	1.12	0.85	1.709	Large Buttresses
21	Dahoma	2.60	0.86	0.93	1.639	Large Buttresses
22	Dahoma	4.10	1.09	1.20	4.233	Large Buttresses
23	Dahoma	4.10	0.70	1.05	2.565	Large Buttresses
24	Dahoma	4.10	1.17	1.20	4.524	Large Buttresses
25	Dahoma	4.80	0.50	0.90	1.999	Large Buttresses
26	Dahoma	2.75	0.94	0.88	1.791	Large Buttresses
27	Ayan	2.90	0.99	0.78	1.810	Heart rot & Mini buttresses
28	Ayan	0.00	0.80	0.80	0.000	No offcut/Mini buttresses
29	Ceiba	7.00	1.95	1.70	18.404	Large Buttresses
30	Guarea	3.00	1.63	1.42	5.508	Large Buttresses
31	Mahogany	0.00	1.13	1.13	0.000	Buttresses but no offcut
32	Mahogany	3.80	1.38	1.03	4.427	Heart rot & L. buttresses
33	Mahogany	0.00	0.91	0.91	0.000	Buttresses but no offcut
34	Mahogany	0.00	1.07	1.07	0.000	L. buttresses but no offcut
35	Mahogany	0.00	0.93	0.93	0.000	L. buttresses but no offcut
36	Mahogany	1.20	0.95	1.23	1.139	Large Buttresses
37	Mahogany	0.00	0.98	0.98	0.000	L. buttresses but no offcut

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No.	Timber Species	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)	Remarks
38	Mahogany	0.00	0.87	0.87	0.000	L. buttresses but no offcut
39	Edinam	0.00	1.00	1.00	0.000	Buttresses but no offcut
40	Adasema	3.60	0.54	0.97	1.743	Large Buttresses
41	Aningeria	1.30	0.80	0.96	0.798	Minimal Buttresses
42	Antrocaryon	0.00	1.89	1.89	0.000	Buttresses but no offcut
43	Walnut	0.00	0.98	0.98	0.000	L. buttresses but no offcut
44	Walnut	0.00	1.01	1.01	0.000	No offcut/Min Buttresses
45	Walnut	1.90	0.93	0.95	1.319	Large Buttresses
46	Ogea	0.00	1.23	1.23	0.000	No buttresses & no offcut
47	Ogea	0.00	1.49	1.49	0.000	No offcut/Min Buttresses
48	Makore	0.00	1.70	1.70	0.000	No offcut/Min Buttresses
49	Makore	0.00	2.19	2.19	0.000	No offcut/Min Buttresses
50	Kusia	0.00	1.20	1.20	0.000	No offcut/Min Buttresses
51	Bompagya	0.00	1.24	1.24	0.000	Buttresses but no offcut
52	Afzelia	0.00	0.93	0.93	0.000	No offcut/Min Buttresses
53	Afzelia	0.00	0.86	0.86	0.000	No buttresses & no offcut
54	Fotie	0.00	0.99	0.99	0.000	No buttresses & no offcut
55	Fotie	0.00	0.95	0.95	0.000	No buttresses & no offcut
56	Fotie	0.00	1.03	1.03	0.000	No buttresses & no offcut
57	Ilomba	0.00	0.70	0.70	0.000	No offcut/Min Buttresses
58	Ilomba	0.00	1.00	1.00	0.000	No offcut/Min Buttresses
59	Ilomba	0.00	0.87	0.87	0.000	No offcut/Min Buttresses
60	Ilomba	0.00	1.18	1.18	0.000	No offcut/Min Buttresses
61	Abura	0.00	1.13	1.13	0.000	Buttresses but No offcut
62	Potrodom	0.00	1.00	1.00	0.000	No offcut/Min Buttresses
63	Ekki	0.00	1.27	1.27	0.000	No offcut/Min Buttresses
64	Pterygota	4.20	0.67	0.95	2.230	Large Buttresses
65	Pterygota	7.60	0.46	0.74	2.267	Heart rot & L. Buttresses
66	Pterygota	2.00	0.75	0.80	0.945	Buttresses
67	Pterygota	3.32	0.52	0.85	1.295	Large Buttresses
68	Pterygota	3.50	0.48	0.93	1.506	Large Buttresses
69	Pterygota	2.29	0.46	0.76	0.710	Large Buttresses
70	Wawa	2.40	0.63	0.93	1.190	Large Buttresses
71	Wawa	2.80	1.00	0.90	1.991	Large Buttresses
72	Wawa	1.90	0.50	1.03	0.978	Large Buttresses
73	Wawa	1.80	0.65	0.72	0.665	Large Buttresses
74	Wawa	1.60	0.85	0.94	1.010	Large Buttresses
75	Wawa	4.10	0.69	0.80	1.798	Large Buttresses
76	Wawa	2.89	0.90	0.92	1.881	Large Buttresses
77	Wawa	2.90	1.00	1.05	2.395	Large Buttresses
78	Wawa	6.20	1.15	1.08	6.062	Large Buttresses
79	Wawa	4.60	1.20	0.82	3.817	Large Buttresses
80	Wawa	9.00	1.25	1.71	15.863	L. buttresses & fluted bole
81	Wawa	10.10	1.25	0.91	9.486	Heart rot & L. Buttresses

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No.	Timber Species	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)	Remarks
82	Wawa	2.00	1.07	0.87	1.494	Large Buttresses
83	Avodire	0.00	0.64	0.64	0.000	No offcut/Min buttresses
84	Avodire	0.00	0.86	0.86	0.000	No offcut/Min buttresses
85	Avodire	0.00	0.67	0.67	0.000	No buttresses & no offcut
86	Avodire	0.00	0.75	0.75	0.000	No offcut/Min buttresses
87	Avodire	0.22	0.89	0.89	0.137	Minimal buttresses
88	Avodire	0.00	0.69	0.69	0.000	No buttresses & no offcut
89	Avodire	0.00	0.67	0.67	0.000	No offcut/Min buttresses
90	Avodire	0.00	0.61	0.61	0.000	No offcut/Min buttresses
91	Avodire	0.00	0.72	0.72	0.000	No offcut/Min buttresses
92	Avodire	0.00	0.64	0.64	0.000	No offcut/Min buttresses
93	Avodire	0.40	0.68	0.68	0.145	Minimal buttresses
94	Avodire	0.00	0.84	0.84	0.000	No offcut/Min buttresses
95	Ofram	2.90	0.90	0.66	1.419	Large Buttresses
96	Ofram	2.90	0.80	0.72	1.320	Large Buttresses
97	Ofram	5.95	0.87	0.78	3.191	Large Buttresses
98	Ofram	4.50	0.95	0.99	3.328	Large Buttresses
99	Danta	2.00	0.71	0.79	0.886	Buttresses
100	Danta	0.00	0.66	0.66	0.000	L. buttresses but no offcut
	Total	**189.02**	**90.57**	**98.15**	**150.15**	
	Mean	**1.89**	**0.91**	**0.98**	**1.50**	
	Std Dev	**2.14**	**0.32**	**0.27**	**2.75**	
	S. E.	**0.21**	**0.03**	**0.03**	**0.27**	
	CV%	**113.38**	**35.52**	**27.62**	**183.02**	
	Minimum	**0.00**	**0.46**	**0.61**	**0.00**	
	Maximum	**10.10**	**2.19**	**2.19**	**18.40**	

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APPENDIX V

PARAMETERS OF EXTRACTED BOLES (EXTRACTED LOGS) OF SAMPLE TREES

Sample Tree Number	Timber Species	Stock Survey Number	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)
1	Niangon	1369	19.20	1.30	0.70	16.44
2	Niangon	1358	21.50	1.17	0.61	14.71
3	Niangon	1356	21.60	0.98	0.72	12.55
4	Niangon	1252	25.30	1.04	0.63	14.70
5	Niangon	1353	18.50	1.20	0.70	14.03
6	Niangon	*N/A	20.80	0.67	0.48	5.55
7	Niangon	3884	21.40	0.81	0.56	8.15
8	Niangon	685	23.40	1.05	0.62	13.67
9	Niangon	1005	18.00	0.79	0.51	6.25
10	Niangon	1701	22.60	0.84	0.37	7.48
11	Niangon	2105	24.60	1.02	0.55	12.98
12	Niangon	810	34.70	1.00	0.41	15.92
13	Niangon	854	23.00	0.74	0.45	6.78
14	Niangon	856	21.10	1.06	0.61	12.40
15	Niangon	1213	22.20	0.63	0.56	6.20
16	Dahoma	519	19.80	1.04	0.70	12.22
17	Dahoma	3927	16.20	1.08	0.75	11.00
18	Dahoma	913	12.60	1.18	1.04	12.25
19	Dahoma	2218	9.80	1.00	0.93	7.18
20	Dahoma	806	20.60	0.85	0.83	11.42
21	Dahoma	858	21.50	0.93	0.83	13.12
22	Dahoma	252	20.10	1.20	0.91	17.91
23	Dahoma	609	27.00	1.05	0.69	16.74
24	Dahoma	591	24.60	1.20	0.70	18.65
25	Dahoma	643	12.60	0.90	0.80	7.18
26	Dahoma	294	21.00	0.88	0.77	11.28
27	Ayan	2946	19.50	0.78	0.70	8.41
28	Ayan	2656	13.70	0.80	0.61	5.45
29	Ceiba	2617	25.90	1.70	1.25	45.30
30	Guarea	3821	19.30	1.42	1.26	27.33
31	Mahogany	2340	26.30	1.13	0.59	16.79
32	Mahogany	2100	23.20	1.03	0.80	15.50
33	Mahogany	405	37.20	0.91	0.75	20.32
34	Mahogany	570	26.30	1.07	0.40	13.48
35	Mahogany	1165	34.00	1.17	0.53	22.04
36	Mahogany	916	26.00	1.23	0.74	21.05
37	Mahogany	1014	20.80	0.98	0.75	12.44

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Sample Tree Number	Timber Species	Stock Survey Number	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)
38	Mahogany	1003	22.00	0.87	0.75	11.40
39	Edinam	2281	26.30	1.00	0.55	13.46
40	Adasema	2627	22.10	0.97	0.84	14.30
41	Aningeria	68	8.90	0.96	0.64	4.65
42	Antrocaryon	1624	17.00	1.89	1.10	31.94
43	Walnut	3883	23.00	0.98	0.56	11.51
44	Walnut	791	17.10	1.01	0.45	8.21
45	Walnut	2056	20.60	0.95	0.75	11.86
46	Ogea	*N/A	18.40	1.23	0.89	16.66
47	Ogea	1858	28.40	1.49	1.00	35.93
48	Makore	232	22.10	1.70	0.95	32.93
49	Makore	2645	27.20	2.19	1.70	82.13
50	Kusia	254	21.50	1.20	0.70	16.30
51	Bompagya	2366	24.60	1.24	0.86	22.01
52	Afzelia	489	24.00	0.93	0.81	14.34
53	Afzelia	262	18.00	0.86	0.60	7.78
54	Fotie	603	29.20	0.99	0.50	14.11
55	Fotie	590	22.90	0.95	0.54	10.74
56	Fotie	467	20.50	1.03	0.77	13.32
57	Ilomba	1041	25.20	0.70	0.35	6.06
58	Ilomba	1029	32.50	1.00	0.50	15.96
59	Ilomba	940	29.00	0.87	0.37	10.18
60	Ilomba	792	30.00	1.18	0.51	19.48
61	Abura	657	20.90	1.24	1.05	21.68
62	Potrodom	1734	17.20	1.00	0.74	10.46
63	Ekki	1800	18.00	1.55	1.08	25.24
64	Pterygota	57	20.00	0.95	0.76	11.63
65	Pterygota	7	21.70	0.74	0.58	7.54
66	Pterygota	30	20.10	0.80	0.61	7.99
67	Pterygota	229	24.70	0.85	0.60	10.50
68	Pterygota	152	34.60	0.93	0.55	15.87
69	Pterygota	230	24.90	0.76	0.62	9.41
70	Wawa	247	23.23	0.93	0.53	10.46
71	Wawa	65	14.90	0.90	0.52	6.32
72	Wawa	242	24.00	1.03	0.62	13.63
73	Wawa	1808	23.00	0.72	0.57	7.62
74	Wawa	1332	17.10	0.94	0.67	8.95
75	Wawa	2298	23.00	0.80	0.59	8.93
76	Wawa	402	18.39	0.92	0.47	7.71
77	Wawa	403	12.60	1.05	0.73	8.10
78	Wawa	404	22.50	1.08	0.89	17.31
79	Wawa	413	21.00	0.82	0.55	8.04
80	Wawa	414	31.10	1.71	1.05	49.20
81	Wawa	1363	20.00	0.91	0.67	10.03

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Sample Tree Number	Timber Species	Stock Survey Number	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)
82	Wawa	1413	23.70	0.87	0.70	11.61
83	Avodire	1706	9.50	0.64	0.51	2.50
84	Avodire	1069	7.70	0.86	0.69	3.68
85	Avodire	1481	10.20	0.67	0.51	2.84
86	Avodire	2186	7.10	0.75	0.74	3.10
87	Avodire	2238	9.30	0.89	0.88	5.72
88	Avodire	13	9.20	0.69	0.67	3.34
89	Avodire	180	11.70	0.67	0.55	3.45
90	Avodire	116	10.50	0.61	0.44	2.33
91	Avodire	119	11.30	0.72	0.59	3.85
92	Avodire	8118	10.70	0.64	0.48	2.69
93	Avodire	120	15.20	0.68	0.48	4.14
94	Avodire	2195	10.40	0.84	0.62	4.45
95	Ofram	2088	22.00	0.66	0.52	6.10
96	Ofram	209	25.90	0.72	0.51	7.92
97	Ofram	2059	27.70	0.78	0.58	10.28
98	Ofram	400	28.00	0.99	0.68	15.87
99	Danta	2161	42.53	0.79	0.52	14.95
100	Danta	152	18.50	0.66	0.44	4.57
	Total		**2110.45**	**98.78**	**68.06**	**1330.14**
	Mean		**21.10**	**0.99**	**0.68**	**13.30**
	Std Dev		**6.69**	**0.28**	**0.21**	**10.76**
	S. E.		**0.67**	**0.03**	**0.02**	**1.08**
	CV%		**31.71**	**28.03**	**31.32**	**80.90**
	Minimum		**7.10**	**0.61**	**0.35**	**2.33**
	Maximum		**42.53**	**2.19**	**1.70**	**82.13**

* N/A Stock survey number was either not written on the stumps or it had been washed away by rains and/or tree exudates.

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APPENDIX VI

PARAMETERS OF CROWN-END OFFCUTS OF SAMPLE TREES

Sample Tree Number	Timber Species	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)	Remarks
1	Niangon	5.30	0.70	0.79	2.32	Wider sapwood
2	Niangon	3.50	0.61	0.64	1.07	Wider sapwood
3	Niangon	8.10	0.72	0.51	2.48	Wider sapwood
4	Niangon	3.80	0.63	0.51	0.98	Wider sapwood
5	Niangon	3.10	0.70	0.70	1.19	Wider sapwood
6	Niangon	3.30	0.48	0.56	0.71	Wider sapwood
7	Niangon	4.00	0.56	0.47	0.84	Wider sapwood
8	Niangon	6.20	0.62	0.48	1.50	Wider sapwood
9	Niangon	2.00	0.51	0.78	0.68	Wider sapwood
10	Niangon	1.70	0.37	0.35	0.17	Wider sapwood
11	Niangon	1.40	0.55	0.69	0.43	Wider sapwood
12	Niangon	1.80	0.41	0.38	0.22	Wider sapwood
13	Niangon	0.00	0.45	0.45	0.00	No offcut
14	Niangon	0.90	0.61	0.95	0.45	Wider sapwood
15	Niangon	0.85	0.56	0.61	0.23	Wider sapwood
16	Dahoma	1.50	0.70	0.75	0.62	Wider sapwood
17	Dahoma	1.90	0.75	0.77	0.86	Wider sapwood
18	Dahoma	3.30	1.04	0.90	2.45	Wider sapwood
19	Dahoma	1.40	0.93	1.18	1.24	Wider sapwood
20	Dahoma	1.38	0.83	1.20	1.15	Wider sapwood
21	Dahoma	3.50	0.83	0.95	2.19	Wider sapwood
22	Dahoma	2.40	0.91	1.10	1.92	Wider sapwood
23	Dahoma	0.70	0.69	0.69	0.26	Wider sapwood
24	Dahoma	1.30	0.70	1.15	0.93	Wider sapwood
25	Dahoma	2.60	0.80	0.83	1.36	Wider sapwood
26	Dahoma	1.20	0.77	0.85	0.62	Wider sapwood
27	Ayan	4.40	0.70	0.68	1.65	
28	Ayan	6.00	0.61	0.53	1.54	
29	Ceiba	4.70	1.25	1.10	5.12	
30	Guarea	5.00	1.26	1.20	5.95	
31	Mahogany	1.00	0.59	0.69	0.32	
32	Mahogany	1.80	0.80	0.81	0.92	Knotty
33	Mahogany	0.00	0.75	0.75	0.00	No offcut
34	Mahogany	7.70	0.40	0.46	1.12	
35	Mahogany	0.00	0.53	0.53	0.00	No offcut
36	Mahogany	0.60	0.74	0.72	0.25	
37	Mahogany	0.00	0.75	0.75	0.00	No offcut

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Sample Tree Number	Timber Species	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)	Remarks
38	Mahogany	0.00	0.75	0.75	0.00	No offcut
39	Edinam	0.00	0.55	0.55	0.00	No offcut
40	Adasema	5.50	0.84	0.52	2.11	
41	Aningeria	5.20	0.64	0.52	1.39	
42	Antrocaryon	0.00	1.10	1.10	0.00	No offcut
43	Walnut	2.90	0.56	0.55	0.70	
44	Walnut	1.30	0.45	0.48	0.22	
45	Walnut	1.60	0.75	0.92	0.89	
46	Ogea	4.30	0.89	0.83	2.50	Wider sapwood
47	Ogea	1.20	1.00	0.98	0.92	Wider sapwood
48	Makore	4.80	0.95	1.14	4.15	Heart rot & sapwood
49	Makore	0.00	1.70	1.70	0.00	No offcut
50	Kusia	4.50	0.70	0.69	1.71	
51	Bompagya	2.80	0.86	0.87	1.65	
52	Afzelia	0.95	0.81	1.00	0.62	
53	Afzelia	0.80	0.60	0.82	0.32	
54	Fotie	1.00	0.50	0.78	0.34	
55	Fotie	4.90	0.54	0.70	1.50	
56	Fotie	3.60	0.77	0.83	1.81	
57	Ilomba	4.30	0.35	0.50	0.63	
58	Ilomba	4.50	0.50	0.53	0.94	
59	Ilomba	4.30	0.37	0.28	0.36	
60	Ilomba	9.00	0.51	0.30	1.24	
61	Abura	2.60	1.05	1.05	2.25	Heart rot
62	Potrodom	0.80	0.74	0.80	0.37	
63	Ekki	2.50	1.08	0.96	2.05	
64	Pterygota	14.20	0.76	0.50	4.62	Undersize!
65	Pterygota	8.40	0.58	0.63	2.42	Undersize!
66	Pterygota	12.60	0.61	0.49	3.03	Undersize!
67	Pterygota	9.20	0.60	0.50	2.20	Undersize!
68	Pterygota	5.50	0.55	0.40	1.00	Undersize!
69	Pterygota	9.70	0.62	0.53	2.54	Undersize!
70	Wawa	4.30	0.53	0.55	0.99	Wider sapwood
71	Wawa	10.80	0.52	0.43	1.93	Wider sapwood
72	Wawa	7.40	0.62	0.60	2.16	Wider sapwood
73	Wawa	1.22	0.57	0.98	0.62	Wider sapwood
74	Wawa	1.00	0.67	0.64	0.34	Wider sapwood
75	Wawa	13.60	0.59	0.41	2.76	Wider sapwood
76	Wawa	1.82	0.47	0.46	0.31	Wider sapwood
77	Wawa	1.90	0.73	1.02	1.17	Splits/Wider sapwood
78	Wawa	12.20	0.89	0.53	5.14	Wider sapwood
79	Wawa	4.40	0.55	0.57	1.08	Wider sapwood
80	Wawa	2.20	1.05	1.15	2.10	Wider sapwood
81	Wawa	7.20	0.67	0.59	2.25	Wider sapwood

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Sample Tree Number	Timber Species	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)	Remarks
82	Wawa	3.60	0.70	0.69	1.37	Wider sapwood
83	Avodire	6.60	0.51	0.42	1.13	
84	Avodire	1.40	0.69	0.64	0.49	
85	Avodire	3.30	0.51	0.57	0.76	Heart rot
86	Avodire	1.00	0.74	0.85	0.50	
87	Avodire	0.90	0.88	1.14	0.73	
88	Avodire	0.82	0.67	0.85	0.38	
89	Avodire	0.71	0.55	0.69	0.22	
90	Avodire	2.80	0.44	0.57	0.57	
91	Avodire	7.00	0.59	0.42	1.44	
92	Avodire	6.50	0.48	0.51	1.25	
93	Avodire	4.30	0.48	0.49	0.79	
94	Avodire	0.85	0.62	0.74	0.31	
95	Ofram	14.90	0.52	0.32	2.18	
96	Ofram	12.00	0.51	0.46	2.22	
97	Ofram	3.40	0.58	0.51	0.80	Heart rot
98	Ofram	13.60	0.68	0.24	2.78	
99	Danta	2.70	0.52	0.43	0.48	Wider sapwood
100	Danta	9.00	0.44	0.30	1.00	Wider sapwood
	Total	**394.70**	**68.06**	**69.43**	**128.50**	
	Mean	**3.95**	**0.68**	**0.69**	**1.28**	
	Std Dev	**3.61**	**0.21**	**0.26**	**1.17**	
	S. E.	**0.36**	**0.02**	**0.03**	**0.12**	
	CV%	**91.43**	**31.32**	**37.35**	**90.81**	
	Minimum	**0.00**	**0.35**	**0.24**	**0.00**	
	Maximum	**14.90**	**1.70**	**1.70**	**5.95**	

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APPENDIX VII

VOLUME ESTIMATES OF BRANCHES OF SAMPLE TREES

Sample Tree Number	Timber Species	Number Of Billets Measured	Total Branch Wood Volume (m3)	Remarks
1	Niangon	3	1.93	Small-sized crown
2	Niangon	2	0.31	Small-sized crown
3	Niangon	2	1.35	Small-sized crown
4	Niangon	1	0.46	Other branches severely crooked
5	Niangon	3	2.57	Medium-sized crown
6	Niangon	1	0.15	Small-sized crown
7	Niangon	2	2.06	Medium-sized crown
8	Niangon	2	0.52	Small-sized crown
9	Niangon	2	0.86	Small-sized crown
10	Niangon	2	0.23	Small-sized crown
11	Niangon	2	1.10	Other branches severely crooked
12	Niangon	4	1.12	Small-sized crown
13	Niangon	4	0.99	Small-sized crown
14	Niangon	2	2.20	Medium-sized crown
15	Niangon	2	1.11	Small-sized crown
16	Dahoma	19	9.10	Huge crown with many branches
17	Dahoma	12	5.05	Large crown with several branches
18	Dahoma	16	10.11	Huge crown with many branches
19	Dahoma	11	11.10	Huge crown with many branches
20	Dahoma	6	4.11	Large crown with several branches
21	Dahoma	7	9.70	Huge crown with many branches
22	Dahoma	6	5.43	Large crown with several branches
23	Dahoma	3	2.49	Other branches rotten
24	Dahoma	11	9.68	Huge crown with many branches
25	Dahoma	5	6.30	Large crown with several branches
26	Dahoma	8	5.71	Large crown with several branches
27	Ayan	1	2.26	Medium-sized crown
28	Ayan	5	1.16	Small-sized crown
29	Ceiba	2	3.60	Other branches severely crooked
30	Guarea	4	8.39	Huge crown with many branches
31	Mahogany	5	1.50	Small-sized crown
32	Mahogany	7	2.55	Medium-sized crown
33	Mahogany	6	1.55	Small-sized crown
34	Mahogany	5	1.42	Small-sized crown
35	Mahogany	9	3.74	Large crown with many branches
36	Mahogany	5	1.53	Small-sized crown
37	Mahogany	7	3.67	Large crown with several branches

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Sample Tree Number	Timber Species	Number Of Billets Measured	Total Branch Wood Volume (m3)	Remarks
38	Mahogany	8	4.21	Large crown with many branches
39	Edinam	5	1.40	Small-sized crown
40	Adasema	6	2.65	Medium-sized crown
41	Aningeria	3	0.44	Small-sized crown
42	Antrocaryon	4	9.40	Large crown with several branches
43	Walnut	6	1.39	Small-sized crown
44	Walnut	4	3.08	Medium-sized crown
45	Walnut	2	4.08	Other branches inaccessible
46	Ogea	7	4.32	Large-sized crown
47	Ogea	9	5.27	Large crown with many branches
48	Makore	7	4.26	Other branches severely crooked
49	Makore	24	14.89	Huge crown with many branches
50	Kusia	4	1.41	Other branches severely crooked
51	Bompagya	2	0.26	Other branches severely crooked
52	Afzelia	7	4.12	Large crown with several branches
53	Afzelia	5	2.15	Medium-sized crown
54	Fotie	5	1.88	Small-sized crown
55	Fotie	3	0.80	Small-sized crown
56	Fotie	6	2.09	Medium-sized crown
57	Ilomba	0	0.00	Branches below 20cm diameter
58	Ilomba	0	0.00	Branches below 20cm diameter
59	Ilomba	0	0.00	Branches below 20cm diameter
60	Ilomba	1	0.55	Others below 20cm diameter
61	Abura	2	6.75	Other branches inaccessible
62	Potrodom	8	3.99	Medium crown with many branches
63	Ekki	13	15.12	Huge crown with many branches
64	Pterygota	4	1.50	Small-sized crown
65	Pterygota	2	2.53	Medium-sized crown
66	Pterygota	2	0.70	Small-sized crown
67	Pterygota	3	0.75	Small-sized crown
68	Pterygota	5	0.67	Small-sized crown
69	Pterygota	4	0.82	Small-sized crown
70	Wawa	3	1.38	Small-sized crown
71	Wawa	2	0.45	Small-sized crown
72	Wawa	4	1.18	Small-sized crown
73	Wawa	5	2.48	Medium-sized crown
74	Wawa	2	2.67	Medium-sized crown
75	Wawa	3	0.40	Small-sized crown
76	Wawa	2	0.60	Small-sized crown
77	Wawa	7	9.55	Large crown with many branches
78	Wawa	7	1.01	Small-sized crown
79	Wawa	4	0.63	Small-sized crown
80	Wawa	12	8.78	Huge crown with many branches
81	Wawa	3	1.16	Small-sized crown

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Sample Tree Number	Timber Species	Number Of Billets Measured	Total Branch Wood Volume (m3)	Remarks
82	Wawa	4	2.29	Medium-sized crown
83	Avodire	4	0.76	Small-sized crown
84	Avodire	3	2.89	Medium-sized crown
85	Avodire	1	0.27	Others below 20cm in diameter
86	Avodire	8	3.07	Medium crown with many branches
87	Avodire	4	4.22	Medium-sized crown
88	Avodire	2	1.12	Small-sized crown
89	Avodire	2	1.34	Small-sized crown
90	Avodire	4	0.95	Small-sized crown
91	Avodire	3	1.14	Small-sized crown
92	Avodire	2	0.41	Small-sized crown
93	Avodire	3	0.69	Small-sized crown
94	Avodire	2	1.95	Small-sized crown
95	Ofram	1	0.09	Others below 20cm in diameter
96	Ofram	0	0.00	Branches below 20cm diameter
97	Ofram	3	0.67	Small-sized crown
98	Ofram	2	0.61	Small-sized crown
99	Danta	2	0.31	Small-sized crown
100	Danta	1	0.53	Others below 20cm in diameter
	Total		**282.17**	
	Mean		**2.82**	
	Std Dev		**3.20**	
	S. E.		**0.32**	
	CV%		**113.41**	
	Minimum		**0.00**	
	Maximum		**15.12**	

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APPENDIX VIII

PARAMETERS OF SOME LARGER-SIZED BRANCHES OF SAMPLE TREES

Number	Timber Species	Stock Survey Number	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)
1	Niangon	1369	5.50	0.67	0.46	1.43
2	Niangon	1353	3.30	0.77	0.72	1.44
3	Niangon	3884	17.20	0.43	0.21	1.55
4	Niangon	856	6.00	0.54	0.53	1.35
5	Dahoma	519	8.00	0.40	0.50	1.29
6	Dahoma	519	4.70	0.47	0.70	1.31
7	Dahoma	519	6.90	0.70	0.63	2.40
8	Dahoma	3927	4.00	0.70	0.64	1.41
9	Dahoma	913	7.30	0.56	0.56	1.80
10	Dahoma	913	3.80	0.68	0.78	1.60
11	Dahoma	913	6.90	0.56	0.47	1.45
12	Dahoma	913	9.50	0.46	0.30	1.13
13	Dahoma	2218	8.10	0.64	0.58	2.37
14	Dahoma	806	11.80	0.52	0.42	2.07
15	Dahoma	858	13.80	0.61	0.47	3.21
16	Dahoma	858	11.90	0.66	0.64	3.95
17	Dahoma	252	3.00	0.80	0.84	1.59
18	Dahoma	252	9.30	0.72	0.48	2.74
19	Dahoma	591	10.00	0.74	0.67	3.91
20	Dahoma	591	6.60	0.60	0.50	1.58
21	Dahoma	643	10.00	0.69	0.64	3.48
22	Dahoma	294	9.50	0.55	0.45	1.88
23	Dahoma	294	11.90	0.42	0.26	1.14
24	Ayan	2946	9.00	0.68	0.42	2.26
25	Ceiba	2617	4.90	1.10	0.68	3.22
26	Guarea	3821	6.00	1.05	0.96	4.77
27	Guarea	3821	5.80	0.90	0.51	2.44
28	Mahogany	2100	5.40	0.57	0.53	1.29
29	Mahogany	1003	6.40	0.68	0.54	1.90
30	Antrocaryon	1624	11.40	0.77	0.67	4.67
31	Antrocaryon	1624	2.70	1.03	1.03	2.25
32	Antrocaryon	1624	11.60	0.45	0.30	1.33
33	Walnut	791	5.80	0.59	0.50	1.36
34	Walnut	2056	11.00	0.57	0.52	2.57
35	Ogea	*N/A	8.60	0.51	0.43	1.50
36	Ogea	*N/A	5.40	0.50	0.54	1.15
37	Ogea	1858	6.00	0.69	0.52	1.76

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Number	Timber Species	Stock Survey Number	Length (m)	Bottom Diameter (m)	Top Diameter (m)	Volume (m3)
38	Ogea	1858	4.20	0.63	0.55	1.15
39	Makore	232	4.00	0.70	0.52	1.19
40	Makore	232	4.50	0.80	0.62	1.81
41	Makore	2645	1.40	1.20	0.84	1.18
42	Makore	2645	2.00	1.30	0.92	1.99
43	Makore	2645	5.50	0.65	0.59	1.67
44	Makore	2645	6.50	0.56	0.42	1.25
45	Makore	2645	4.60	0.60	0.62	1.35
46	Abura	657	10.10	0.79	0.60	3.90
47	Abura	657	9.00	0.70	0.56	2.84
48	Ekki	1800	9.00	0.84	0.82	4.87
49	Ekki	1800	8.30	0.53	0.41	1.46
50	Ekki	1800	10.20	0.85	0.60	4.34
51	Pterygota	7	15.00	0.58	0.24	2.32
52	Wawa	1808	9.00	0.58	0.36	1.65
53	Wawa	1332	12.80	0.64	0.32	2.57
54	Wawa	403	16.90	0.98	0.27	6.86
55	Wawa	403	10.80	0.55	0.40	1.96
56	Wawa	414	3.70	0.79	0.59	1.41
57	Wawa	414	7.70	1.00	0.63	4.23
58	Wawa	1413	5.80	0.66	0.42	1.39
59	Avodire	1069	9.60	0.65	0.41	2.23
60	Avodire	2238	5.40	0.82	0.66	2.35
61	Avodire	2195	7.20	0.65	0.45	1.77
	Total		**472.20**	**42.03**	**33.42**	**136.32**
	Mean		**7.74**	**0.69**	**0.55**	**2.23**
	Minimum		**1.40**	**0.40**	**0.21**	**1.13**
	Maximum		**17.20**	**1.30**	**1.03**	**6.86**
	Std Dev		**3.50**	**0.19**	**0.17**	**1.19**
	CV%		**45.17**	**27.26**	**31.48**	**53.10**
	S. E.		**0.45**	**0.02**	**0.02**	**0.15**

*** N/A Stock survey number was either not written on the stumps or it had been washed away by rains and/or tree exudates.**

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APPENDIX IX

SECTIONAL VOLUMES (M^3) OF SAMPLE TREES

Sample Tree Number	Timber Species	Stump Wood Volume (m^3)	Butt-End Offcut Volume (m^3)	Extracted Bole Volume (m^3)	Crown-End Offcut Volume (m^3)	Branch Wood Volume (m^3)	Total Tree Volume (m^3)
1	Niangon	0.32	2.93	16.44	2.32	1.93	23.95
2	Niangon	0.38	1.34	14.71	1.07	0.31	17.81
3	Niangon	0.27	1.14	12.55	2.48	1.35	17.78
4	Niangon	0.15	1.21	14.70	0.98	0.46	17.50
5	Niangon	0.47	1.56	14.03	1.19	2.57	19.82
6	Niangon	0.33	0.85	5.55	0.71	0.15	7.59
7	Niangon	0.16	1.18	8.15	0.84	2.06	12.39
8	Niangon	0.64	0.90	13.67	1.50	0.52	17.23
9	Niangon	0.39	0.46	6.25	0.68	0.86	8.64
10	Niangon	0.55	0.00	7.48	0.17	0.23	8.44
11	Niangon	0.17	1.46	12.98	0.43	1.10	16.14
12	Niangon	0.21	1.30	15.92	0.22	1.12	18.78
13	Niangon	0.18	0.41	6.78	0.00	0.99	8.36
14	Niangon	0.15	1.02	12.40	0.45	2.20	16.22
15	Niangon	0.42	1.18	6.20	0.23	1.11	9.13
16	Dahoma	0.36	2.09	12.22	0.62	9.10	24.40
17	Dahoma	1.04	3.42	11.00	0.86	5.05	21.37
18	Dahoma	0.45	3.30	12.25	2.45	10.11	28.55
19	Dahoma	0.56	2.77	7.18	1.24	11.10	22.85
20	Dahoma	1.03	1.71	11.42	1.15	4.11	19.43
21	Dahoma	0.44	1.64	13.12	2.19	9.70	27.09
22	Dahoma	0.75	4.23	17.91	1.92	5.43	30.24
23	Dahoma	0.37	2.57	16.74	0.26	2.49	22.43
24	Dahoma	0.80	4.52	18.65	0.93	9.68	34.58
25	Dahoma	0.14	2.00	7.18	1.36	6.30	16.98
26	Dahoma	0.42	1.79	11.28	0.62	5.71	19.81
27	Ayan	0.51	1.81	8.41	1.65	2.26	14.64
28	Ayan	0.35	0.00	5.45	1.54	1.16	8.50
29	Ceiba	2.39	18.40	45.30	5.12	3.60	74.81
30	Guarea	2.15	5.51	27.33	5.95	8.39	49.33
31	Mahogany	0.83	0.00	16.79	0.32	1.50	19.44
32	Mahogany	1.62	4.43	15.50	0.92	2.55	25.01
33	Mahogany	0.65	0.00	20.32	0.00	1.55	22.52
34	Mahogany	0.58	0.00	13.48	1.12	1.42	16.61
35	Mahogany	0.58	0.00	22.04	0.00	3.74	26.35
36	Mahogany	0.64	1.14	21.05	0.25	1.53	24.61

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Sample Tree Number	Timber Species	Stump Wood Volume (m^3)	Butt-End Offcut Volume (m^3)	Extracted Bole Volume (m^3)	Crown-End Offcut Volume (m^3)	Branch Wood Volume (m^3)	Total Tree Volume (m^3)
37	Mahogany	0.68	0.00	12.44	0.00	3.67	16.79
38	Mahogany	0.54	0.00	11.40	0.00	4.21	16.14
39	Edinam	0.65	0.00	13.46	0.00	1.40	15.51
40	Adasema	0.18	1.74	14.30	2.11	2.65	20.98
41	Aningeria	0.35	0.80	4.65	1.39	0.44	7.64
42	Antrocaryon	3.65	0.00	31.94	0.00	9.40	44.98
43	Walnut	0.68	0.00	11.51	0.70	1.39	14.28
44	Walnut	0.63	0.00	8.21	0.22	3.08	12.14
45	Walnut	0.61	1.32	11.86	0.89	4.08	18.75
46	Ogea	0.83	0.00	16.66	2.50	4.32	24.32
47	Ogea	1.40	0.00	35.93	0.92	5.27	43.52
48	Makore	2.04	0.00	32.93	4.15	4.26	43.38
49	Makore	1.88	0.00	82.13	0.00	14.89	98.91
50	Kusia	0.68	0.00	16.30	1.71	1.41	20.10
51	Bompagya	1.12	0.00	22.01	1.65	0.26	25.04
52	Afzelia	0.68	0.00	14.34	0.62	4.12	19.76
53	Afzelia	0.46	0.00	7.78	0.32	2.15	10.71
54	Fotie	0.54	0.00	14.11	0.34	1.88	16.87
55	Fotie	0.71	0.00	10.74	1.50	0.80	13.76
56	Fotie	0.54	0.00	13.32	1.81	2.09	17.76
57	Ilomba	0.31	0.00	6.06	0.63	0.00	7.00
58	Ilomba	0.51	0.00	15.96	0.94	0.00	17.41
59	Ilomba	0.30	0.00	10.18	0.36	0.00	10.84
60	Ilomba	1.09	0.00	19.48	1.24	0.55	22.36
61	Abura	0.65	0.00	21.68	2.25	6.75	31.33
62	Potrodom	0.75	0.00	10.46	0.37	3.99	15.57
63	Ekki	0.82	0.00	25.24	2.05	15.12	43.23
64	Pterygota	0.28	2.23	11.63	4.62	1.50	20.26
65	Pterygota	0.17	2.27	7.54	2.42	2.53	14.92
66	Pterygota	0.38	0.94	7.99	3.03	0.70	13.04
67	Pterygota	0.17	1.30	10.50	2.20	0.75	14.93
68	Pterygota	0.11	1.51	15.87	1.00	0.67	19.16
69	Pterygota	0.15	0.71	9.41	2.54	0.82	13.63
70	Wawa	0.27	1.19	10.46	0.99	1.38	14.28
71	Wawa	0.71	1.99	6.32	1.93	0.45	11.40
72	Wawa	0.16	0.98	13.63	2.16	1.18	18.11
73	Wawa	0.20	0.67	7.62	0.62	2.48	11.58
74	Wawa	0.51	1.01	8.95	0.34	2.67	13.48
75	Wawa	0.26	1.80	8.93	2.76	0.40	14.14
76	Wawa	0.45	1.88	7.71	0.31	0.60	10.95
77	Wawa	0.59	2.40	8.10	1.17	9.55	21.80
78	Wawa	0.73	6.06	17.31	5.14	1.01	30.26
79	Wawa	0.79	3.82	8.04	1.08	0.63	14.36

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Sample Tree Number	Timber Species	Stump Wood Volume (m^3)	Butt-End Offcut Volume (m^3)	Extracted Bole Volume (m^3)	Crown-End Offcut Volume (m^3)	Branch Wood Volume (m^3)	Total Tree Volume (m^3)
80	Wawa	0.98	15.86	49.20	2.10	8.78	76.92
81	Wawa	1.47	9.49	10.03	2.25	1.16	24.40
82	Wawa	0.54	1.49	11.61	1.37	2.29	17.30
83	Avodire	0.19	0.00	2.50	1.13	0.76	4.59
84	Avodire	0.29	0.00	3.68	0.49	2.89	7.34
85	Avodire	0.21	0.00	2.84	0.76	0.27	4.08
86	Avodire	0.33	0.00	3.10	0.50	3.07	7.00
87	Avodire	0.39	0.14	5.72	0.73	4.22	11.21
88	Avodire	0.22	0.00	3.34	0.38	1.12	5.06
89	Avodire	0.22	0.00	3.45	0.22	1.34	5.23
90	Avodire	0.12	0.00	2.33	0.57	0.95	3.97
91	Avodire	0.12	0.00	3.85	1.44	1.14	6.55
92	Avodire	0.16	0.00	2.69	1.25	0.41	4.51
93	Avodire	0.18	0.15	4.14	0.79	0.69	5.95
94	Avodire	0.39	0.00	4.45	0.31	1.95	7.10
95	Ofram	0.40	1.42	6.10	2.18	0.09	10.19
96	Ofram	0.45	1.32	7.92	2.22	0.00	11.92
97	Ofram	0.46	3.19	10.28	0.80	0.67	15.40
98	Ofram	0.57	3.33	15.87	2.78	0.61	23.15
99	Danta	0.28	0.89	14.95	0.48	0.31	16.91
100	Danta	0.27	0.00	4.57	1.00	0.53	6.38
	Total	**58.88**	**150.15**	**1330.14**	**128.50**	**282.17**	**1949.84**
	Mean	**0.59**	**1.50**	**13.30**	**1.28**	**2.82**	**19.50**
	Std Dev	**0.54**	**2.75**	**10.76**	**1.17**	**3.20**	**14.71**
	S. E.	**0.05**	**0.27**	**1.08**	**0.12**	**0.32**	**1.47**
	CV%	**91.06**	**183.02**	**80.90**	**90.81**	**113.41**	**75.45**
	Minimum	**0.11**	**0.00**	**2.33**	**0.00**	**0.00**	**3.97**
	Maximum	**3.65**	**18.40**	**82.13**	**5.95**	**15.12**	**98.91**

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APPENDIX X

PERCENTAGE (%) DISTRIBUTION OF SECTIONAL VOLUMES OF SAMPLE TREES

No.	Timber Species	Stump Wood Volume (%)	Butt-End Offcut Volume (%)	Extracted Bole Volume (%)	Crown-End Offcut Volume (%)	Branch Wood Volume (%)	Total Tree Volume (%)	Proportion of Bole Volume Extracted (%)
1	Niangon	1.32	12.24	68.67	9.69	8.08	100.00	74.71
2	Niangon	2.12	7.55	82.57	6.04	1.73	100.00	84.02
3	Niangon	1.49	6.39	70.57	13.93	7.62	100.00	76.39
4	Niangon	0.88	6.93	83.98	5.60	2.61	100.00	86.23
5	Niangon	2.39	7.88	70.76	6.02	12.95	100.00	81.29
6	Niangon	4.42	11.19	73.18	9.30	1.92	100.00	74.61
7	Niangon	1.26	9.56	65.78	6.78	16.63	100.00	78.90
8	Niangon	3.69	5.23	79.34	8.69	3.04	100.00	81.83
9	Niangon	4.49	5.37	72.35	7.90	9.89	100.00	80.30
10	Niangon	6.57	0.00	88.61	2.05	2.77	100.00	91.13
11	Niangon	1.05	9.04	80.41	2.65	6.84	100.00	86.32
12	Niangon	1.13	6.91	84.79	1.18	5.99	100.00	90.19
13	Niangon	2.21	4.88	81.12	0.00	11.80	100.00	91.97
14	Niangon	0.93	6.28	76.44	2.78	13.58	100.00	88.45
15	Niangon	4.56	12.90	67.84	2.51	12.19	100.00	77.26
16	Dahoma	1.49	8.55	50.11	2.54	37.31	100.00	79.93
17	Dahoma	4.86	16.01	51.48	4.03	23.61	100.00	67.39
18	Dahoma	1.57	11.57	42.89	8.59	35.39	100.00	66.38
19	Dahoma	2.45	12.13	31.42	5.43	48.56	100.00	61.08
20	Dahoma	5.33	8.79	58.79	5.94	21.15	100.00	74.56
21	Dahoma	1.61	6.05	48.45	8.08	35.82	100.00	75.48
22	Dahoma	2.47	14.00	59.23	6.35	17.95	100.00	72.18
23	Dahoma	1.63	11.44	74.65	1.17	11.11	100.00	83.99
24	Dahoma	2.30	13.08	53.94	2.68	28.00	100.00	74.91
25	Dahoma	0.81	11.77	42.28	8.00	37.14	100.00	67.26
26	Dahoma	2.10	9.04	56.93	3.13	28.80	100.00	79.96
27	Ayan	3.47	12.36	57.49	11.25	15.43	100.00	67.98
28	Ayan	4.14	0.00	64.12	18.12	13.61	100.00	74.23
29	Ceiba	3.19	24.60	60.56	6.84	4.81	100.00	63.61
30	Guarea	4.36	11.17	55.40	12.06	17.02	100.00	66.76
31	Mahogany	4.28	0.00	86.36	1.67	7.69	100.00	93.56
32	Mahogany	6.46	17.70	61.98	3.66	10.20	100.00	69.02
33	Mahogany	2.89	0.00	90.25	0.00	6.86	100.00	96.90
34	Mahogany	3.52	0.00	81.18	6.77	8.53	100.00	88.75
35	Mahogany	2.19	0.00	83.62	0.00	14.19	100.00	97.45
36	Mahogany	2.59	4.63	85.54	1.02	6.22	100.00	91.21
37	Mahogany	4.04	0.00	74.11	0.00	21.84	100.00	94.82

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No.	Timber Species	Stump Wood Volume (%)	Butt-End Offcut Volume (%)	Extracted Bole Volume (%)	Crown-End Offcut Volume (%)	Branch Wood Volume (%)	Total Tree Volume (%)	Proportion of Bole Volume Extracted (%)
38	Mahogany	3.32	0.00	70.63	0.00	26.05	100.00	95.52
39	Edinam	4.20	0.00	86.76	0.00	9.04	100.00	95.38
40	Adasema	0.87	8.31	68.15	10.05	12.61	100.00	77.99
41	Aningeria	4.61	10.44	60.94	18.19	5.82	100.00	64.71
42	Antrocaryon	8.11	0.00	71.00	0.00	20.89	100.00	89.75
43	Walnut	4.76	0.00	80.62	4.92	9.70	100.00	89.29
44	Walnut	5.15	0.00	67.67	1.82	25.36	100.00	90.66
45	Walnut	3.26	7.04	63.24	4.72	21.74	100.00	80.80
46	Ogea	3.42	0.00	68.51	10.29	17.78	100.00	83.33
47	Ogea	3.21	0.00	82.56	2.12	12.11	100.00	93.93
48	Makore	4.71	0.00	75.90	9.57	9.82	100.00	84.16
49	Makore	1.91	0.00	83.04	0.00	15.05	100.00	97.76
50	Kusia	3.38	0.00	81.10	8.50	7.03	100.00	87.23
51	Bompagya	4.49	0.00	87.90	6.57	1.04	100.00	88.82
52	Afzelia	3.44	0.00	72.57	3.13	20.86	100.00	91.70
53	Afzelia	4.34	0.00	72.57	3.03	20.06	100.00	90.78
54	Fotie	3.20	0.00	83.65	2.00	11.16	100.00	94.15
55	Fotie	5.15	0.00	78.09	10.94	5.82	100.00	82.91
56	Fotie	3.05	0.00	74.99	10.21	11.75	100.00	84.98
57	Ilomba	4.40	0.00	86.61	8.99	0.00	100.00	86.61
58	Ilomba	2.93	0.00	91.68	5.39	0.00	100.00	91.68
59	Ilomba	2.74	0.00	93.90	3.35	0.00	100.00	93.90
60	Ilomba	4.89	0.00	87.10	5.54	2.47	100.00	89.31
61	Abura	2.08	0.00	69.20	7.19	21.53	100.00	88.18
62	Potrodom	4.79	0.00	67.17	2.40	25.64	100.00	90.33
63	Ekki	1.91	0.00	58.38	4.74	34.98	100.00	89.77
64	Pterygota	1.39	11.01	57.41	22.79	7.40	100.00	62.00
65	Pterygota	1.11	15.20	50.52	16.22	16.94	100.00	60.83
66	Pterygota	2.88	7.24	61.28	23.24	5.36	100.00	64.75
67	Pterygota	1.14	8.68	70.37	14.77	5.05	100.00	74.11
68	Pterygota	0.57	7.86	82.84	5.22	3.52	100.00	85.86
69	Pterygota	1.10	5.21	69.05	18.60	6.04	100.00	73.49
70	Wawa	1.86	8.33	73.23	6.90	9.67	100.00	.81.08
71	Wawa	6.20	17.46	55.47	16.94	3.93	100.00	57.73
72	Wawa	0.87	5.40	75.24	11.95	6.54	100.00	80.51
73	Wawa	1.72	5.75	65.82	5.32	21.39	100.00	83.73
74	Wawa	3.79	7.49	66.39	2.50	19.83	100.00	82.81
75	Wawa	1.85	12.71	63.13	19.50	2.81	100.00	64.95
76	Wawa	4.07	17.18	70.44	2.82	5.49	100.00	74.53
77	Wawa	2.70	10.99	37.13	5.39	43.79	100.00	66.06
78	Wawa	2.40	20.03	57.21	17.00	3.35	100.00	59.20
79	Wawa	5.51	26.58	55.99	7.55	4.36	100.00	58.55
80	Wawa	1.28	20.62	63.96	2.72	11.42	100.00	72.20
81	Wawa	6.04	38.87	41.11	9.24	4.74	100.00	43.16

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No.	Timber Species	Stump Wood Volume (%)	Butt-End Offcut Volume (%)	Extracted Bole Volume (%)	Crown-End Offcut Volume (%)	Branch Wood Volume (%)	Total Tree Volume (%)	Proportion of Bole Volume Extracted (%)
82	Wawa	3.12	8.64	67.11	7.90	13.23	100.00	77.35
83	Avodire	4.21	0.00	54.47	24.67	16.65	100.00	65.36
84	Avodire	3.96	0.00	50.08	6.63	39.32	100.00	82.54
85	Avodire	5.19	0.00	69.70	18.61	6.50	100.00	74.55
86	Avodire	4.73	0.00	44.23	7.13	43.91	100.00	78.85
87	Avodire	3.50	1.22	51.08	6.54	37.66	100.00	81.93
88	Avodire	4.44	0.00	66.06	7.46	22.04	100.00	84.75
89	Avodire	4.12	0.00	66.10	4.16	25.63	100.00	88.88
90	Avodire	2.95	0.00	58.83	14.38	23.84	100.00	77.25
91	Avodire	1.87	0.00	58.74	22.03	17.37	100.00	71.09
92	Avodire	3.57	0.00	59.65	27.77	9.01	100.00	65.56
93	Avodire	3.05	2.44	69.51	13.36	11.64	100.00	78.67
94	Avodire	5.47	0.00	62.72	4.38	27.43	100.00	86.43
95	Ofram	3.93	13.92	59.87	21.41	0.86	100.00	60.39
96	Ofram	3.80	11.07	66.47	18.66	0.00	100.00	66.47
97	Ofram	2.97	20.72	66.76	5.17	4.36	100.00	69.81
98	Ofram	2.45	14.38	68.55	12.00	2.62	100.00	70.39
99	Danta	1.64	5.24	88.40	2.86	1.86	100.00	90.08
100	Danta	4.29	0.00	71.65	15.71	8.36	100.00	78.18
	Total	**320.32**	**655.27**	**6817.67**	**795.58**	**1411.16**	**10000.00**	**7938.69**
	Mean	**3.20**	**6.55**	**68.18**	**7.96**	**14.11**	**100.00**	**79.39**
	Minimum	**0.57**	**0.00**	**31.42**	**0.00**	**0.00**	**100.00**	**43.16**
	Maximum	**8.11**	**38.87**	**93.90**	**27.77**	**48.56**	**100.00**	**97.76**
	Std Dev	**1.55**	**7.34**	**13.13**	**6.43**	**11.36**	**0.00**	**11.16**
	S.E.	**0.15**	**0.73**	**1.31**	**0.64**	**1.14**	**0.00**	**1.12**
	CV%	**48.32**	**111.96**	**19.25**	**80.87**	**80.51**	**0.00**	**14.05**

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APPENDIX XI

SECTIONAL DISTRIBUTION (M^3) OF LOGGING RESIDUE IN SAMPLE TREES

Sample Tree Number	Timber Species	Stock Survey Number	Stump Wood Volume (m^3)	Butt-End Offcut Volume (m^3)	Crown-End Offcut Volume (m^3)	Branch Wood Volume (m^3)	Total Residue Volume (m^3)
1	Niangon	1369	0.32	2.93	2.32	1.93	7.50
2	Niangon	1358	0.38	1.34	1.07	0.31	3.10
3	Niangon	1356	0.27	1.14	2.48	1.35	5.23
4	Niangon	1252	0.15	1.21	0.98	0.46	2.80
5	Niangon	1353	0.47	1.56	1.19	2.57	5.80
6	Niangon	*N/A	0.33	0.85	0.71	0.15	2.03
7	Niangon	3884	0.16	1.18	0.84	2.06	4.24
8	Niangon	685	0.64	0.90	1.50	0.52	3.56
9	Niangon	1005	0.39	0.46	0.68	0.86	2.39
10	Niangon	1701	0.55	0.00	0.17	0.23	0.96
11	Niangon	2105	0.17	1.46	0.43	1.10	3.16
12	Niangon	810	0.21	1.30	0.22	1.12	2.86
13	Niangon	854	0.18	0.41	0.00	0.99	1.58
14	Niangon	856	0.15	1.02	0.45	2.20	3.82
15	Niangon	1213	0.42	1.18	0.23	1.11	2.94
16	Dahoma	519	0.36	2.09	0.62	9.10	12.17
17	Dahoma	3927	1.04	3.42	0.86	5.05	10.37
18	Dahoma	913	0.45	3.30	2.45	10.11	16.31
19	Dahoma	2218	0.56	2.77	1.24	11.10	15.67
20	Dahoma	806	1.03	1.71	1.15	4.11	8.01
21	Dahoma	858	0.44	1.64	2.19	9.70	13.97
22	Dahoma	252	0.75	4.23	1.92	5.43	12.33
23	Dahoma	609	0.37	2.57	0.26	2.49	5.68
24	Dahoma	591	0.80	4.52	0.93	9.68	15.93
25	Dahoma	643	0.14	2.00	1.36	6.30	9.80
26	Dahoma	294	0.42	1.79	0.62	5.71	8.53
27	Ayan	2946	0.51	1.81	1.65	2.26	6.22
28	Ayan	2656	0.35	0.00	1.54	1.16	3.05
29	Ceiba	2617	2.39	18.40	5.12	3.60	29.51
30	Guarea	3821	2.15	5.51	5.95	8.39	22.00
31	Mahogany	2340	0.83	0.00	0.32	1.50	2.65
32	Mahogany	2100	1.62	4.43	0.92	2.55	9.51
33	Mahogany	405	0.65	0.00	0.00	1.55	2.20
34	Mahogany	570	0.58	0.00	1.12	1.42	3.13
35	Mahogany	1165	0.58	0.00	0.00	3.74	4.32
36	Mahogany	916	0.64	1.14	0.25	1.53	3.56

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Sample Tree Number	Timber Species	Stock Survey Number	Stump Wood Volume (m^3)	Butt-End Offcut Volume (m^3)	Crown-End Offcut Volume (m^3)	Branch Wood Volume (m^3)	Total Residue Volume (m^3)
37	Mahogany	1014	0.68	0.00	0.00	3.67	4.35
38	Mahogany	1003	0.54	0.00	0.00	4.21	4.74
39	Edinam	2281	0.65	0.00	0.00	1.40	2.05
40	Adasema	2627	0.18	1.74	2.11	2.65	6.68
41	Aningeria	68	0.35	0.80	1.39	0.44	2.98
42	Antrocaryon	1624	3.65	0.00	0.00	9.40	13.05
43	Walnut	3883	0.68	0.00	0.70	1.39	2.77
44	Walnut	791	0.63	0.00	0.22	3.08	3.92
45	Walnut	2056	0.61	1.32	0.89	4.08	6.89
46	Ogea	*N/A	0.83	0.00	2.50	4.32	7.66
47	Ogea	1858	1.40	0.00	0.92	5.27	7.59
48	Makore	232	2.04	0.00	4.15	4.26	10.46
49	Makore	2645	1.88	0.00	0.00	14.89	16.77
50	Kusia	254	0.68	0.00	1.71	1.41	3.80
51	Bompagya	2366	1.12	0.00	1.65	0.26	3.03
52	Afzelia	489	0.68	0.00	0.62	4.12	5.42
53	Afzelia	262	0.46	0.00	0.32	2.15	2.94
54	Fotie	603	0.54	0.00	0.34	1.88	2.76
55	Fotie	590	0.71	0.00	1.50	0.80	3.01
56	Fotie	467	0.54	0.00	1.81	2.09	4.44
57	Ilomba	1041	0.31	0.00	0.63	0.00	0.94
58	Ilomba	1029	0.51	0.00	0.94	0.00	1.45
59	Ilomba	940	0.30	0.00	0.36	0.00	0.66
60	Ilomba	792	1.09	0.00	1.24	0.55	2.88
61	Abura	657	0.65	0.00	2.25	6.75	9.65
62	Potrodom	1734	0.75	0.00	0.37	3.99	5.11
63	Ekki	1800	0.82	0.00	2.05	15.12	18.00
64	Pterygota	57	0.28	2.23	4.62	1.50	8.63
65	Pterygota	7	0.17	2.27	2.42	2.53	7.38
66	Pterygota	30	0.38	0.94	3.03	0.70	5.05
67	Pterygota	229	0.17	1.30	2.20	0.75	4.42
68	Pterygota	152	0.11	1.51	1.00	0.67	3.29
69	Pterygota	230	0.15	0.71	2.54	0.82	4.22
70	Wawa	247	0.27	1.19	0.99	1.38	3.82
71	Wawa	65	0.71	1.99	1.93	0.45	5.08
72	Wawa	242	0.16	0.98	2.16	1.18	4.48
73	Wawa	1808	0.20	0.67	0.62	2.48	3.96
74	Wawa	1332	0.51	1.01	0.34	2.67	4.53
75	Wawa	2298	0.26	1.80	2.76	0.40	5.22
76	Wawa	402	0.45	1.88	0.31	0.60	3.24
77	Wawa	403	0.59	2.40	1.17	9.55	13.70
78	Wawa	404	0.73	6.06	5.14	1.01	12.95
79	Wawa	413	0.79	3.82	1.08	0.63	6.32

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Sample Tree Number	Timber Species	Stock Survey Number	Stump Wood Volume (m^3)	Butt-End Offcut Volume (m^3)	Crown-End Offcut Volume (m^3)	Branch Wood Volume (m^3)	Total Residue Volume (m^3)
80	Wawa	414	0.98	15.86	2.10	8.78	27.72
81	Wawa	1363	1.47	9.49	2.25	1.16	14.37
82	Wawa	1413	0.54	1.49	1.37	2.29	5.69
83	Avodire	1706	0.19	0.00	1.13	0.76	2.09
84	Avodire	1069	0.29	0.00	0.49	2.89	3.67
85	Avodire	1481	0.21	0.00	0.76	0.27	1.24
86	Avodire	2186	0.33	0.00	0.50	3.07	3.90
87	Avodire	2238	0.39	0.14	0.73	4.22	5.48
88	Avodire	13	0.22	0.00	0.38	1.12	1.72
89	Avodire	180	0.22	0.00	0.22	1.34	1.77
90	Avodire	116	0.12	0.00	0.57	0.95	1.63
91	Avodire	119	0.12	0.00	1.44	1.14	2.70
92	Avodire	8118	0.16	0.00	1.25	0.41	1.82
93	Avodire	120	0.18	0.15	0.79	0.69	1.81
94	Avodire	2195	0.39	0.00	0.31	1.95	2.65
95	Ofram	2088	0.40	1.42	2.18	0.09	4.09
96	Ofram	209	0.45	1.32	2.22	0.00	4.00
97	Ofram	2059	0.46	3.19	0.80	0.67	5.12
98	Ofram	400	0.57	3.33	2.78	0.61	7.28
99	Danta	2161	0.28	0.89	0.48	0.31	1.96
100	Danta	152	0.27	0.00	1.00	0.53	1.81
	Total		**58.88**	**150.15**	**128.50**	**282.17**	**619.70**
	Mean		**0.59**	**1.50**	**1.28**	**2.82**	**6.20**
	Std Dev		**0.54**	**2.75**	**1.17**	**3.20**	**5.42**
	CV%		**91.06**	**183.02**	**90.81**	**113.41**	**87.52**
	Minimum		**0.11**	**0.00**	**0.00**	**0.00**	**0.66**
	Maximum		**3.65**	**18.40**	**5.95**	**15.12**	**29.51**
	S. E.		**0.05**	**0.27**	**0.12**	**0.32**	**0.54**

*** N/A Stock survey number was either not written on the stumps or it had been washed away by rains and/or tree exudates.**

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APPENDIX XII

PERCENTAGE DISTRIBUTION (%) OF LOGGING RESIDUE IN SAMPLE TREES

Sample Tree Number	Timber Species	Stock Survey Number	Stump Wood (%)	Butt-End Offcut (%)	Crown-End Offcut (%)	Branch Wood (%)	Total Tree Residue (%)
1	Niangon	1369	4.22	39.06	30.92	25.79	100.00
2	Niangon	1358	12.14	43.33	34.63	9.90	100.00
3	Niangon	1356	5.07	21.72	47.34	25.87	100.00
4	Niangon	1252	5.47	43.24	34.98	16.32	100.00
5	Niangon	1353	8.17	26.95	20.59	44.29	100.00
6	Niangon	N/A	16.46	41.70	34.66	7.17	100.00
7	Niangon	3884	3.67	27.93	19.81	48.59	100.00
8	Niangon	685	17.88	25.33	42.08	14.70	100.00
9	Niangon	1005	16.24	19.41	28.56	35.79	100.00
10	Niangon	1701	57.67	0.00	18.02	24.31	100.00
11	Niangon	2105	5.37	46.15	13.55	34.93	100.00
12	Niangon	810	7.44	45.44	7.74	39.39	100.00
13	Niangon	854	11.70	25.82	0.00	62.48	100.00
14	Niangon	856	3.95	26.64	11.79	57.62	100.00
15	Niangon	1213	14.17	40.12	7.79	37.91	100.00
16	Dahoma	519	2.98	17.14	5.10	74.78	100.00
17	Dahoma	3927	10.02	33.00	8.32	48.66	100.00
18	Dahoma	913	2.75	20.25	15.04	61.96	100.00
19	Dahoma	2218	3.57	17.69	7.92	70.81	100.00
20	Dahoma	806	12.92	21.34	14.41	51.33	100.00
21	Dahoma	858	3.12	11.73	15.67	69.48	100.00
22	Dahoma	252	6.06	34.33	15.59	44.02	100.00
23	Dahoma	609	6.43	45.12	4.61	43.84	100.00
24	Dahoma	591	5.00	28.40	5.81	60.79	100.00
25	Dahoma	643	1.40	20.40	13.85	64.34	100.00
26	Dahoma	294	4.88	20.99	7.27	66.86	100.00
27	Ayan	2946	8.17	29.08	26.46	36.30	100.00
28	Ayan	2656	11.55	0.00	50.50	37.95	100.00
29	Ceiba	2617	8.10	62.37	17.35	12.18	100.00
30	Guarea	3821	9.77	25.04	27.03	38.16	100.00
31	Mahogany	2340	31.40	0.00	12.21	56.39	100.00
32	Mahogany	2100	16.99	46.54	9.64	26.83	100.00
33	Mahogany	405	29.63	0.00	0.00	70.37	100.00
34	Mahogany	570	18.71	0.00	35.96	45.33	100.00
35	Mahogany	1165	13.38	0.00	0.00	86.62	100.00
36	Mahogany	916	17.93	32.00	7.06	43.01	100.00
37	Mahogany	1014	15.62	0.00	0.00	84.38	100.00

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Sample Tree Number	Timber Species	Stock Survey Number	Stump Wood (%)	Butt-End Offcut (%)	Crown-End Offcut (%)	Branch Wood (%)	Total Tree Residue (%)
38	Mahogany	1003	11.29	0.00	0.00	88.71	100.00
39	Edinam	2281	31.74	0.00	0.00	68.26	100.00
40	Adasema	2627	2.74	26.09	31.56	39.60	100.00
41	Aningeria	68	11.80	26.73	46.56	14.90	100.00
42	Antrocaryon	1624	27.97	0.00	0.00	72.03	100.00
43	Walnut	3883	24.55	0.00	25.37	50.08	100.00
44	Walnut	791	15.93	0.00	5.63	78.43	100.00
45	Walnut	2056	8.87	19.14	12.85	59.14	100.00
46	Ogea	*N/A	10.87	0.00	32.67	56.46	100.00
47	Ogea	1858	18.38	0.00	12.17	69.44	100.00
48	Makore	232	19.54	0.00	39.71	40.75	100.00
49	Makore	2645	11.23	0.00	0.00	88.77	100.00
50	Kusia	254	17.87	0.00	44.95	37.19	100.00
51	Bompagya	2366	37.07	0.00	54.32	8.61	100.00
52	Afzelia	489	12.54	0.00	11.40	76.06	100.00
53	Afzelia	262	15.82	0.00	11.04	73.14	100.00
54	Fotie	603	19.54	0.00	12.23	68.23	100.00
55	Fotie	590	23.52	0.00	49.91	26.57	100.00
56	Fotie	467	12.20	0.00	40.81	46.99	100.00
57	Ilomba	1041	32.86	0.00	67.14	0.00	100.00
58	Ilomba	1029	35.24	0.00	64.76	0.00	100.00
59	Ilomba	940	44.98	0.00	55.02	0.00	100.00
60	Ilomba	792	37.94	0.00	42.93	19.13	100.00
61	Abura	657	6.76	0.00	23.34	69.90	100.00
62	Potrodom	1734	14.60	0.00	7.30	78.09	100.00
63	Ekki	1800	4.58	0.00	11.40	84.03	100.00
64	Pterygota	57	3.27	25.84	53.50	17.38	100.00
65	Pterygota	7	2.25	30.71	32.79	34.25	100.00
66	Pterygota	30	7.44	18.71	60.01	13.84	100.00
67	Pterygota	229	3.84	29.28	49.84	17.03	100.00
68	Pterygota	152	3.30	45.80	30.39	20.50	100.00
69	Pterygota	230	3.55	16.83	60.10	19.52	100.00
70	Wawa	247	6.94	31.13	25.79	36.15	100.00
71	Wawa	65	13.93	39.21	38.04	8.82	100.00
72	Wawa	242	3.50	21.82	48.26	26.41	100.00
73	Wawa	1808	5.03	16.82	15.57	62.58	100.00
74	Wawa	1332	11.27	22.28	7.44	59.00	100.00
75	Wawa	2298	5.02	34.47	52.88	7.63	100.00
76	Wawa	402	13.77	58.11	9.56	18.57	100.00
77	Wawa	403	4.30	17.48	8.57	69.65	100.00
78	Wawa	404	5.62	46.82	39.72	7.83	100.00
79	Wawa	413	12.53	60.39	17.16	9.92	100.00
80	Wawa	414	3.54	57.22	7.56	31.67	100.00
81	Wawa	1363	10.25	66.01	15.69	8.05	100.00

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Sample Tree Number	Timber Species	Stock Survey Number	Stump Wood (%)	Butt-End Offcut (%)	Crown-End Offcut (%)	Branch Wood (%)	Total Tree Residue (%)
82	Wawa	1413	9.49	26.27	24.02	40.23	100.00
83	Avodire	1706	9.24	0.00	54.18	36.58	100.00
84	Avodire	1069	7.93	0.00	13.29	78.78	100.00
85	Avodire	1481	17.13	0.00	61.41	21.46	100.00
86	Avodire	2186	8.49	0.00	12.78	78.73	100.00
87	Avodire	2238	7.15	2.50	13.38	76.97	100.00
88	Avodire	13	13.07	0.00	21.97	64.96	100.00
89	Avodire	180	12.14	0.00	12.26	75.60	100.00
90	Avodire	116	7.16	0.00	34.93	57.91	100.00
91	Avodire	119	4.52	0.00	53.38	42.10	100.00
92	Avodire	8118	8.84	0.00	68.83	22.33	100.00
93	Avodire	120	10.01	8.01	43.81	38.17	100.00
94	Avodire	2195	14.66	0.00	11.76	73.58	100.00
95	Ofram	2088	9.80	34.70	53.35	2.15	100.00
96	Ofram	209	11.33	33.03	55.65	0.00	100.00
97	Ofram	2059	8.95	62.36	15.57	13.13	100.00
98	Ofram	400	7.79	45.72	38.16	8.33	100.00
99	Danta	2161	14.14	45.21	24.63	16.02	100.00
100	Danta	152	15.13	0.00	55.40	29.47	100.00
	Total		**1256.81**	**1906.94**	**2596.95**	**4239.30**	**10000.00**
	Mean		**12.57**	**19.07**	**25.97**	**42.39**	**100.00**
	Minimum		**1.40**	**0.00**	**0.00**	**0.00**	**100.00**
	Maximum		**57.67**	**66.01**	**68.83**	**88.77**	**100.00**
	Std Dev		**9.88**	**19.36**	**19.19**	**25.45**	**0.00**
	S. E.		**0.99**	**1.94**	**1.92**	**2.54**	**0.00**
	CV%		**78.63**	**101.51**	**73.91**	**60.03**	**0.00**

* N/A Stock survey number was either not written on the stumps or it had been washed away by rains and/or tree exudates.

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APPENDIX XIII

COMPARISON OF HARVESTING EFFICIENCIES AMONG DIFFERENT HARVESTED TIMBER SPECIES

Timber Species	$\bar{x}$ ± CI[1] (%)	SE[2] (%)	Sample size	Timber Species	$\bar{x}$ ± CI[1] (%)	SE[2] (%)	Sample size	t-value	P[3]	Signif[4] Status
Afzelia	91.24 ± 5.83	0.46	2	Ofram	66.77 ± 7.30	2.29	4	7.09	< 0.002	**
Afzelia	91.24 ± 5.83	0.46	2	Wawa	69.37 ± 7.44	3.42	13	6.35	< 0.0005	***
Afzelia	91.24 ± 5.83	0.46	2	Pterygota	70.17 ± 10.02	3.90	6	2.96	< 0.025	*
Afzelia	91.24 ± 5.83	0.46	2	Ayan	71.10 ± 39.73	3.13	2	6.37	< 0.024	*
Afzelia	91.24 ± 5.83	0.46	2	Dahoma	73.01 ± 4.66	2.09	11	3.59	< 0.004	**
Afzelia	91.24 ± 5.83	0.46	2	Avodire	77.99 ± 4.87	2.21	12	2.36	< 0.036	*
Afzelia	91.24 ± 5.83	0.46	2	Danta	84.13 ± 75.59	5.95	2	1.19	> 0.442	ns
Afzelia	91.24 ± 5.83	0.46	2	Walnut	86.92 ± 13.26	3.08	3	1.08	> 0.358	ns
Afzelia	91.24 ± 5.83	0.46	2	Fotie	87.35 ± 14.86	3.45	3	0.87	> 0.448	ns
Afzelia	91.24 ± 5.83	0.46	2	Ogea	88.63 ± 67.39	5.30	2	0.49	> 0.709	ns
Afzelia	91.24 ± 5.83	0.46	2	Ilomba	90.37 ± 4.98	1.57	4	0.37	> 0.732	ns
Afzelia	91.24 ± 5.83	0.46	2	Mahogany	90.90 ± 7.78	3.29	8	0.05	> 0.962	ns
Afzelia	91.24 ± 5.83	0.46	2	Makore	90.96 ± 86.37	6.80	2	0.04	> 0.974	ns
Makore	90.96 ± 86.37	6.80	2	Ofram	66.77 ± 7.30	2.29	4	4.48	< 0.011	*
Makore	90.96 ± 86.37	6.80	2	Wawa	69.37 ± 7.44	3.42	13	2.34	< 0.036	*
Makore	90.96 ± 86.37	6.80	2	Pterygota	70.17 ± 10.02	3.90	6	2.66	< 0.037	*
Makore	90.96 ± 86.37	6.80	2	Dahoma	73.01 ± 4.66	2.09	11	3.24	< 0.008	**
Makore	90.96 ± 86.37	6.80	2	Danta	84.13 ± 75.59	5.95	2	0.76	> 0.530	ns
Makore	90.96 ± 86.37	6.80	2	Walnut	86.92 ± 13.26	3.08	3	0.63	> 0.575	ns
Makore	90.96 ± 86.37	6.80	2	Fotie	87.35 ± 14.86	3.45	3	0.54	> 0.630	ns
Makore	90.96 ± 86.37	6.80	2	Ogea	88.63 ± 67.39	5.30	2	0.27	> 0.814	ns
Makore	90.96 ± 86.37	6.80	2	Ilomba	90.37 ± 4.98	1.57	4	0.08	> 0.946	ns
Makore	90.96 ± 86.37	6.80	2	Mahogany	90.90 ± 7.78	3.29	8	0.01	> 0.994	ns
Mahogany	90.90 ± 7.78	3.29	8	Ofram	66.77 ± 7.30	2.29	4	4.82	< 0.001	**
Mahogany	90.90 ± 7.78	3.29	8	Wawa	69.37 ± 7.44	3.42	13	4.24	< 0.0005	***
Mahogany	90.90 ± 7.78	3.29	8	Pterygota	70.17 ± 10.02	3.90	6	4.08	< 0.002	**
Mahogany	90.90 ± 7.78	3.29	8	Ayan	71.10 ± 39.73	3.13	2	2.83	< 0.022	*

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Timber Species	$\bar{x}$ ± CI[1] (%)	SE[2] (%)	Sample size	Timber Species	$\bar{x}$ ± CI[1] (%)	SE[2] (%)	Sample size	t-value	P[3]	Signif[4] Status
Mahogany	90.90 ± 7.78	3.29	8	Dahoma	73.01 ± 4.66	2.09	11	4.82	< 0.0005	***
Mahogany	90.90 ± 7.78	3.29	8	Avodire	77.99 ± 4.87	2.21	12	3.39	< 0.003	**
Mahogany	90.90 ± 7.78	3.29	8	Niangon	82.91 ± 3.29	1.53	15	2.52	< 0.020	*
Mahogany	90.90 ± 7.78	3.29	8	Danta	84.13 ± 75.59	5.95	2	0.93	> 0.379	ns
Mahogany	90.90 ± 7.78	3.29	8	Walnut	86.92 ± 13.26	3.08	3	0.69	> 0.510	ns
Mahogany	90.90 ± 7.78	3.29	8	Fotie	87.35 ± 14.86	3.45	3	0.60	> 0.560	ns
Mahogany	90.90 ± 7.78	3.29	8	Ogea	88.63 ± 67.39	5.30	2	0.32	> 0.760	ns
Mahogany	90.90 ± 7.78	3.29	8	Ilomba	90.37 ± 4.98	1.57	4	0.11	> 0.916	ns
Ilomba	90.37 ± 4.98	1.57	4	Ofram	66.77 ± 7.30	2.29	4	8.50	< 0.0005	***
Ilomba	90.37 ± 4.98	1.57	4	Wawa	69.37 ± 7.44	3.42	13	5.59	< 0.0005	***
Ilomba	90.37 ± 4.98	1.57	4	Pterygota	70.17 ± 10.02	3.90	6	4.02	< 0.004	**
Ilomba	90.37 ± 4.98	1.57	4	Ayan	71.10 ± 39.73	3.13	2	6.36	< 0.003	**
Ilomba	90.37 ± 4.98	1.57	4	Dahoma	73.01 ± 4.66	2.09	11	4.75	< 0.0005	***
Ilomba	90.37 ± 4.98	1.57	4	Avodire	77.99 ± 4.87	2.21	12	3.09	< 0.008	**
Ilomba	90.37 ± 4.98	1.57	4	Danta	84.13 ± 75.59	5.95	2	1.02	> 0.478	ns
Ilomba	90.37 ± 4.98	1.57	4	Walnut	86.92 ± 13.26	3.08	3	1.09	> 0.326	ns
Ilomba	90.37 ± 4.98	1.57	4	Fotie	87.35 ± 14.86	3.45	3	0.88	> 0.418	ns
Ilomba	90.37 ± 4.98	1.57	4	Ogea	88.63 ± 67.39	5.30	2	0.43	> 0.686	ns
Ogea	88.63 ± 67.39	5.30	2	Ofram	66.77 ± 7.30	2.29	4	4.62	< 0.010	*
Ogea	88.63 ± 67.39	5.30	2	Dahoma	73.01 ± 4.66	2.09	11	2.91	< 0.014	*
Ogea	88.63 ± 67.39	5.30	2	Avodire	77.99 ± 4.87	2.21	12	1.82	> 0.094	ns
Ogea	88.63 ± 67.39	5.30	2	Niangon	82.91 ± 3.29	1.53	15	1.25	> 0.229	ns
Ogea	88.63 ± 67.39	5.30	2	Danta	84.13 ± 75.59	5.95	2	0.57	> 0.630	ns
Ogea	88.63 ± 67.39	5.30	2	Walnut	86.92 ± 13.26	3.08	3	0.31	> 0.780	ns
Ogea	88.63 ± 67.39	5.30	2	Fotie	87.35 ± 14.86	3.45	3	0.22	> 0.843	ns
Fotie	87.35 ± 14.86	3.45	3	Ofram	66.77 ± 7.30	2.29	4	5.19	< 0.003	**
Fotie	87.35 ± 14.86	3.45	3	Wawa	69.37 ± 7.44	3.42	13	2.41	< 0.030	*
Fotie	87.35 ± 14.86	3.45	3	Pterygota	70.17 ± 10.02	3.90	6	2.80	< 0.027	*
Fotie	87.35 ± 14.86	3.45	3	Ayan	71.10 ± 39.73	3.13	2	3.23	< 0.048	*
Fotie	87.35 ± 14.86	3.45	3	Dahoma	73.01 ± 4.66	2.09	11	3.25	< 0.007	**
Fotie	87.35 ± 14.86	3.45	3	Avodire	77.99 ± 4.87	2.21	12	1.95	> 0.073	ns
Fotie	87.35 ± 14.86	3.45	3	Niangon	82.91 ± 3.29	1.53	15	1.18	> 0.255	ns
Fotie	87.35 ± 14.86	3.45	3	Danta	84.13 ± 75.59	5.95	2	0.51	> 0.644	ns

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Timber Species	$\bar{x}$ ± CI[1] (%)	SE[2] (%)	Sample size	Timber Species	$\bar{x}$ ± CI[1] (%)	SE[2] (%)	Sample size	t-value	P[3]	Signif[4] Status
Fotie	87.35 ± 14.86	3.45	3	Walnut	86.92 ± 13.26	3.08	3	0.09	> 0.930	ns
Walnut	86.92 ± 13.26	3.08	3	Ofram	66.77 ± 7.30	2.29	4	5.39	< 0.003	**
Walnut	86.92 ± 13.26	3.08	3	Wawa	69.37 ± 7.44	3.42	13	2.37	< 0.033	*
Walnut	86.92 ± 13.26	3.08	3	Pterygota	70.17 ± 10.02	3.90	6	2.77	< 0.028	*
Walnut	86.92 ± 13.26	3.08	3	Ayan	71.10 ± 39.73	3.13	2	3.43	< 0.042	*
Walnut	86.92 ± 13.26	3.08	3	Dahoma	73.01 ± 4.66	2.09	11	3.19	< 0.008	**
Walnut	86.92 ± 13.26	3.08	3	Avodire	77.99 ± 4.87	2.21	12	1.88	> 0.083	ns
Walnut	86.92 ± 13.26	3.08	3	Niangon	82.91 ± 3.29	1.53	15	1.08	> 0.296	ns
Walnut	86.92 ± 13.26	3.08	3	Danta	84.13 ± 75.59	5.95	2	0.47	> 0.671	ns
Danta	84.13 ± 75.59	5.95	2	Ofram	66.77 ± 7.30	2.29	4	3.46	< 0.026	*
Danta	84.13 ± 75.59	5.95	2	Ayan	71.10 ± 39.73	3.13	2	1.94	> 0.231	ns
Danta	84.13 ± 75.59	5.95	2	Dahoma	73.01 ± 4.66	2.09	11	2.04	> 0.066	ns
Danta	84.13 ± 75.59	5.95	2	Avodire	77.99 ± 4.87	2.21	12	1.04	> 0.319	ns
Danta	84.13 ± 75.59	5.95	2	Niangon	82.91 ± 3.29	1.53	15	0.26	> 0.795	ns
Niangon	82.91 ± 3.29	1.53	15	Ofram	66.77 ± 7.30	2.29	4	5.01	< 0.0005	***
Niangon	82.91 ± 3.29	1.53	15	Wawa	69.37 ± 7.44	3.42	13	3.61	< 0.002	**
Niangon	82.91 ± 3.29	1.53	15	Pterygota	70.17 ± 10.02	3.90	6	3.73	< 0.001	**
Niangon	82.91 ± 3.29	1.53	15	Dahoma	73.01 ± 4.66	2.09	11	3.91	< 0.001	**
Niangon	82.91 ± 3.29	1.53	15	Avodire	77.99 ± 4.87	2.21	12	1.88	> 0.072	ns
Avodire	77.99 ± 4.87	2.21	12	Ofram	66.77 ± 7.30	2.29	4	2.73	< 0.016	*
Avodire	77.99 ± 4.87	2.21	12	Wawa	69.37 ± 7.44	3.42	13	2.08	< 0.049	*
Avodire	77.99 ± 4.87	2.21	12	Pterygota	70.17 ± 10.02	3.90	6	1.88	> 0.078	ns
Avodire	77.99 ± 4.87	2.21	12	Ayan	71.10 ± 39.73	3.13	2	1.21	> 0.250	ns
Avodire	77.99 ± 4.87	2.21	12	Dahoma	73.01 ± 4.66	2.09	11	1.63	> 0.119	ns
Dahoma	73.01 ± 4.66	2.09	11	Ofram	66.77 ± 7.30	2.29	4	1.65	> 0.122	ns
Dahoma	73.01 ± 4.66	2.09	11	Wawa	69.37 ± 7.44	3.42	13	0.91	> 0.375	ns
Dahoma	73.01 ± 4.66	2.09	11	Pterygota	70.17 ± 10.02	3.90	6	0.71	> 0.490	ns
Dahoma	73.01 ± 4.66	2.09	11	Ayan	71.10 ± 39.73	3.13	2	0.37	> 0.720	ns
Ayan	71.10 ± 39.73	3.13	2	Ofram	66.77 ± 7.30	2.29	4	1.10	> 0.333	ns
Ayan	71.10 ± 39.73	3.13	2	Wawa	69.37 ± 7.44	3.42	13	0.19	> 0.851	ns
Ayan	71.10 ± 39.73	3.13	2	Pterygota	70.17 ± 10.02	3.90	6	0.13	> 0.902	ns
Pterygota	70.17 ± 10.02	3.90	6	Ofram	66.77 ± 7.30	2.29	4	0.65	> 0.531	ns
Pterygota	70.17 ± 10.02	3.90	6	Wawa	69.37 ± 7.44	3.42	13	0.14	> 0.891	ns
Wawa	69.37 ± 7.44	3.42	13	Ofram	66.77 ± 7.30	2.29	4	0.63	> 0.536	ns

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1: $\bar{x}$ is the sample mean of the proportions (%) of the bole volumes extracted from a given harvested timber species; and, CI is the 95 % confidence interval for the sample mean for that particular timber species.

2: SE is the standard error of the sample mean of the proportions (%) of the bole volumes extracted for a given harvested timber species.

3: *P* is the observed significance level (or probability) associated with the computed student-*t* value of 2 compared sample means.

4: (*), (**), and (***) indicates significant differences between 2 sample means at the 95 %, 99 %, and 99.9 % confidence levels respectively. (ns) indicates non- significant difference between 2 sample means at the 95 % confidence level.

APPENDIX XIV

HARVESTING EFFICIENCY OF LARGE-SCALE LOGGING COMPANY (# 1)

Sample Tree Number	Timber Species	Stump Wood Volume (%)	Butt-End Offcut Volume (%)	Extracted Bole Volume (%)	Total Crown Volume (%)	Total Tree Volume (%)	Proportion of Bole Volume Extracted (%)
1	Niangon	1.32	12.24	68.67	17.77	100.00	74.71
2	Niangon	2.12	7.55	82.57	7.76	100.00	84.02
3	Niangon	1.49	6.39	70.57	21.55	100.00	76.39
4	Niangon	0.88	6.93	83.98	8.22	100.00	86.23
5	Niangon	2.39	7.88	70.76	18.97	100.00	81.29
6	Niangon	4.42	11.19	73.18	11.22	100.00	74.61
7	Niangon	1.26	9.56	65.78	23.40	100.00	78.90
8	Niangon	3.69	5.23	79.34	11.73	100.00	81.83
9	Niangon	4.49	5.37	72.35	17.79	100.00	80.30
10	Niangon	6.57	0.00	88.61	4.82	100.00	91.13
11	Niangon	1.05	9.04	80.41	9.50	100.00	86.32
12	Dahoma	1.49	8.55	50.11	39.85	100.00	79.93
13	Dahoma	4.86	16.01	51.48	27.65	100.00	67.39
14	Dahoma	1.57	11.57	42.89	43.98	100.00	66.38
15	Dahoma	2.45	12.13	31.42	54.00	100.00	61.08
16	Guarea	4.36	11.17	55.40	29.07	100.00	66.76
17	Ayan	3.47	12.36	57.49	26.68	100.00	67.98
18	Ayan	4.14	0.00	64.12	31.73	100.00	74.23
19	Ceiba	3.19	24.60	60.56	11.65	100.00	63.61
20	Mahogany	4.28	0.00	86.36	9.36	100.00	93.56
21	Mahogany	6.46	17.70	61.98	13.87	100.00	69.02
22	Edinam	4.20	0.00	86.76	9.04	100.00	95.38
23	Adasema	0.87	8.31	68.15	22.67	100.00	77.99
24	Antrocaryon	8.11	0.00	71.00	20.89	100.00	89.75
25	Walnut	4.76	0.00	80.62	14.62	100.00	89.29
26	Walnut	5.15	0.00	67.67	27.18	100.00	90.66
27	Ogea	3.42	0.00	68.51	28.07	100.00	83.33
28	Makore	4.71	0.00	75.90	19.39	100.00	84.16
29	Makore	1.91	0.00	83.04	15.05	100.00	97.76
30	Kusia	3.38	0.00	81.10	15.53	100.00	87.23
31	Bompagya	4.49	0.00	87.90	7.62	100.00	88.82
	Total	**106.95**	**203.77**	**2168.67**	**620.61**	**3100.00**	**2490.02**
	Mean	**3.45**	**6.57**	**69.96**	**20.02**	**100.00**	**80.32**
	Minimum	**0.87**	**0.00**	**31.42**	**4.82**		**61.08**
	Maximum	**8.11**	**24.60**	**88.61**	**54.00**		**97.76**
	CV%	**53.01**	**98.13**	**19.83**	**57.24**		**12.30**
	S. E.	**0.33**	**1.16**	**2.49**	**2.06**		**1.77**

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APPENDIX XV

HARVESTING EFFICIENCY OF LARGE-SCALE LOGGING COMPANY (# 2)

Sample Tree Number	Timber Species	Stump Wood Volume (%)	Butt-End Offcut Volume (%)	Extracted Bole Volume (%)	Total Crown Volume (%)	Total Tree Volume (%)	Proportion of Bole Volume Extracted (%)
1	Niangon	1.13	6.91	84.79	7.17	100.00	90.19
2	Niangon	2.21	4.88	81.12	11.80	100.00	91.97
3	Niangon	0.93	6.28	76.44	16.35	100.00	88.45
4	Niangon	4.56	12.90	67.84	14.70	100.00	77.26
5	Dahoma	5.33	8.79	58.79	27.09	100.00	74.56
6	Dahoma	1.61	6.05	48.45	43.90	100.00	75.48
7	Dahoma	2.47	14.00	59.23	24.30	100.00	72.18
8	Dahoma	1.63	11.44	74.65	12.28	100.00	83.99
9	Dahoma	2.30	13.08	53.94	30.68	100.00	74.91
10	Dahoma	0.81	11.77	42.28	45.14	100.00	67.26
11	Afzelia	3.44	0.00	72.57	23.99	100.00	91.70
12	Afzelia	4.34	0.00	72.57	23.09	100.00	90.78
13	Mahogany	2.89	0.00	90.25	6.86	100.00	96.90
14	Mahogany	3.52	0.00	81.18	15.30	100.00	88.75
15	Mahogany	2.19	0.00	83.62	14.19	100.00	97.45
16	Mahogany	2.59	4.63	85.54	7.24	100.00	91.21
17	Mahogany	4.04	0.00	74.11	21.84	100.00	94.82
18	Mahogany	3.32	0.00	70.63	26.05	100.00	95.52
19	Fotie	3.20	0.00	83.65	13.16	100.00	94.15
20	Fotie	5.15	0.00	78.09	16.76	100.00	82.91
21	Fotie	3.05	0.00	74.99	21.96	100.00	84.98
22	Ilomba	4.40	0.00	86.61	8.99	100.00	86.61
23	Ilomba	2.93	0.00	91.68	5.39	100.00	91.68
24	Ilomba	2.74	0.00	93.90	3.35	100.00	93.90
25	Ilomba	4.89	0.00	87.10	8.00	100.00	89.31
26	Abura	2.08	0.00	69.20	28.72	100.00	88.18
27	Potrodom	4.79	0.00	67.17	28.04	100.00	90.33
28	Ekki	1.91	0.00	58.38	39.72	100.00	89.77
29	Ogea	3.21	0.00	82.56	14.24	100.00	93.93
30	Walnut	3.26	7.04	63.24	26.46	100.00	80.80
	Total	**90.93**	**107.76**	**2214.54**	**586.76**	**3000.00**	**2609.96**
	Mean	**3.03**	**3.59**	**73.82**	**19.56**	**100.00**	**87.00**
	Minimum	**0.81**	**0.00**	**42.28**	**3.35**		**67.26**
	Maximum	**5.33**	**14.00**	**93.90**	**45.14**		**97.45**
	Std Dev	**1.25**	**4.95**	**13.04**	**11.13**		**7.96**
	CV%	**41.34**	**137.91**	**17.67**	**56.89**		**9.14**
	S. E.	**0.23**	**0.90**	**2.38**	**2.03**		**1.45**

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APPENDIX XVI

HARVESTING EFFICIENCY OF MEDIUM-SCALE LOGGING COMPANY

Sample Tree Number	Timber Species	Stump Wood Volume (%)	Butt-End Offcut Volume (%)	Extracted Bole Volume (%)	Total Crown Volume (%)	Total Tree Volume (%)	Proportion of Bole Volume Extracted (%)
1	Wawa	1.72	5.75	65.82	26.71	100.00	83.73
2	Wawa	3.79	7.49	66.39	22.33	100.00	82.81
3	Wawa	1.85	12.71	63.13	22.31	100.00	64.95
4	Wawa	4.07	17.18	70.44	8.31	100.00	74.53
5	Wawa	2.70	10.99	37.13	49.17	100.00	66.06
6	Wawa	2.40	20.03	57.21	20.35	100.00	59.20
7	Wawa	5.51	26.58	55.99	11.92	100.00	58.55
8	Wawa	1.28	20.62	63.96	14.14	100.00	72.20
9	Wawa	6.04	38.87	41.11	13.98	100.00	43.16
10	Wawa	3.12	8.64	67.11	21.13	100.00	77.35
11	Avodire	4.21	0.00	54.47	41.32	100.00	65.36
12	Avodire	3.96	0.00	50.08	45.96	100.00	82.54
13	Avodire	5.19	0.00	69.70	25.11	100.00	74.55
14	Avodire	4.73	0.00	44.23	51.04	100.00	78.85
15	Avodire	3.50	1.22	51.08	44.20	100.00	81.93
16	Avodire	4.44	0.00	66.06	29.50	100.00	84.75
17	Avodire	4.12	0.00	66.10	29.79	100.00	88.88
18	Avodire	2.95	0.00	58.83	38.22	100.00	77.25
19	Avodire	1.87	0.00	58.74	39.39	100.00	71.09
20	Avodire	3.57	0.00	59.65	36.78	100.00	65.56
21	Avodire	3.05	2.44	69.51	24.99	100.00	78.67
22	Avodire	5.47	0.00	62.72	31.81	100.00	86.43
23	Ofram	3.93	13.92	59.87	22.27	100.00	60.39
24	Ofram	3.80	11.07	66.47	18.66	100.00	66.47
25	Ofram	2.97	20.72	66.76	9.54	100.00	69.81
26	Ofram	2.45	14.38	68.55	14.62	100.00	70.39
27	Danta	1.64	5.24	88.40	4.71	100.00	90.08
28	Danta	4.29	0.00	71.65	24.07	100.00	78.18
29	Dahoma	2.10	9.04	56.93	31.93	100.00	79.96
	Total	**100.72**	**246.90**	**1778.11**	**774.27**	**2900.00**	**2133.65**
	Mean	**3.47**	**8.51**	**61.31**	**26.70**	**100.00**	**73.57**
	Minimum	**1.28**	**0.00**	**37.13**	**4.71**		**43.16**
	Maximum	**6.04**	**38.87**	**88.40**	**51.04**		**90.08**
	Std Dev	**1.26**	**9.91**	**10.27**	**12.62**		**10.62**
	CV%	**36.41**	**116.45**	**16.75**	**47.28**		**14.43**
	S. E.	**0.23**	**1.84**	**1.91**	**2.34**		**1.97**

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APPENDIX XVII

HARVESTING EFFICIENCY OF SMALL-SCALE LOGGING COMPANY

Sample Tree Number	Timber Species	Stump Wood Volume (%)	Butt-End Offcut Volume (%)	Extracted Bole Volume (%)	Total Crown Volume (%)	Total Tree Volume (%)	Proportion of Bole Volume Extracted (%)
1	Pterygota	1.39	11.01	57.41	30.19	100.00	62.00
2	Pterygota	1.11	15.20	50.52	33.17	100.00	60.83
3	Pterygota	2.88	7.24	61.28	28.60	100.00	64.75
4	Pterygota	1.14	8.68	70.37	19.82	100.00	74.11
5	Pterygota	0.57	7.86	82.84	8.74	100.00	85.86
6	Pterygota	1.10	5.21	69.05	24.64	100.00	73.49
7	Wawa	1.86	8.33	73.23	16.58	100.00	81.08
8	Wawa	6.20	17.46	55.47	20.87	100.00	57.73
9	Wawa	0.87	5.40	75.24	18.49	100.00	80.51
10	Aningeria	4.61	10.44	60.94	24.01	100.00	64.71
	Total	**21.73**	**96.83**	**656.34**	**225.10**	**1000.00**	**705.05**
	Mean	**2.17**	**9.68**	**65.63**	**22.51**	**100.00**	**70.51**
	Minimum	**0.57**	**5.21**	**50.52**	**8.74**		**57.73**
	Maximum	**6.20**	**17.46**	**82.84**	**33.17**		**85.86**
	Std Dev	**1.86**	**4.00**	**10.11**	**7.21**		**9.81**
	CV%	**85.43**	**41.26**	**15.41**	**32.02**		**13.91**
	S. E.	**0.59**	**1.26**	**3.20**	**2.28**		**3.10**

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APPENDIX XVIII

COMPARISON OF HARVESTING EFFICIENCIES AMONG LOGGING COMPANIES

Logger[1]	$\bar{x} \pm CI^2$ (%)	SE[3] (%)	Sample Size	Logger[1]	$\bar{x} \pm CI^2$ (%)	SE[3] (%)	Sample Size	t-value	P^4	Signif.[5] Status
LS # 2	87.00 ± 2.97	1.45	30	SS	70.51 ± 7.01	3.10	10	5.36	< 0.0005	***
LS # 2	87.00 ± 2.97	1.45	30	MS	73.57 ± 4.04	1.97	29	5.51	< 0.0005	***
LS # 2	87.00 ± 2.97	1.45	30	LS # 1	80.32 ± 3.62	1.77	31	2.90	< 0.005	**
LS # 1	80.32 ± 3.62	1.77	31	SS	70.51 ± 7.01	3.10	10	2.74	< 0.009	**
LS # 1	80.32 ± 3.62	1.77	31	MS	73.57 ± 4.04	1.97	29	2.55	< 0.013	*
MS	73.57 ± 4.04	1.97	29	SS	70.51 ± 7.01	3.10	10	0.80	> 0.427	ns

1: LS # 1 represents the first large-scale logger; LS # 2 represents the second large-scale logger; MS represents the medium-scale logger; and, SS represents the small-scale logger.

2: $\bar{x}$ is the sample mean of the proportions (%) of the bole volumes extracted by a logging company; and, CI is the 95 % confidence interval for the sample mean for that particular logging company.

3: SE is the standard error of the sample mean of the proportions (%) of the bole volumes extracted by a logging company.

4: *P* is the observed significance level (or probability) associated with the computed student-*t* value of 2 compared sample means.

5: (*), (**), and (***) indicates significant differences between 2 sample means at the 95 %, 99 %, and 99.9 % confidence levels respectively. (ns) indicates non- significant difference between 2 sample means at the 95 % confidence level.

APPENDIX XIX

REQUIRED SAMPLE SIZES FOR NIANGON TIMBER SPECIES

Parameter	Summary Statistics			Number of	Samples Required	
	Mean (m)	SE (m)	CV (%)	Observations	$^*n_1$	$^*n_2$
Stumps						
Top diameter	0.66	0.04	22.80	15	23	12
Height	0.88	0.04	16.34	15	13	8
Butt-end offcuts						
Bottom diameter	0.66	0.04	22.80	15	23	12
Top diameter	0.95	0.05	20.87	15	20	10
Length	2.04	0.23	44.54	15	80	37
Extracted boles						
Bottom diameter	0.95	0.05	20.87	15	20	10
Top diameter	0.57	0.03	18.77	15	16	9
Length	22.53	1.02	17.49	15	15	8
Top-end offcuts						
Bottom diameter	0.57	0.03	18.77	15	16	9
Top diameter	0.59	0.04	28.30	15	34	17
Length	3.06	0.57	72.05	15	200	93

* n_1 = required sample sizes estimated at ±10 % allowable error and 95 % confidence level; and,

* n_2 = required sample sizes estimated at ±15 % allowable error and 95 % confidence level.

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APPENDIX XX

REQUIRED SAMPLE SIZES FOR DAHOMA TIMBER SPECIES

Parameter	Summary Statistics			Number of	Samples Required	
	Mean (m)	SE (m)	CV (%)	Observations	*n_1	*n_2
Stumps						
Top diameter	0.90	0.07	24.19	11	25	13
Height	0.85	0.05	18.49	11	16	9
Butt-end offcuts						
Bottom diameter	0.90	0.07	24.19	11	25	13
Top diameter	1.03	0.04	12.53	11	9	4 to 8
Length	3.60	0.25	22.83	11	23	12
Extracted boles						
Bottom diameter	1.03	0.04	12.53	11	9	4 to 8
Top diameter	0.81	0.03	13.57	11	10	5 to 7
Length	18.71	1.61	28.46	11	34	17
Top-end offcuts						
Bottom diameter	0.81	0.03	13.57	11	10	5 to 7
Top diameter	0.94	0.06	19.68	11	18	10
Length	1.93	0.27	47.10	11	89	42

*** n_1 = required sample sizes estimated at ±10 % allowable error and 95 % confidence level; and,**

*** n_2 = required sample sizes estimated at ±15 % allowable error and 95 % confidence level.**

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APPENDIX XXI

REQUIRED SAMPLE SIZES FOR MAHOGANY TIMBER SPECIES

Parameter	Summary Statistics			Number of	Samples Required	
	Mean (m)	SE (m)	CV (%)	Observations	*n_1	*n_2
Stumps						
Top diameter	1.03	0.06	16.16	8	13	7
Height	0.89	0.04	14.19	8	11	6
Butt-end offcuts						
Bottom diameter	1.03	0.06	16.16	8	13	7
Top diameter	1.02	0.04	11.91	8	8	4 to 7
Length	0.63	0.48	215.98	8	1792	797
Extracted boles						
Bottom diameter	1.05	0.04	12.00	8	9	4 to 7
Top diameter	0.66	0.05	21.28	8	20	11
Length	26.98	2.04	21.38	8	21	11
Top-end offcuts						
Bottom diameter	0.66	0.05	21.28	8	20	11
Top diameter	0.68	0.04	17.87	8	15	8
Length	1.39	0.93	189.69	8	1383	615

* n_1 = required sample sizes estimated at ±10 % allowable error and 95 % confidence level; and,

* n_2 = required sample sizes estimated at ±15 % allowable error and 95 % confidence level.

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APPENDIX XXII

REQUIRED SAMPLE SIZES FOR PTERYGOTA TIMBER SPECIES

Parameter	Summary Statistics			Number of	Samples Required	
	Mean (m)	SE (m)	CV (%)	Observations	*n_1	*n_2
Stumps						
Top diameter	0.56	0.05	22.17	6	22	11
Height	0.83	0.05	16.15	6	13	7
Butt-end offcuts						
Bottom diameter	0.56	0.05	22.17	6	22	11
Top diameter	0.84	0.04	10.44	6	7	4 to 5
Length	3.82	0.83	52.95	6	113	51
Extracted boles						
Bottom diameter	0.84	0.04	10.44	6	7	4 to 5
Top diameter	0.62	0.03	11.76	6	8	5
Length	24.33	2.23	22.47	6	22	12
Top-end offcuts						
Bottom diameter	0.62	0.03	11.76	6	8	5
Top diameter	0.51	0.03	14.58	6	11	7
Length	9.93	1.26	31.16	6	41	20

*** n_1 = required sample sizes estimated at ±10 % allowable error and 95 % confidence level; and,**

*** n_2 = required sample sizes estimated at ±15 % allowable error and 95 % confidence level.**

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APPENDIX XXIII

REQUIRED SAMPLE SIZES FOR WAWA TIMBER SPECIES

Parameter	Summary Statistics			Number of	Samples Required	
	Mean (m)	SE (m)	CV (%)	Observations	*n_1	*n_2
Stumps						
Top diameter	0.93	0.07	27.19	13	31	16
Height	0.78	0.04	20.22	13	19	10
Butt-end offcuts						
Bottom diameter	0.93	0.07	27.19	13	31	16
Top diameter	0.98	0.07	24.88	13	27	14
Length	4.02	0.77	69.16	13	184	86
Extracted boles						
Bottom diameter	0.98	0.07	24.88	13	27	14
Top diameter	0.66	0.04	24.45	13	26	13
Length	21.12	1.30	22.22	13	22	11
Top-end offcuts						
Bottom diameter	0.66	0.04	24.45	13	26	13
Top diameter	0.66	0.07	35.75	13	53	25
Length	5.51	1.21	78.98	13	240	111

* n_1 = required sample sizes estimated at ±10 % allowable error and 95 % confidence level; and,

* n_2 = required sample sizes estimated at ±15 % allowable error and 95 % confidence level.

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APPENDIX XXIV

REQUIRED SAMPLE SIZES FOR AVODIRE TIMBER SPECIES

Parameter	Summary Statistics			Number of	Samples Required	
	Mean (m)	SE (m)	CV (%)	Observations	*n_1	*n_2
Stumps						
Top diameter	0.72	0.03	12.96	12	9	5 to 6
Height	0.56	0.04	22.42	12	22	12
Butt-end offcuts						
Bottom diameter	0.72	0.03	12.96	12	9	5 to 6
Top diameter	0.72	0.03	12.96	12	9	5 to 6
Length	0.05	0.04	245.08	12	2308	1026
Extracted boles						
Bottom diameter	0.72	0.03	12.96	12	9	5 to 6
Top diameter	0.60	0.04	21.70	12	21	11
Length	10.23	0.60	20.20	12	19	10
Top-end offcuts						
Bottom diameter	0.60	0.04	21.70	12	21	11
Top diameter	0.66	0.06	32.20	12	43	21
Length	3.02	0.72	82.84	12	264	120

*** n_1 = required sample sizes estimated at ±10 % allowable error and 95 % confidence level; and,**

*** n_2 = required sample sizes estimated at ±15 % allowable error and 95 % confidence level.**

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