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The Development of Forest Energy Resources

GHANA

FOREST INVENTORY REPORT

for

Subri River, Bonsa River, Neung and Pra Suhien Forest Reserves

by

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SUMMARY

Between March 1980 and June 1982 a forest inventory of 107,850 ha of reserved forest comprising Subri River, Bonsa River, Pra Suhien, and Neung Forest Reserves in the Western Region of Ghana was carried out. A stratified sample of 1 ha. fixed plots on a systematic 1.25 by 1.5 km grid was employed. Subplots of 0.04 and 0.08 ha were used to estimate understorey trees to 5 cm diameter. A total of 505 plots were laid. In addition volume sampling was carried out by optical dendrometry (1441 trees) and felled sampling (102 trees over 40 cm diameter). The felled sampling included large and samll trees, and estiamted bole and branch wood. A total volume tarif was produced, as well as bole volume tarifs for species groups.

Results showed average total volumes around 460 m^3/ha of which 54 m^3/ha was bole wood of quality timber species, 72 m^3/ha of pulp and paper species, and 234 m^3/ha extractable for wood energy. With the estimated stacking factor of 0.624, wood energy averaged 375 steres/ha. Residual wood comprised 100 m^3/ha of very small material, buttress wood, etc not practicably utilisable. Large size classes were somewhat deficient, with heavy regeneration in all reserves, consistent with their logged-over condition, but considerable quantities of valuable timbers remain.

Some species were widely distributed and common such a *Piptadeniastrum africanum*, a useful construction timber. *Turraeanthus africanus* useful for pulp or plywood was very common in Pra Suhien FR, and common on parts of Subri River FR. Other common species were *Dialium aubrevillei*, *Uapaca guineensis*, *Parkia bicolor*, *Ceiba pentandra*, and *Sacoglottis gabonensis*.

A permanent Forest Inventory Unit was established to permit extension of the inventory to other reserves by the Ghana Forestry Department. Data processing facilities based on low cost microcomputers were introduced and proved reliable, cost-effective, and easily used by local staff.

ACKNOWLEDGMENTS

The work described in this report was carried out under the auspices of UNDP/FAO Project GHA/74/013; accordingly it owes much to the energy and involvement of the Project Manager, Dr.D.E. Earl.

The Chief Conservator of Forests, Ghana, Mr. J. Francois, gave every encouragement and assistance to the work. Forestry Department staff executed all phases of the field work, often under conditions of considerable hardship and difficulty. The Forestry Department also provided an excellent counterpart to the present author in the person of Senior Asst. Conservator of Forests F.K. Odoom; in the later stages the fieldwork was carried out entirely under the latter's direction.

Conservator of Forests for the Western/Central Regions, Mr. E.K. Afanyadey, and Project Co-Manager Dr.E.Y. Djokotoe also assisted the work materially at different times.

DISCLAIMER

This field document is one of a series of reports prepared during the course of UNDP/FAO Project GHA/74/013 "Development of Forest Energy Resources in Ghana". The conclusions and recommendations are those considered appropriate at the time of its preparation. As a field document, the contents of the report are the sole responsibility of the project; endorsement by the FAO is not necessarily implied.

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1. INTRODUCTION

1.1 Objectives

The present author's terms of reference were to prepare stand tables by size classes and species of total volume on Subri River, Bonsa River, Neung, and Pra Suhien Forest Reserves, in line with the recommendations of an earlier consultant's report [1]*. The principle objective of this exercise was to provide basic information for the planning and management of these reserves for the production of renewable energy.

Secondary objectives were the training of Forestry Department personnel in inventory procedures, instrument use, and data processing and analysis. These secondary objectives were crystallized into the formation of a Forest Inventory Unit within the Forestry Department which should retain a capability for ongoing inventory operations and mensurational analysis after the closure of UNDP/FAO project.

Interest in a pulp and paper mill at Daboase led to inventory analysis focussing to some extent upon the availability of indigenous pulp and paper species, and providing useful data in this respect to a number of visiting missions concerned with the mill.

Mensurational studies carried out by the author on plantation species are not covered by this report, but are detailed elsewhere [6]; another report should be forthcoming on taper functions for *Gmelina arborea*.

1.2 Background

Figure 1 shows the four forest reserves included in the inventory. Their respective areas are as follows:

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* Numbers in square brackets are references.

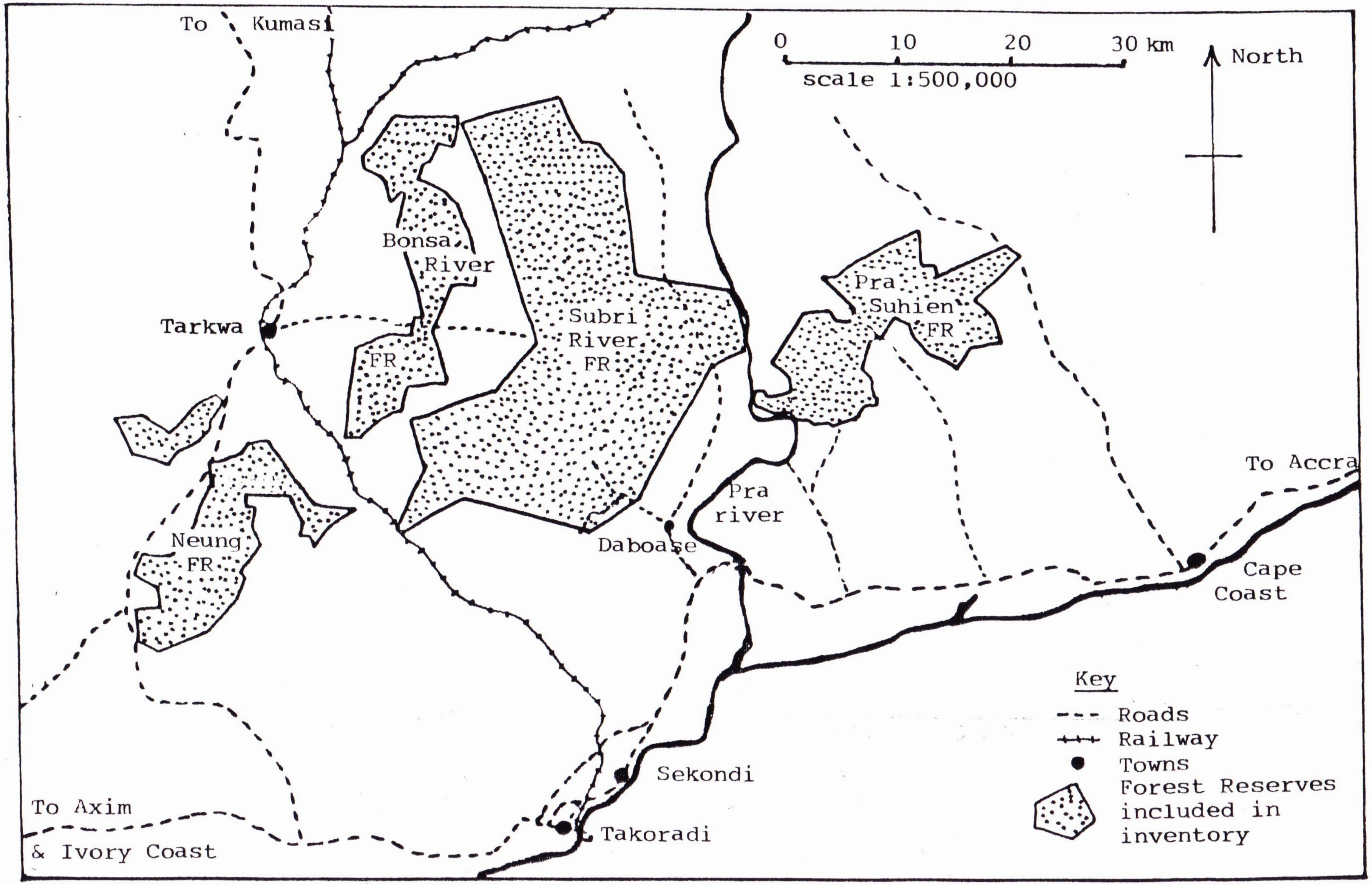


Figure 1 : Location of forest reserves covered by the inventory

Subri River FR	57,030 ha.
Bonsa River FR	16,370
Neung FR	16,370
Pra Suhien FR	18,080
Total	107,850 ha.

According to Hall's recent classification of forest ecosystems in Ghana [2], these reserves lie in the moist evergreen forest zone. The Forestry Department's older classification according to Taylor [3] places the reserves on the transition between the rainforest and the moist semi-deciduous Celtis-Triplochiton forest.

Rainfall varies from 1800 mm per annum on the western margin of the inventory zone to 1300 mm in the east. Topography is generally undulating, sometimes steeply so, at altitudes from 50 to 170 m. above sea level. The area is transected by numerous small rivers, which drain ultimately to the Pra or Bonsa Rivers.

The forests have mostly been exploited for commercial timbers, sometimes on a number of occasions. This has lead to an enrichment of smaller size classes, and an impoverishment of the primary economic species. Secondary species (e.g. <u>Turreanthus africanus</u>, Avodire; <u>Piptadeniastrum africanum</u>, Dahoma) are still found in considerable quantity and appear to be regenerating well. Evidence of this logging activities is widespread, both as crown and bole damage, and from the network of extraction roads. Many of these latter proved useful during the inventory for four-wheel drive access and as footpaths. Pra Suhien is however the only reserve of the four in which logging is still current on a significant scale.

2. SAMPLING METHOD

2.1 Sampling design

In line with earlier consultant's recommendations [1], it was decided to use a systematic sampling design, stratified into blocks. The blocks were considered to be primarily logistic rather than statistical in function. Within blocks, plots were laid on a 1.5 by 1.5 km square grid (Bonsa River, Neung, and Pra Suhien FR's) or a 1.25 by 1.5 km grid (Subri River FR). The orientation of the grid was variable between blocks and was determined primarily by logistic and topographic factors.

2.2 Plot layout

The plot layout was as suggested by the original consultant [1], but with minor amendments. Figure 2 shows the dimensions. Each plot was 250 m. long, subdivided into five sections for recording purposes. The plots were 20 m. wide each side of the access lines giving a total of 250 by 40 m. or 1 ha. area. At the start of the main plot two overlapping subplots were recorded, termed A and B respectively. Subplot A was 20 m by 20 m. Subplot B was 40 m. by 20 m and included A. Different diameter measurement limits were imposed on subplots A and B as against those on the main plot, as detailed below.

Measurements taken on the plot were as follows:

Main plot	:	Diameter and species of all trees 40 cm diameter and above.
Subplot A	:	Diameter and species of all trees of 5 cm and above.
Subplot B	:	Diameter and species of all trees of 10 cm and above.

Diameter was either measured by girth tape graduated in πcm units; or, where this was not possible, estimated optically

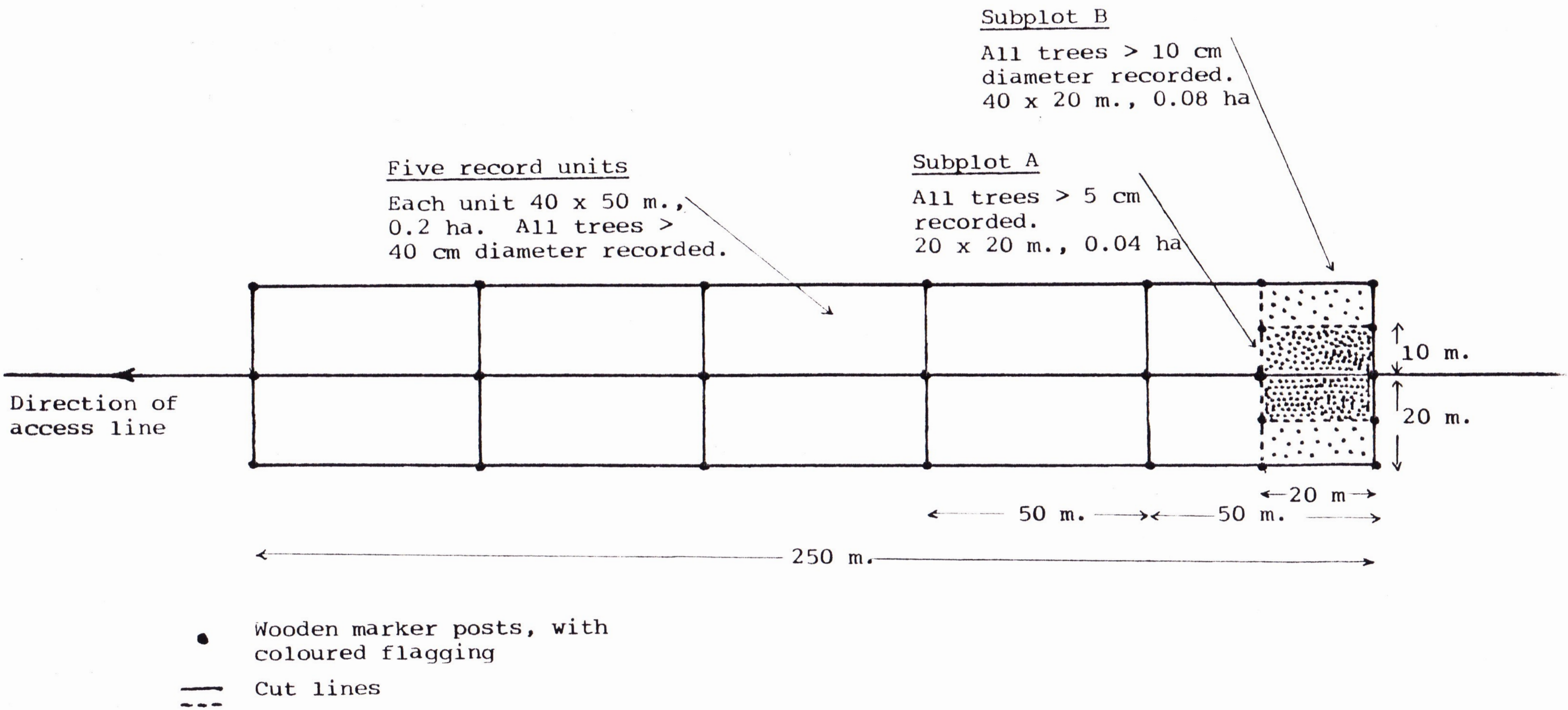


Figure 2 : Inventory plot layout

using a Relascope. The point of measurement was at 1.3 m. above ground except for buttressed or aerial rooted trees, where it was 1 m. above the point of convergence of the buttress or aerial roots.

Species identification was by trained tree spotters, and was based on the list given in Appendix A. This is a revision of an older Forestry Department list made by J.B. Hall for the project in June 1980.

2.3 Block layout

Figure 3 shows the typical organization of plots within a block for one example. The main access lines run parallel, either from the reserve boundary, or from a base line. Block areas ranged considerably, as shown in Table 1, generally becoming larger as the work progressed. This reflected the increasing efficiency of the inventory teams, as the blocks were intended to represent one month's work by a team.

The access lines between plots were surveyed by chain and compass, with slope corrections being applied on slopes over 5°. All forest reserves are marked with boundary pillars of concrete at 880 yard (c. 800 m.) intervals. Field instructions included a map of each block, similar to figure 3, and compass bearings and distances for each line and plot, initially starting with the numbered reserve boundary pillars. Outline maps of each reserve showing the boundary pillar locations and numbers are available from the Forest Planning Branch of the Forestry Department in Kumasi.

Table 1 : Details of Inventory Blocks

Block	Area	No. Plots	Sampling %
SUBRI RIVER			
1	3960	24	
2	2310	11	
3	3690	21	
4	4240	19	
5	5030	23	
6	2130	15	
7	2860	15	
8	4100	19	
9	5660	25	
10	3710	18	
11	3170	13	
12	4360	24	
13	3130	20	
14	2980	15	
15	3210	17	
16	2490	13	
Total	57030 ha.	292	0.51 %
BONSA RIVER			
1	5320	22	
2	6020	26	
3	5030	23	
Total	16370 ha.	71	0.43 %
NEUNG			
1	3140	14	
2	4920	20	
3	8310	34	
Total	16370 ha.	68	0.42 %
PRA SUHIEN			
1	7990	34	
2	10090	40	
Total	18080 ha.	74	0.41 %
Grand total	107,850 ha.	505	0.47 %

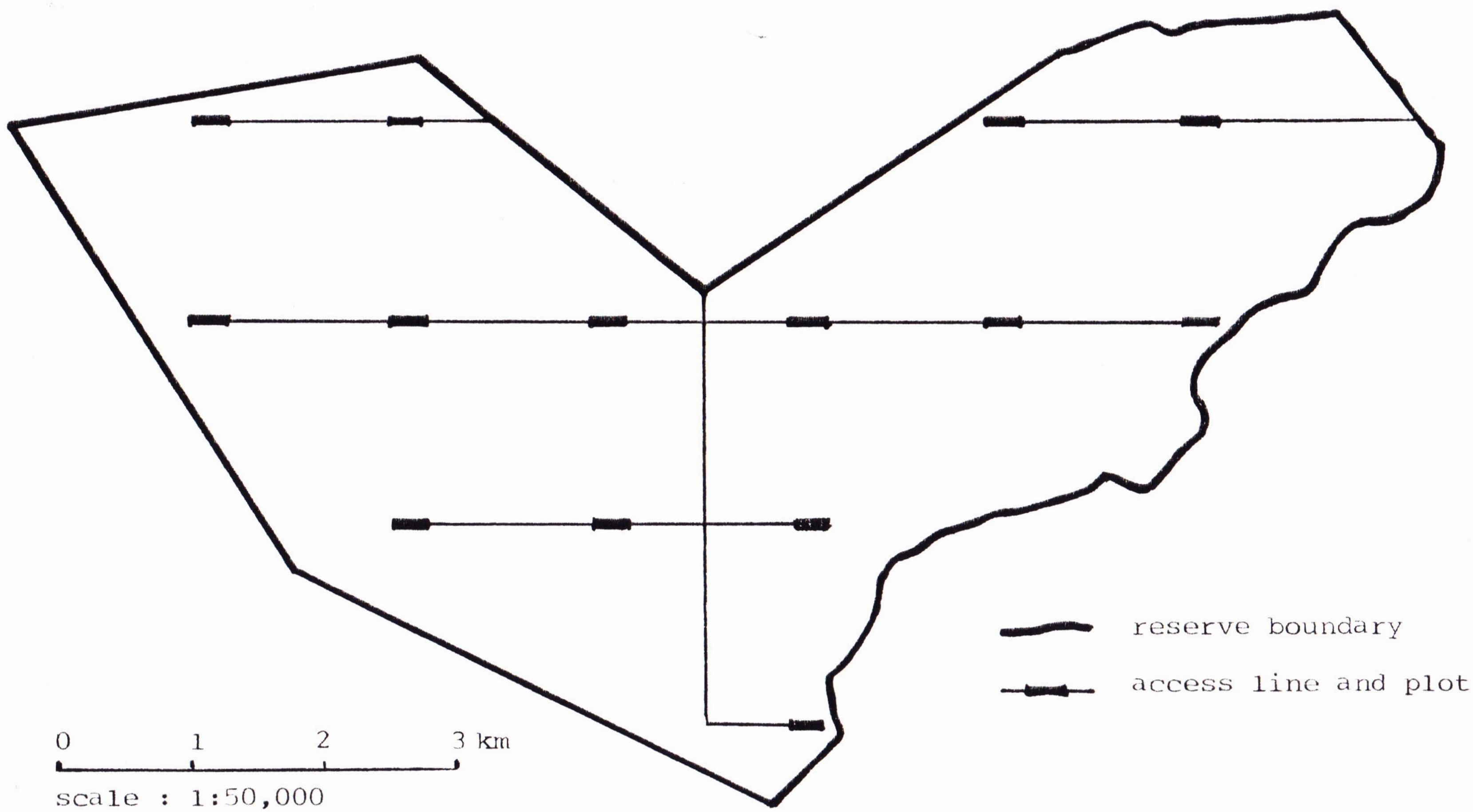


Figure 3 : Typical layout of inventory block (Neung FR, inventory block 1)

3. VOLUME ASSESSMENT

3.1 Use of volume tarifs

To proceed from the data on tree diameters and species to volume estimates required a volume tarif to estimate volume from diameter. Construction of such a tarif implied the measurement of volume on sample trees. General procedures and methods for such sampling are discussed in [4].

In the present work, two types of tarif were developed:

a. Bole volume tarif based on the measurement of standing trees. The bole volume will be closely correlated with timber volume, but, because it omits branchwood and buttresses, is not sufficient for a fuelwood and pulpwood inventory.

b. Total volume tarif based on the measurement of felled trees. Total volume includes all wood in the buttress, bole, and branches, in the present case down to a practical measurement limit of 5 cm diameter. Total volume is closely related to potential pulpwood, fuelwood and charcoal yields, but is not a good indicator of timber yield.

3.2 Bole volume tarifs

The bole volume tarif was derived from measurement of upper stem diameters using the wide-angle Spiegel Relascope mounted on a tripod. The general procedure was to measure and record the diameter and height at the reference point (1.3 m. or above buttress), at the point of crown-break or the first large branch, and then at ¼, ½, and ¾ of the total bole height, giving 5 measurements per tree.

The sampling crews travelled with the enumeration teams and picked one large tree (diameter over 40 cm) per record unit (see figure 2) on each plot. The criteria for selection were that the tree should be of reasonable form and the bole clearly visible for measurement.

The raw diameter and height data were then converted to bole volumes by computer, and used to update the coefficient estimates for a regression model of the form:

$$V = a_s + b_s.D^2 \qquad -(3.1)$$

where V is bole volume in m^3, D is diamter in cm., and a_s and b_s are species-specific coefficients. A second computer program then grouped the individual species regressions into those which were statistically similar at the P=0.99 level. These then became the tarif groups for similar species. The computer program usage is described in Appendix B.

The bole volume tarif work was an ongoing and relatively inexpensive operation.

3.3 Total volume tarifs

Progress in total volume estimation was severely limited by the availability of chainsaws, fuel, lubricants, spares, workshop staff, and hence was both much delayed, and more limited in scope than would have been desirable.

The procedure finally adopted was to fell an area of some 5.8 ha as for the normal Subri Conversion Technique [5], but with the operations being carried out by the inventory teams. The total area was subdivided into 9 plots, as per figure 4. On each plot, the following procedures were carried out:

a. For trees less than 40 cm diameter

The trees were measured for diameter, felled, cross-cut into 1 m. lengths, stacked, and the external dimensions of the stacks recorded.

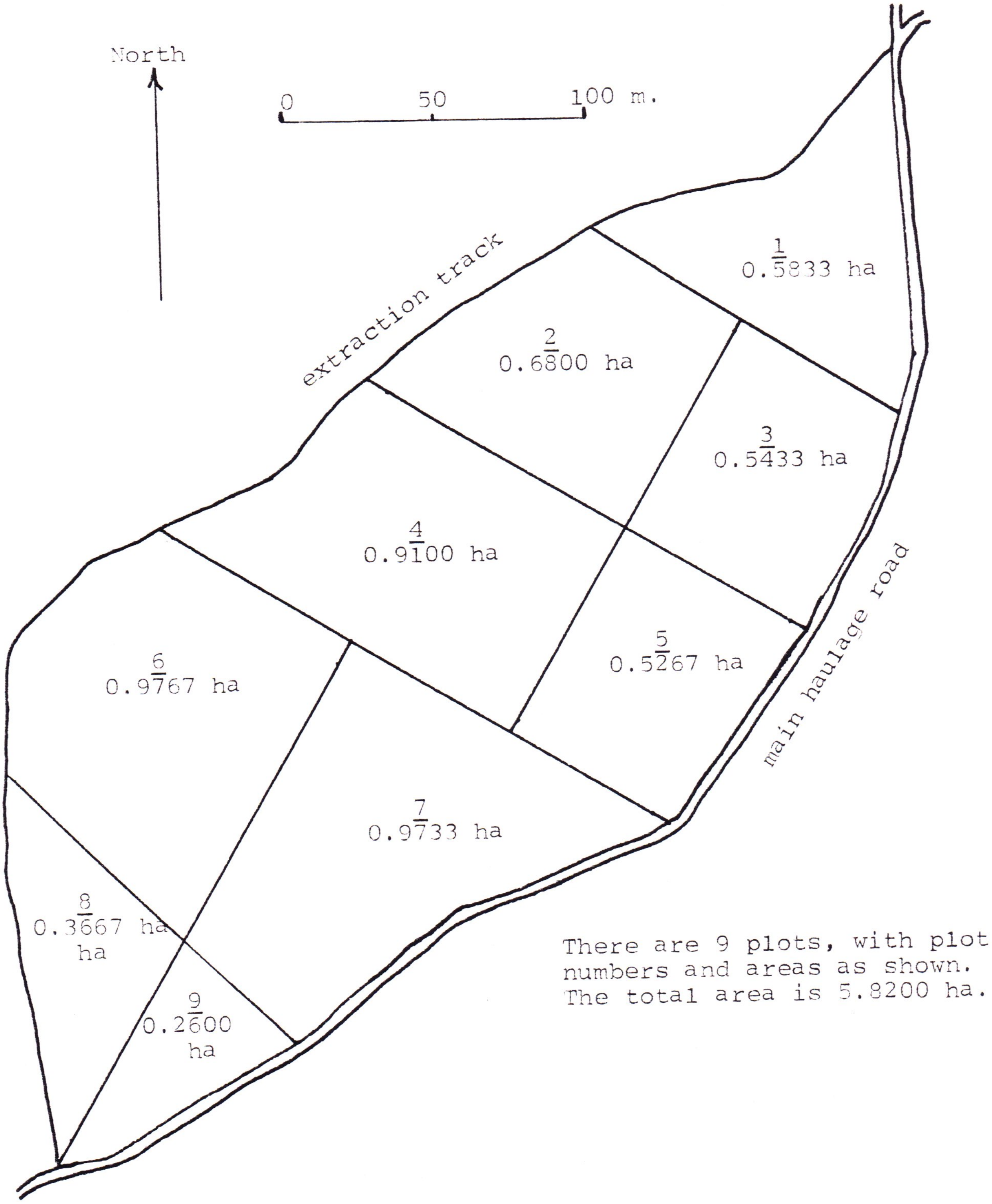


Figure 4 : Diagram of area felled for total volume sampling

A sub-sample of stacks were measured piece by piece to obtain stacking factors to convert stacked volume to solid over-bark volume.

b. <u>For trees over 40 cm diameter</u>

Trees were measured standing for bole volume by Relascope and then felled. Bole and large branches were measured by diameter tape. Small branches were cross-cut and stacked. Bole volume, branch volume, and buttress volume were estimated separately. The standing measurements were to provide a check on the accuracy of Relascope estimation.

In all 101 large trees were felled and measured on the 5.8 ha. experimental area. This was a much smaller sample than was desirable, but within the operational constraints that existed, was the best that could be achieved. Results of the tarif determinations are discussed with the other inventory results in section 6.

4. FIELD ORGANIZATION

4.1 Personnel structure of field team

Field teams were generally organized into three parties, including two line cutting and survey parties and one enumeration party. A small section of three or four labourers was also placed in charge of the base camp. The structure was as follows:

Field team
Officer-in-charge : Senior Technical Officer

Line cutting party 1
Technical Officer : booking
Technical officer : compass & clinometer
Labourers (4) : poles & tapes
Labourers (4) : cutting & brushing

Line cutting party 2
As for LCP 1

Enumeration party
Technical officer : booking
Technical officer : Relascope
Forest guards (4) : tree identification
Labourers (4) : brushing

Volume assessment group
Technical officer : Relascope
Labourers (3) : Tape & brushing

Base camp
Labourers (4) : cooks & camp boys. Usually on rotation with cutting & brushing labs.
Driver (1) : communications & emergency transport

Field team totals:

Senior Technical Officers	1
Technical Officers	7
Forest Guards	4
Drivers	1
Labourers	27

The names of the personnel actually employed on the inventory exercise are given in Appendix C.

Ideally, it was intended that two full teams should be operational at once. In practice, a variety of other tasks, including plantation inventory, volume sampling, and control re-enumerations disrupted the pattern, and resulted in a situation were there would be three line cutting and two enumeration parties, one of which would do control re-enumeration.

The greatest limiting factor was the shortage of adequately trained Forest Guards for tree identification. Most of the older Forest Guards could identify the primary and secondary commercial species, but the minor species were often not being identified correctly. Future inventory projects should bear in mind the need for training in this area.

The organization was also rather top-heavy with Technical Officers. Those solely engaged in booking could have been replaced by trained and literate labourers. However, the Forestry Department wished to train Technical Officers in inventory procedures, and for this reason, the structure described above was retained.

4.2 Logistic support

4.2.1 Transport

Transport available to the inventory for most of the period of active operations consisted of two long-wheel base petrol Land-Rovers, and the occasional use of a 7 or 10 ton truck. This latter facility was used exclusively at the beginning of the month to convey the bulk of the labour force with rations and tents as near as possible to their intended base camps. Land Rovers were used for interim communications and recconn-aissance, and also for bulk transport when no truck was available.

This situation was not very satisfactory. The Land-Rover is a very uneconomical vehicle with respect to petrol use, and was also heavily overstressed in its bulk transport role.

Nor were sufficient vehicles available for supervisory personnel to travel to the field on a regular basis. This necessarily affected the quality of the work.

4.2.2 Food supply

The food supply situation in the villages bordering inventory areas was generally inadequate with respect to oils and proteins, although carbohydrate staples such as cassava and plantain could be had. Prices were however at all times high relative to salaries.

In this situation, the World Food Program supplies distributed through the Forestry Department were of the greatest assistance. Lack of adequate storage and transportation to the field created problems, but it could be said with a large measure of truth that the success of the inventory operation was a direct consequence of the availability of World Food Program rations.

4.2.3 Shelter

Initially, large tropicalized tents of military design, housing 12-15 men, were used for shelter. These items, imported under the UNDP equipment budget, were very satisfactory for the first year, but thereafter began to deteriorate, and were unserviceable after about 18 months.

Locally made tents were also tried. However, the canvas was not treated with anti-fungal agents, and they disintegrated within a few days in the rain forest.

Subsequently plastic sheeting was used in conjunction with lean-to shelters made from bamboo and raffia. These are moderately satisfactory and of low cost.

Village shelter was occasionally available, although no where on the scale envisaged by the consultant's report [1].

4.2.4 Clothing

No special clothing or clothing allowance was provided to inventory workers, in spite of the fact that their personal articles suffered considerable damage in the constant walking through heavy bush.

Boots were provided on a fairly regular basis. The initial distribution was from Forestry Department sources. A subsequent issue was funded from the UNDP equipment budget after experience showed that locally available boots were of inadequate quality to be cost-effective, usually deteriorating within a few weeks.

4.2.5 General comments on equipment

In the consultant's report, little attention was paid to the cost of logistic support and personal equipment, as at the time (1977) most of these items were readily available from local sources and could be supplied by the Forestry Department. Consequently there was no proper budgetary provision for these items from UNDP sources. However, by 1980, very few items were available on the local market, and almost all needs had to be met from UNDP funds.

4.3 Schedule of operations

The schedule of operations carried out is shown diagrammatically in figure 5. Generally a full team was kept at enumeration and line cutting work between September 1980 and June 1982, except for a break during the major wet season of 1981 (July-August) when other tasks were undertaken. The remaining personnel in the Inventory Unit undertook other mensurational tasks such as planatation inventory and volume sampling (see [6] for details), but occasionally a full second team was organized, as between March and June 1981.

The table below shows the start and finish dates for the enumeration of each forest reserve, and the number of man-months

```
Mar 80   Jun      Sep      Dec      Mar 81   Jun      Sep      Dec      Mar 82   Jun 82
  .        .        .        .        .        .        .        .        .        .
_________________________________________________________________________________________

 Planning
*--------->             ≈≈        ≈≈≈          ≈≈≈≈                       ≈≈≈≈    ≈≈≈≈≈

      Training
     *----------->

                 complete Subri River FR
                *-------------------------------->

                                               felled volume
                                              *--------------------->
                                               sampling

                   plantation volume           plantation
                  *------------->             *--------->
                   sampling                    inventory
                                                         Bonsa River
                                                        *--------->
                                                         FR
                                                                  Neung
                                                                *--------->
                                                                   FR
                                                                         Pra Suhien
                                                                        *---------->
                                                                           FR
```

Figure 5 : Schedule of operations on forest inventory

(≈ represents control re-enumeration of selected plots) required:

	start	finish	m/m
Subri River FR	1 Aug 80	31 Jun 81	600
Bonsa River FR	1 Nov 81	31 Jan 82	120
Neung FR	1 Feb 82	30 Apr 82	120
Pra Suhien FR	1 May 82	30 Jun 82	120
Felled volume sampling	1 Jul 81	31 Jan 82	280
Total man-months			1240

4.4 Costs

Table 2 shows the basis of the average cost estimates. It is helpful to separate costs for enumeration from those for cutting access lines, as a different sampling design (e.g. cluster sampling) could reduce the line cutting required for the same proportion of enumerated area.

From table 2, the following unit costs can be estimated:

Item	man/months	Cedis *
Enumeration per plot	0.7604	380
Access line, per km	0.6923	346
Plot total(enum. & access)	1.9010	950
Cost per Km^2 forest sampled	0.8901	445

The following assumptions are used in deriving these estimates:

1. Average distance of line cut per plot is 1.65 km.
2. Average monthly salary including allowances is ₵500.
3. Enumeration is 40% of total cost, line cutting 60 %.

* Official rate: 1 US $ is 2.75 Ghana Cedis.

Reserve	Area ha.	No. of plots	km. of line	man/months enum.	man/months line cut.	man/months total
Subri River	57,030	292	481	240	360	600
Bonsa River	16,370	71	117	48	72	120
Neung	16,370	68	112	48	72	120
Pra Suhien	18,080	74	122	48	72	120
TOTAL	107,850	505	832	384	576	960

Table 2 : Inventory costs by forest reserve

5. DATA PROCESSING

5.1 Introduction

In line with the second objective described in section 1.1, that of providing the basis for ongoing management inventory by the Forestry Department, a data processing system was set up based around low-cost desk top microcomputers, for the processing of inventory and other mensurational data. The latter included the plantation inventory and yield tables described in [6].

Computer systems can be divided into hardware i.e. the physical machinery of computer, printer, keyboard, and display etc.; and software, or the computer programs which instruct the system to carry out the required functions. The software can in turn be divided into the system software, supplied by the manufacturer to carry out basic general purpose functions, and applications software, designed to execute specialized tasks required of the computer in a particular application.

5.2 Description of inventory data processing system

5.2.1 Data capture

During plot measurement, tree diameters were recorded in pencil together with the vernacular names of species on form inv/4. Relascope volume measurements were recorded on form inv/8. Examples of these forms are shown in Appendix D. The indigenous names were later converted to code numbers via the species list. Completed forms for plots during a month were returned to the Inventory Unit computer centre for entry and validation.

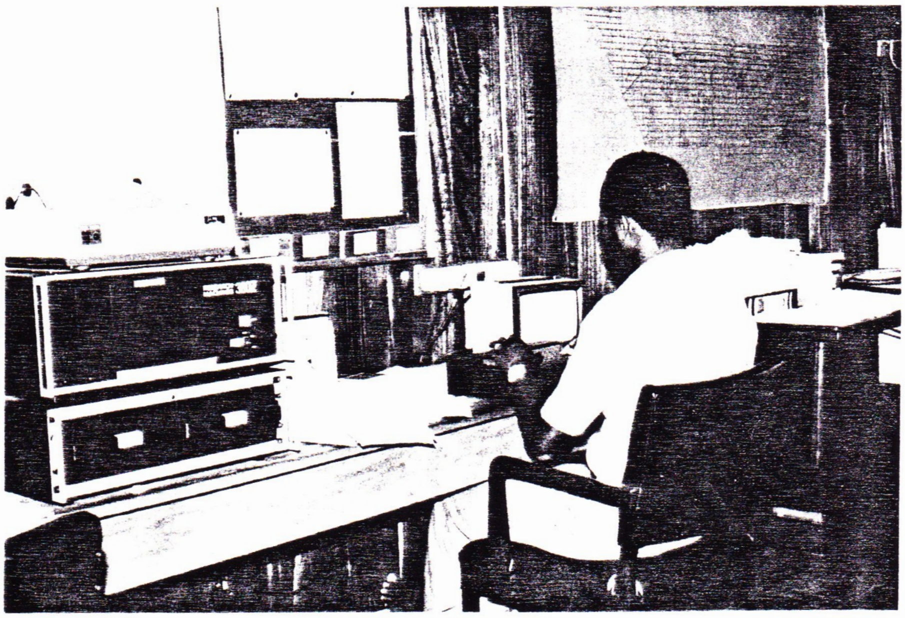


Plate 1 : Computer system being used to process forest inventory data

5.2.2 Data entry, validation, and correction

Data was entered directly from the computer keyboard onto magnetic discette (see plate 1). In the case of plot enumeration data, the TXED screen editor [8] was used to construct a file according to the format described in Appendix B. For Relascope volume measurements, a specialised program (A of the inventory suite) was used for simultaneous data entry and validation.

Enumeration data entered via TXED was subsequently validated using program G of the suite. Correction of errors noted at this stage was by the screen editor TXED.

All data was thus stored on magnetic discettes. A single discette can hold 480 kilobytes of effective data, equivalent to around 300 plots of enumeration data, on the RML 380Z FDS-2 system.

5.2.3 System hardware

The system used was a Research Machines RML 380Z computer with 56 kilobytes of random-access memory and twin 8" discettes. An OKI Microline 80 printer was attached. Technical details of the hardware are given in the system manual [7], whilst Appendix E gives details of the supplier and specifications.

To provide back-up in case of hardware failures, two identical systems were installed. This allowed components to be switched between a functioning and mal-functioning machine until the fault is isolated to a particular circuit board, cable or device. In the case of circuit boards, faults can be further isolated to a particular chip when these are socketed.

In practice no hardware faults have occurred since the systems were installed (commencing June 1980) except for an older Anadex DP 8000 printer, which failed and was replaced by the OKI Microline 80 printers in January 1981. These latter have functioned faultlessly.

The system was installed in several stages. Originally two RML 380Z computers were purchased with cassette tape backing store in June 1980, together with the Anadex DP8000 printer. The latter failed in October 1980 and was sent to the UK for repair. After return, it failed again, and was written off. Two OKI Microline 80 printers were installed in February 1981. In June 1981 the FDS-2 8" disc systems arrived, together with additional memory for one of the RML 380Z systems, which had originally been only 16K bytes. In September 1981, the display screen was upgraded from 40 to a variable 40/80 character width with new circuit boards.

The total capital cost of the system developed in this way was $23,000. Current replacement cost for the two systems would be $14,000, reflecting the reduction in microcomputer prices since 1980.

5.2.4 System software

The operating system provided with the RML 380Z FDS-2 system was CP/M. This is a widely used disc operating system for desk top machines using the Z80 processor. The RML380Z also has a ROM (read-only memory) monitor which in the current version is COS 4.0. This controls the primitive functions of the machine, including the valuable diagnostic 'software front-panel', and provides a bootstrap loader for the disc operating system. Both these operating systems are documented in detail in the system manual [7].

Additional system programs supplied and used for data entry and correction and program compilation are the TXED screen editor [8], the BASIC interpreter [9], and the FORTRAN compiler [11]. The latter includes a relocating assembler with Zilog mnemonics [10].

5.2.5 Applications software - the inventory program suite

The inventory program suite documented in Appendix B constitute the main applications programs for the indigenous inventory data processing. In addition some regression analysis described in section 6 was carried out using the SNIFTA multivariate nonlinear regression package documented in [12].

The inventory suite is coded in the BASIC language, with the various functional programs being called via a common "menu" program which links them all together. Operation is designed to be interactive and easily learnt by staff at the technical level.

The programs provide the following functions:

- Entry and checking of relascope volume data; creation of a volume function masterfile for each species; grouping of species volume functions according to similarity of form; and creation of species-group files for the stand table programs.

- Error checking of inventory data, covering diameter ranges appropriate to each subplot, species number range, and format and sequence of plot and subplot headers.

- Definition of species groups to be included in a particular analysis, and selection of data files to be included.

- Calculation and printing of stand tables of stem numbers, bole volumes, and total volumes with details of sampling errors.

- Comparison of plot original and re-measurement data with summary output of trees inconsistently identified or measured, to control quality of field work.

5.3 Data processing operations

Apart from the inputs by the present author in developing the original programs, three persons are required to operate the computer system for normal inventory and mensurational work loads. They are as follows:

1. Inventory Unit officer-in-charge

   Duties: Apart from administration and planning of all inventory and mensurational work undertaken for the unit, must be fully conversant with BASIC programming and able to write programs for inventory analysis, and volume calculation. Must be familiar with the use of multiple regression programs. Will carry out himself or direct the carrying out of mensurational and inventory analysis as required.

   Qualifications: Tertiary qualification in forest science. Post-graduate degree or diploma in mensuration or inventory.

2. Programmer

   Duties: Day-to-day operation of the computer system. Maintenance of disc files and records. Programming under direction in BASIC and other high level languages. Data entry and editing. Running inventory suite of programs.

   Qualifications: University degree in computer science.

3. Clerical assistant

   Duties: Assist with data entry. Collation and filing of printouts. Cleaning computer equipment. Operation of reprographic equipment for inventory reports.

   Qualifications: Secondary school leaver.

6. INVENTORY RESULTS

6.1 Tree total volume tarif

The felled volume sampling work referred to in Section 3.3 resulted in 101 trees over 40 cm. being measured in detail for buttress, bole, and crown volumes. Figure 6 shows the total volume data thus obtained, plotted on logarithmic axes. A regression model was fitted to this data of the form:

$$\log_{10} V = a + b.\ \log_{10} D \qquad -(6.1)$$

where V is tree total volume, D is tree reference diameter in cm, and a and b are coefficients. This equation gave the following results:

a	-3.30972
b	2.28048
R^2	0.84761
Residual sd	0.14213

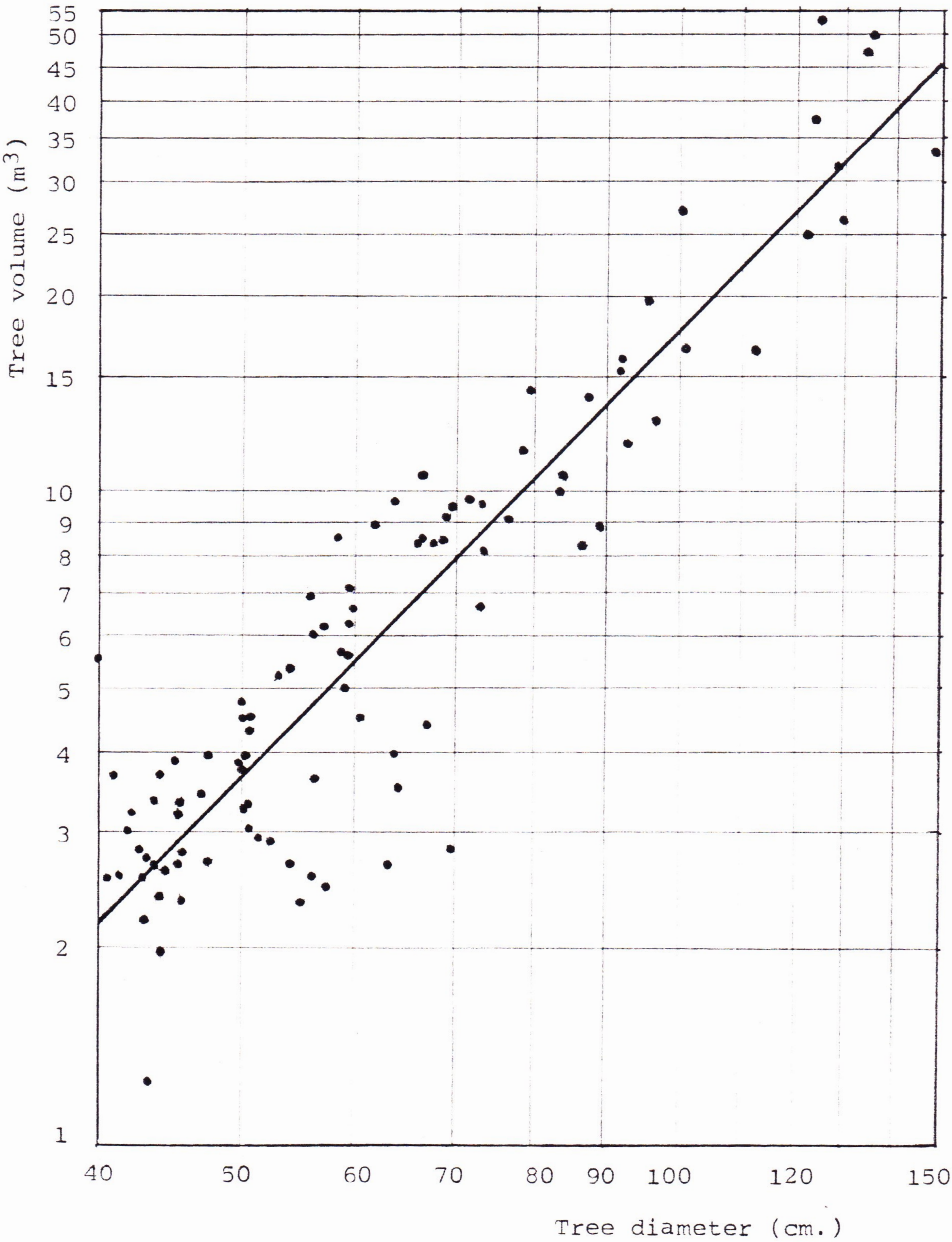
After conversion by taking antilogs to both sides, equation (6.1) becomes:

$$V = 0.0004900947\ D^{2.28048} \qquad -(6.2)$$

Only large trees (over 40 cm) were included in this sample, and the probability therefore existed of bias when the equation was used to estimate volume of trees less than 40 cm in diameter. Smaller trees had not been measured individually for volume. Instead, volume of small trees was recorded on a per plot basis for the 9 plots; and a stand table of diameter distribution was also recorded.

Applying equation (6.2) to the stand table for the nine plots gave a predicted volume for small trees V_p, which could be compared with the observed volumes V_o. The average ratio of these quantities for the nine plots represented the correction factor for bias to be applied when

Figure 6 : Total volume tarif for indigenous trees



• Sample tree volumes and diameters. Note both scales are logarithmic.

—— Volume tarif line: $V = 0.000490047.D^{2.28048}$

using the total volume tarif for small trees. The ratio was estimated as:

$$V_p / V_o = 0.7410 \qquad -(6.3)$$

When calculating volumes using the total volume tarif, the following system was used:

- If tree diameter was 40 cm or over, equation (6.2) was applied.

- If tree diameter was less than 40 cm, volume was calculated from (6.2) and then multiplied by the factor 0.7410 to give estimated total volume.

6.2 Bole volume tarifs

The bole volume tarifs used for calculating inventory results were derived from optical estimates of upper stem diameters sampled as described in section 3.2, and recorded on form inv/8 (Appendix D).

Two computer programs (Modules A and C of the inventory system described in Appendix B) were used to process the data:

- Module A calculated bole volume V and diameter D from raw relascope observations, and updated species regression statistics on a disc file comprising:

N	number of trees sampled for that species
ΣD^2	sum of diameters squared
ΣD^4	sum of squares of diameters squared
ΣV	sum of volumes
ΣV^2	sum of squares of volumes
$\Sigma D^2 V$	sum of products of volumes and diameters squared

stored for each species sampled.

- Module C grouped species whose regression coefficients for the model:

$$V = a + b. D^2 \qquad -(6.4)$$

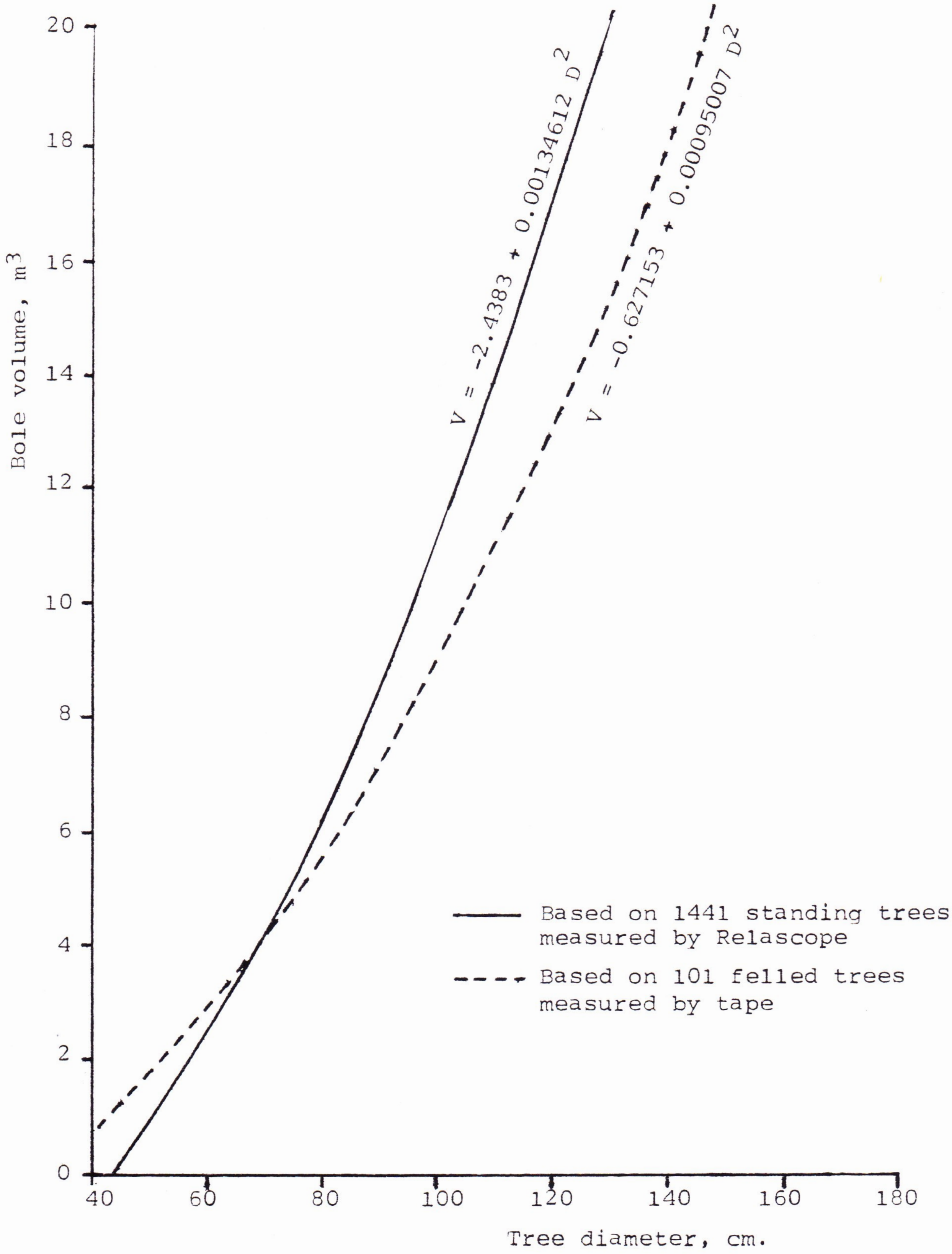
were not significantly different at the P=0.99 level, and then printed details of the tarif groups formed. A disc file was also formed as output summarizing the pooled regression coefficients for each tarif group, and the codes of the species included in that group; this file was read by the stand tables program (module J) when bole volume estimates were required.

The data collected from relascope volume measurement on the reserves covered by this report comprised 1441 sample trees from 132 species. These are grouped into the 5 volume tarif groups described in Appendix F, with one 'average' tarif derived from the pooled regression to be used for volume estimation with species not sampled.

Figure 7 compares the overall pooled regression based on 1441 trees measured by relascope with the homologous regression (equation 6.4) fitted to the bole volumes from the sample of 101 trees felled and measured on the ground. It will be seen that the two functions are reasonably comparable, given the differences in size and geographic origin of the sample, and the differences in measurement method.

Relascope volume sampling requires great care and accuracy. Figure 8 gives a direct comparison between bole volume measured by Relascope and that measured by tape after felling, for the 101 sample trees. The figure shows that of 94 valid measurements (7 were rejected due to recording errors) 34 were more than ± 30% in error. The 30% error limit represents instrument error if the average relative diameter viewed by the Relascope is 1½ bands. These results suggest that there is considerable scope for improved accuracy through further training and better supervision of field personnel. They

Figure 7 : Bole volume tarifs derived from Relascope and felled volume sampling



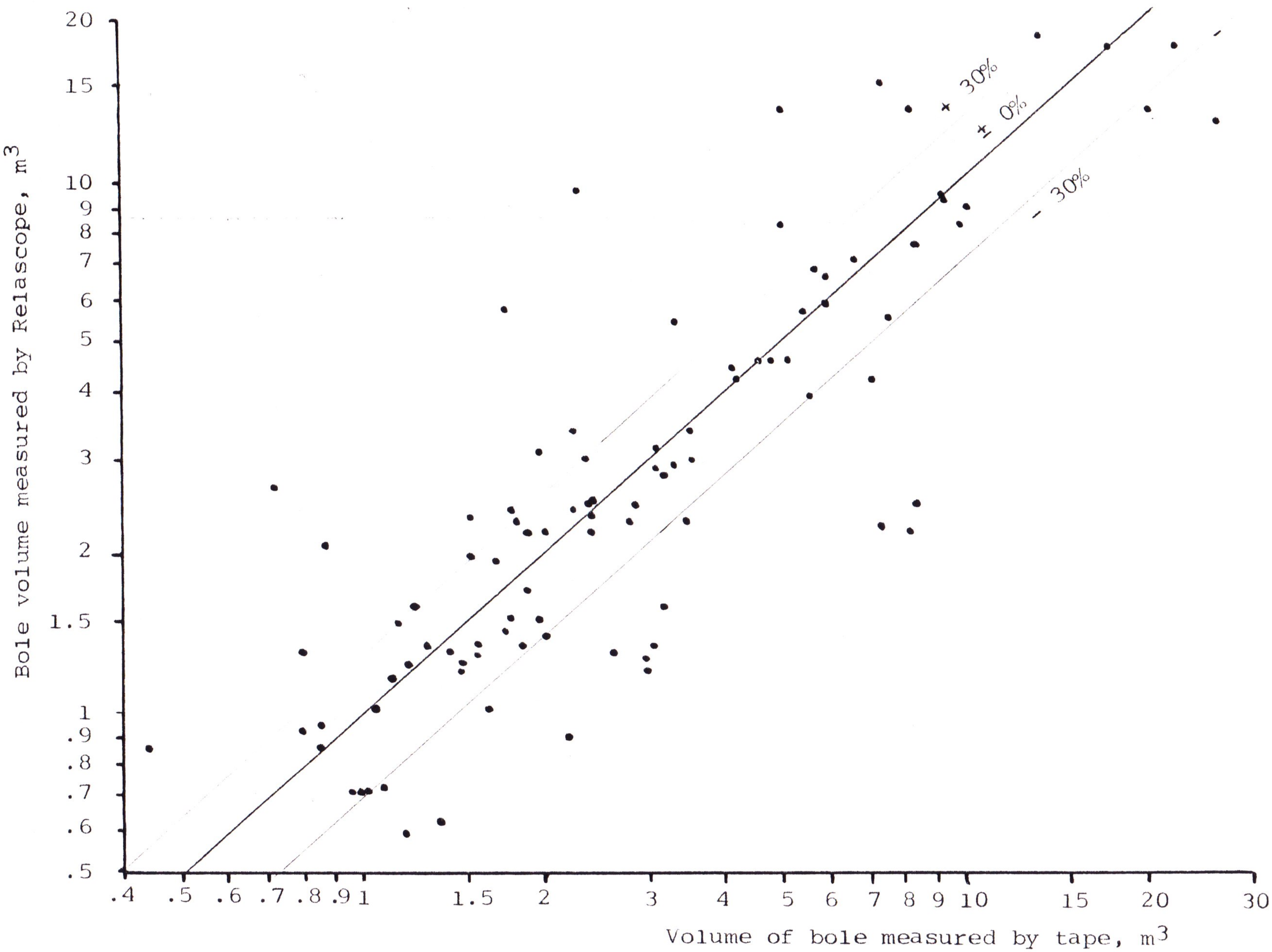


Figure 8 : Comparison of bole volume measurement by Relascope and tape

also underline the importance of controlled felling for volume sampling, not only for total volume estimation, but also to check the standard of relascope use.

Note that for bole volumes quoted as such in results below, the tarifs in Appendix F were used. For total volume, equation (6.2) was used, with modifier ratio (6.3) for smaller trees (less than 40 cm.).

6.3 Consistency of species identification

To check on the reliability of species identification, 69 of the total of 505 inventory plots were measured twice, on separate occasions by different field crews, and the two sets of data compared by means of program H in the inventory data processing suite (see Appendix B for details).

The results obtained showed that of the 266 species observed down to the 5 cm diameter limit, only 50 were identified with over 70% consistency. Consistency of identification in this context is defined as the ratio of correct observations to the total number of observations for a species. Correct observations are those that occur on both the original and remeasurement plots.

Taking different diameter limits made little difference to the number of species consistently identified, as shown below:

Diameter limit, cm.	5	40	80
Total trees observed	8962	4217	637
Total species observed	266	207	102
Species > 70% consistent	50	52	45

For publication purposes, those species identified with over 70% consistency at diameters 40 cm and above were

Table 3 : List of species identified with over 70 % consistency

Code	Botanical name	Local name(s)	Usage codes
62	AFROSTYRAX LEPIDOPHYLLUS	DUAGYENNE	
31	ALBIZIA FERRUGINEA	AWIEMFOSAMINA/ALBIZZIA	MCJ
73	ALSTONIA BOONEI	SINURO	SVJ
76	AMPHIMAS PTEROCARPOIDES	YAYA	H
91	ANTHOSTEMA AUBRYANUM	KYIRIKUSA	
21	ANTIARIS TOXICARIA(A.AFRICANA&A.WELWITSCHII)	KYENKYEN	SYJX
94	ANTROCARYON MICRASTER	APROKUMA	McR
111	BERLINIA OCCIDENTALIS	KWATAFO-MPABOA	McR
118	BOMBAX BREVICUSPE	ONYINAKOBEN/DUAKOBERE	S
35	CANARIUM SCHWEINFURTHII	BEDIWONUA/CAARIUM	MTVYCJXR
143	CEIBA PENTANDRA	ONYINA	SYX
1	CHLOROPHORA EXCELSA	ODUM	HTCJR
169	CLEISTOPHOLIS PATENS	NGONENKYENE	
190	CORYNANTHE PACHYCERAS	PAMPRAMA	
191	COULA EDULIS	BODWUE	HTCcX
212	DACRYODES KLAINEANA	ADWEA	HR
227	DIALIUM AUBREVILLEI	DUABANKYE	H
242	DIOSPYROS GABUNENSIS	KUSIBIRI	
276	ELAEIS GUINEENSIS	ABE	
16	ENTANDROPHRAGMA CANDOLLEI	PENKWA-AKOA/CANDOLLEI	MYJ
287	ERYTHROXYLUM MANNII	PEPEANINI	HVY
329	FUNTUMIA AFRICANA	OKAE	SJ
17	GUAREA CEDRATA	KWABOHORO/GUAREA	MTVcJX
15	HERITIERA UTILIS(TARRIETIA UTILIS)	NYANKOM	MTcJ
374	KEAYODENDRON BRIDELIOIDES(CASEARIA BRIDELIOIDES)	AKOKOSRADEE	
8	KHAYA IVORENSIS	DUBINI/MAHOGANY	MVYcJ
378	LANNEA WELWITSCHII	KUMANINI	S
19	LOPHIRA ALATA	KAKU	HTB
12	LOVOA TRICHILIOIDES	DUBINIBIRI/WALNUT	HVJ
414	MARANTHES ROBUSTA(PARINARI ROBUSTA)	AFAMBERE	HTcR
24	MITRAGYNA CILIATA	SUBAHA/ABURA	MVJ
440	MONODORA MYRISTICA	WEDEABA	H
443	MUSANGA CECROPIOIDES	ODWUMA	
444	MYRIANTHUS ARBOREUS	NYANKUMA	
10	NAUCLEA DIDERRICHII	KUSIA	HTVCJR
463	OKOUBAKA AUBREVILLEI	ODII	
470	ONGOKEA GORE	BODWE	HJR
481	PACHYPODANTHIUM STAUDTII	KUMDWIE	M
489	PARKIA BICOLOR	ASOMA	Sc
502	PENTADESMA BUTYRACEA	ABOTOASEBIE	MTJR
20	PIPTADENIASTRUM AFRICANUM	DAHOMA	HTCR
523	PROTOMEGABARIA STAPFIANA	AGYAHERE	
541	RICINODENDRON HEUDELOTII	WAMA	
557	SACOGLOTTIS GABONENSIS	FAWERE	HJR
565	SCYTOPETALUM TIEGHEMII	OPRIM	H
13	TERMINALIA IVORENSIS	EMIRE/EMERI	MT
630	TRILEPISIUM MADAGASCARIENSE(BOSQUEIA ANGOLENSIS)	OKURE	
14	TRIPLOCHITON SCLEROXYLON	WAWA	MVYJPX
27	TURRAEANTHUS AFRICANUS	APAPAYE/AVODIRE	MVJ
634	UAPACA GUINEENSIS	KONTAN	HCJ
651	VITEX FERRUGINEA	OTWENTOROWA	
667	ZANTHOXYLUM GILLETII(FAGARA MACROPHYLLA)	OKUO	HJ

chosen for individual listing on the stand tables. Table 3 gives the relevant species. The key to the usage codes will be found in Appendix A.

It is probable that some misidentifications are correct to the generic level. For example, the *Diospyros* species have very similar external appearance, being small, very straight trees with hard black, vertically fissured bark. Some tree spotters tend to lump all such trees as 'Kusibiri' (*D. gabunensis*) whilst others label them 'Sanza-minika' (*D. sanza-minika*). Unfortunately, with the temporary plots used on the inventory, it is impossible to build up a matrix of cross-identifications between similar species. With permanent plots, this would be relatively easy, and constitutes an important argument in favour of their use.

6.4 Post-stratification of inventory blocks

The total of 24 inventory blocks used for pre-stratifying the sampling area can be grouped in various ways according to geographic or ecological considerations. Table 4 shows the abundance (expressed in total volume per ha., m^3) of 17 common species from the list of reliably identified species in Table 3. Each of the species included is either the first or second most abundant on some one block.

On the basis of an examination of the species abundances, and of geographical factors, the following post stratification is performed:

(1) Subri River Forest Reserve's 16 blocks are concatenated to 7 blocks, as follows (see figure 9):

Block A: Old block 5. Ecologically similar to E below, but geographically separated. Likely to be the main plantation area if the Daboase pulp mill is established.

Table 4 : Abundance of 17 common species, by inventory blocks

Inventory block no.	Afrostyrax lepidophyllus	Berlinia occidentalis	Ceiba pentandra	Dacryodes klaineana	Dialium aubrevillei	Funtumia africana	Heritiera utilis	Lophira alata	Parkia bicolor	Piptadeniastrum africanum	Protomegabaria stapfiana	Ricinodendron heudelotii	Sacoglottis gabonensis	Turreanthus africanus	Uapaca guineensis	Total (all species)
Subri River Forest Reserve																
1	3	5	4	8	22	8	17	7	9	29	4	7	10	-	5	415
2	-	6	6	10	14	3	11	5	12	29	44	2	7	6	8	462
3	-	22	-	9	7	4	25	15	9	8	6	3	81	-	21	458
4	25	12	5	4	7	3	19	6	11	14	13	6	38	1	22	450
5	4	1	6	10	7	4	3	2	9	21	-	10	9	3	7	298
6	46	-	5	9	9	4	10	5	26	21	1	21	14	60	4	487
7	21	-	11	11	16	4	9	9	12	14	2	10	3	57	3	441
8	-	25	-	8	26	4	23	9	11	13	-	1	2	1	10	378
9	-	10	5	6	16	10	19	21	13	28	8	4	-	1	15	449
10	-	4	9	4	9	10	2	3	9	27	-	6	-	3	6	402
11	-	-	6	5	2	7	5	6	12	22	-	4	-	-	6	336
12	-	1	12	10	9	11	11	8	11	26	-	9	-	10	7	438
13	-	1	12	8	6	8	4	-	8	37	9	3	-	-	2	385
14	-	-	10	6	13	7	2	10	17	28	-	10	6	2	7	388
15	-	2	24	1	5	17	5	-	12	30	-	15	-	7	5	391
16	-	1	6	4	5	3	9	2	11	31	-	4	-	15	20	435
Bonsa River Forest Reserve																
1	-	-	2	13	17	5	25	17	14	22	5	-	4	1	9	372
2	-	9	6	8	13	9	11	12	10	25	4	4	3	-	5	357
3	-	-	4	13	16	-	13	-	16	23	-	2	2	7	6	366
Neung Forest Reserve																
1	-	1	-	14	10	2	7	8	5	8	-	1	10	-	6	216
2	-	19	4	23	15	4	24	6	5	15	-	4	3	3	18	417
3	-	10	2	19	16	1	12	1	11	10	-	1	-	-	10	371
Pra Suhien Forest Reserve																
1	-	1	18	2	-	6	1	3	5	28	8	3	-	49	2	404
2	-	5	20	7	-	5	9	5	8	28	23	6	1	97	4	444

Figures are total volumes, in m^3/ha.

Block B: Old blocks 1 and 2. Wetter and hillier areas than to the east, on the wet evergreen forest margin. This is indicated by the increased presence of Dialium.

Block C: Old blocks 3 and 4. Characterised by a high proportion of Sacoglottis gabonensis (Fawere). Predominantly swampy, level areas. Uapaca and Heritiera are also common.

Block D: Old blocks 6 and 7. Flat areas transected by many small rivers. Heavily logged in past. Not swampy (sandy soil). Dominated by Turraeanthus africanus (Avodire) and Afrostyrax lepidophyllus (Duagyenne).

Block E: Old blocks 12, 13, 14, and 15. A large homogenous area of undulating country similar to block A, and dominated by Dahoma (Piptadeniastrum africanum) and Ceiba pentandra (Onyina).

Block F: Old blocks 8 and 9. Swampy transitional zone similar to C but lacking Sacoglottis. Dialium is more common, perhaps indicating higher rainfall.

Block G: Old blocks 10, 11, 16. Piptadeniastrum is again the commonest species, but lacks the high proportions of Ceiba found on E.

(2) Each of the smaller reserves (Bonsa River, Neung, Pra Suhien) is sufficiently internally homogeneous to be treated as a single block.

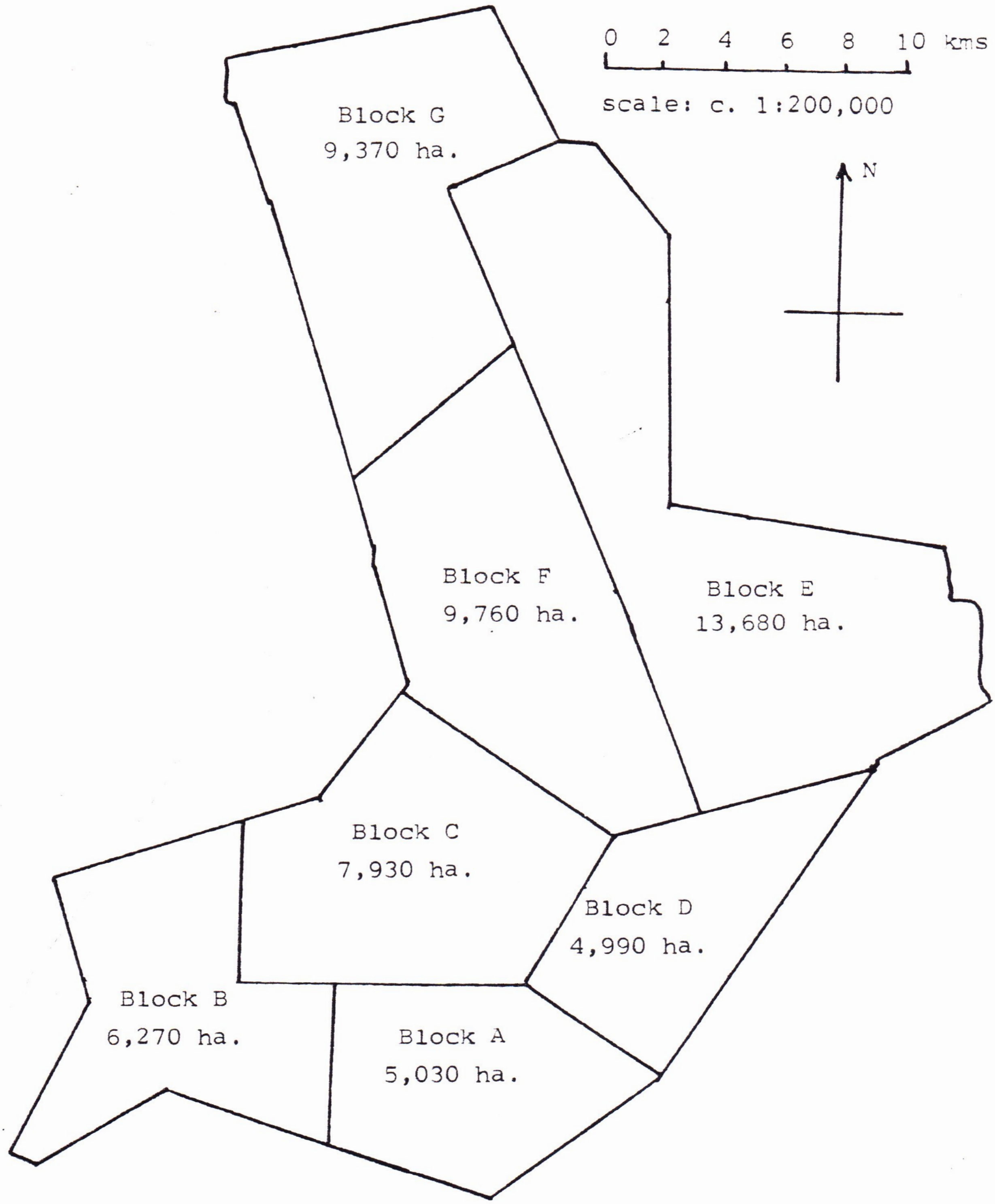


Figure 9 : Revised stratification of Subri River FR, based on species abundances

6.5 Volumes of timber, pulp, and fuelwood

Table 5 shows the volumes of wood on the inventory area according to different usage categories. These categories have been devised with the specific features of the Subri Conversion Technique [5] in view, and are as follows:

1. Timber Timber volumes include species usable for quality veneers, heavy construction, and joinery, house-framing, etc. However, pulp species are excluded from the group. Timber volumes are over-bark bole volumes from the reference diameter measurement point (1.3 m or 1 m above buttress) to the point of crown-break. Only trees over 40 cm diameter are included.

2. Pulp There are approximately 25 indigenous species suitable for pulp. Volumes in this case are total volumes to a measurement limit of 5 cm., and include trees down to 5 cm diameter.

3. Carbonisable wood includes all wood other than pulp species and the bole wood of timber trees, but excludes the residual wood that is practically unharvestable. Carbonisable wood is expressed in both m^3/ha over bark, and in stacked m^3 per hectare, or steres/ha. The conversion factor used is 0.624 m^3/stere (see Section 6.).

4. Residual volume is estimated at 30% of the difference between total volume and pulp and timber volumes. Practical field experience has shown that even with intensive control of charcoal-making operations, only about 70% of the total volume is harvested [13]. Constraints of time and cost would appear to make gathering of the balance impracticable.

The table shows that on Subri River FR as a whole, carbonisable volumes are around 234 m^3/ha, being c. 50% of

Block	Area ha.	Timber volumes excl. pulp spp. Veneer	Constr.	Other	Total	Pulp m^3/ha	Carbonisable m^3/ha	steres	Residual m^3/ha	Total m^3/ha
Subri A	5,030	9.6	18.0	12.3	39.9	59.8	180.8	289.7	77.5	358.0
B	6,270	11.0	43.6	14.3	68.9	52.1	248.8	398.7	106.6	476.4
C	7,930	17.7	26.8	35.8	80.3	56.3	255.1	408.8	109.3	501.0
D	4,990	14.1	19.2	21.2	54.5	140.9	233.8	374.7	100.2	529.4
E	13,680	8.7	26.1	12.5	47.3	94.0	222.7	356.9	95.5	459.5
F	9,760	12.2	28.3	11.5	52.0	36.7	260.5	417.5	111.6	460.8
G	9,370	12.3	19.3	7.0	38.6	75.5	224.4	359.6	96.2	434.7
Subri Total	57,030	11.9	26.1	15.6	53.6	72.4	234.1	375.2	100.3	460.4
Bonsa River	16,370	11.7	19.7	14.7	31.4	46.4	233.0	373.4	99.9	410.7
Neung	16,370	7.2	28.7	14.6	50.5	25.1	224.2	359.3	96.1	395.9
Pra Suhien	18,080	10.9	22.4	11.2	44.5	155.4	187.7	300.8	80.4	468.0

Table 5 : Volumes/ha of inventory blocks in different usage categories.

the total volume to a 5cm measurement limit. Timber yields are around 54 m^3/ha. Approximately 72 m^3/ha of pulp species can be realised. In locations where Turraeanthus is abundant, pulp yields are locally much higher. Block D for example, which is close to the proposed pulpmill at Daboase, carries a total of 703,000 m^3 of pulp on 4,990 ha within 12½ km of the mill.

It is worth noting that yields on block A are generally lower than those on the rest of the reserve. This reflects the salvage logging that has been carried on in that part of the reserve since the early 1970's in anticipation of plantation development. Subri block A is the present site of most project activities.

The specific species included in each group are shown in Appendix A.2.

The figures given in Table 5 are means, and not reliable minimum estimates. The latter are not additive between categories, making logical presentation in table form difficult. Table 6 shows the sampling errors for the pulpwood and total volumes, together with reliable minimum estimates at the 95% level.

It can be seen from Table 6 that the coefficient of variation of the volume means is around 3½% for total volume, and 10% for pulpwood volume. This is well within acceptable limits. Figure 10 shows the distribution of individual plot total volumes.

Block		Area ha.	No. Plots	Sample %	Pulp volumes			Total volumes		
					Mean	CV%	RME 95%	Mean	CV%	RME 95%
Subri	A	5,030	23	0.46	59.8	15.8	40.9	358.0	8.4	298.0
	B	6,270	35	0.56	52.1	10.6	41.1	476.4	3.3	445.1
	C	7,930	40	0.50	56.3	13.1	41.5	501.1	3.3	467.7
	D	4,990	30	0.60	140.9	14.7	99.5	529.4	5.1	475.2
	E	13,680	76	0.56	93.9	9.0	77.0	459.5	3.1	431.4
	F	9,760	44	0.45	36.7	9.9	29.4	460.8	3.2	431.2
	G	9,370	44	0.47	75.5	8.6	62.5	434.7	3.1	407.5
Subri Total		57,030	292	0.51	72.4	4.6	65.7	460.4	1.4	447.2
Bonsa River		16,370	71	0.43	46.4	8.2	38.8	410.7	3.3	384.1
Neung		16,370	68	0.42	25.1	12.4	18.9	395.9	3.1	371.2
Pra Suhien		18,080	73	0.40	155.4	7.4	132.5	468.0	3.2	438.0

Table 6 : Summary of inventory sampling errors for pulpwood and total volumes. All volumes in m^3/ha.

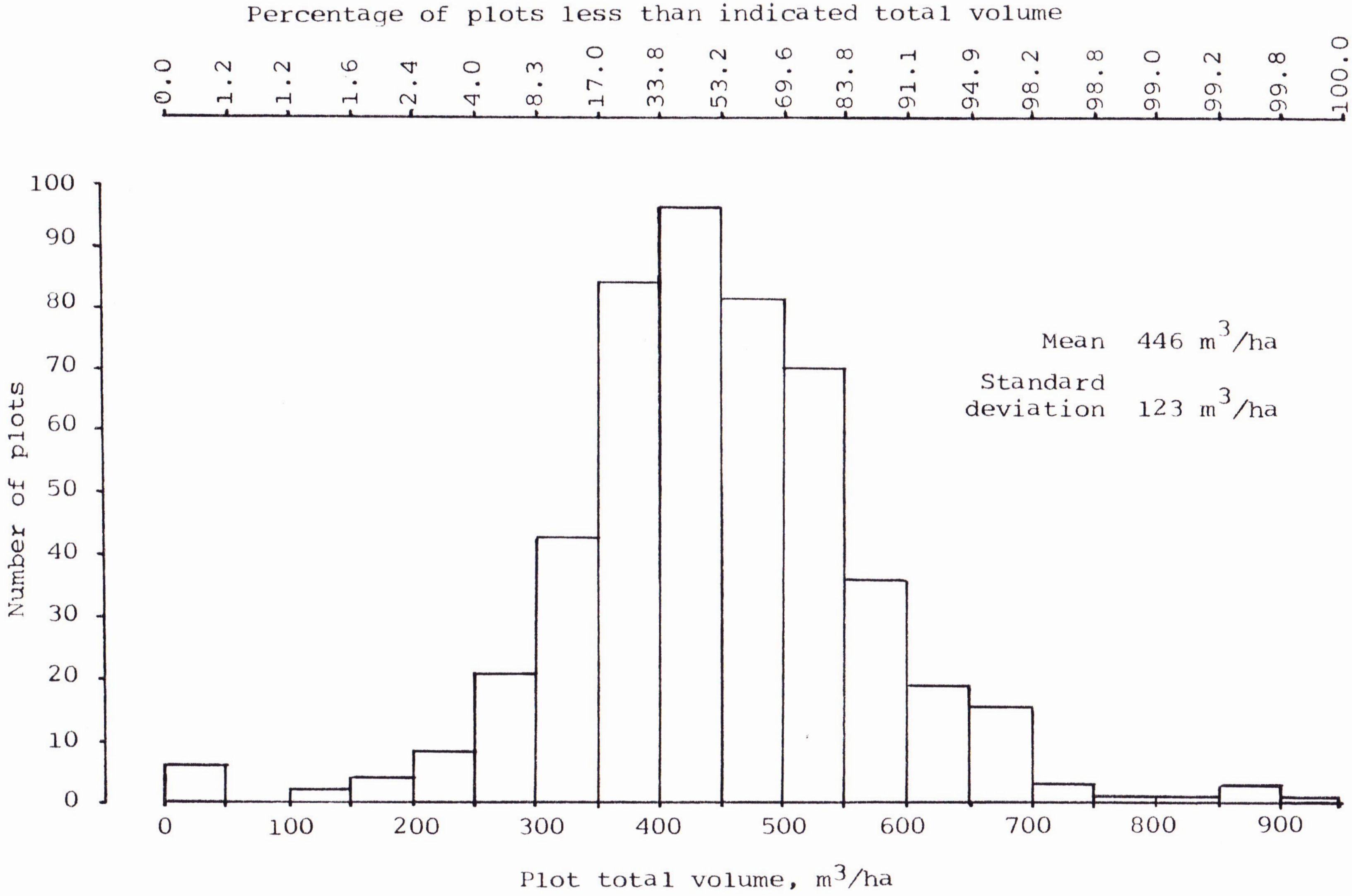


Figure 10 : Frequency distribution of inventory plot total volumes

6.6 Size distribution of stocking and volume

The tables given in Appendix C show details of the distribution of total volume and stocking between species and size classes. Table 7 synthesises some relevant details from this information.

Rows a and b of the table give the stocking per ha., respectively, of the reliably identified species (listed in Table 3), and of all trees. Row c gives the percentage of the stocking included in the reliably identified species. It can be seen that total stocking is of the order of 997 stems per ha, of which 955 per ha. are less than 40 cm diameter. Overall, 28% of the trees are reliably identified, but above 40cm diameter, this rises to around 50%, with a trend of increasing reliability with increasing tree size.

The diameter distribution of stocking is the classical reverse J shape usually associated with mixed-age natural forests. The stocking of larger trees appears to be relatively low, whilst that of small trees is high, suggesting that the forest is in a dynamic stage of recovery between logging cycles, which is in fact the case.

Rows d-f of the table show the distribution of volume by size classes for the reliably identified species, all species together, and the percentage of reliably identified volume. It can be seen that the volume distribution differs markedly from that for stem numbers. Whilst trees over 40cm diameter account for only 4% of the total stocking, they account for 62% of total volume. The percentage of reliably identified volume is similar to that for stocking.

Row g of the table shows the cumulative percentage of volume above a certain size class. Thus, 62% of the volume is above 40 cm diameter, 44% above 60 cm, etc. These refer to tree diameters, and not to piece diameters. The latter subject is discussed in the next section.

Bole volumes can be calculated by the inventory system. Tables for bole volumes could not be included in Appendix C

	Units	Diameter classes, cm. 5-39	40-59	60-89	90-119	120-149	150+	Total
a. Stocking of reliably identified species	n/ha	257	11.72	5.99	1.88	0.67	0.16	277.4
b. Stocking of all species	n/ha	955	25.21	12.27	3.30	1.05	0.23	997.1
c. Reliably identified spp. as % of total stocking	%	27	46	49	57	64	70	28
d. Total volume of reliably identified species	m^3/ha	69.2	36.7	48.6	33.2	20.6	9.8	218.1
e. Total volume of all species	m^3/ha	176.0	80.7	100.1	57.3	31.4	15.0	460.5
f. Reliably identified spp. as % of total volume	%	39	45	49	58	66	65	47
g. Cumulative % of total volume above lower diam.	%	100	62	44	23	10	3	-
h. Bole volumes, all species	m^3/ha	-	25.9	52.9	33.3	18.1	8.0	138.2
i. Bole volumes as % of total volumes	%	-	32	53	58	58	53	30
j. Coefficient of variation of total volume	%	1.71	2.06	2.47	4.09	6.82	15.62	1.44

Table 7 : Diameter distribution of some parameters of stocking and volume on Subri River Forest Reserve

for reasons of space. Row h in table 7 gives the bole volume distribution for trees over 40 cm diameter. It can be seen that for the 40-60 cm class, about 68% of total volume is constituted by buttress and branchwood, mostly the latter. The percentage of branchwood falls to about 42% in the larger diameter classes. Overall, 70% of the total volume is made up of branchwood, buttresses, and trees below 40 cm diameter. Only 30% comprises the boles of larger trees; that is a total of 138 m^3/ha of bole wood from 461 m^3/ha of total volume.

Row j gives the coefficient of variation of total volume of all species (row e). It can be seen that it is well within acceptable limits. In particular, the sparsely populated 150 cm plus class is sufficiently sampled by the ½% inventory.

A more efficient sampling design, using relascope plots giving a sampling fraction dependent on diameter class is an obvious way of cutting inventory costs. The information given in Table 7 and in the separate tables in Appendix C would help in optimizing such a design.

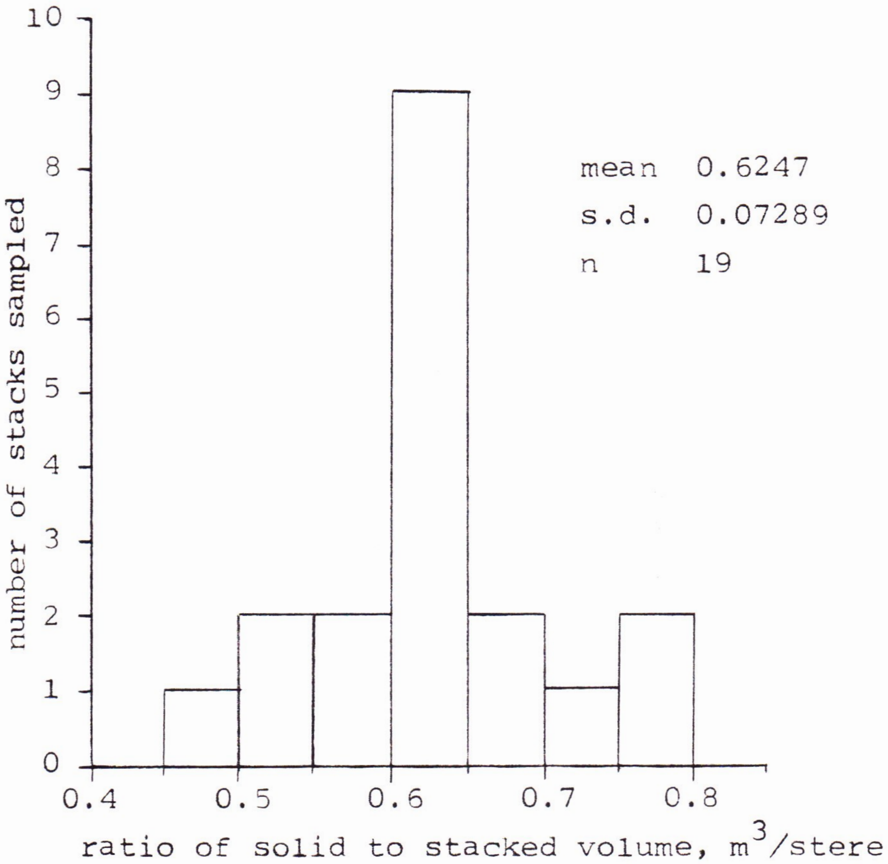
6.7 Ratio of solid to stacked volume

During the felled tree measurement operations detailed in Section 3.3, small trees, and branchwood of larger trees, were cut into 1 metre lengths and stacked. The exterior dimensions of the stacks were measured, and converted to solid volume by a factor derived by sampling. The sampled stacks were measured piece by piece to give exact solid volume.

The sample comprised 19 stacks, measured in detail. Figure 11 shows the frequency distribution of the ratios of solid over stacked volume. The mean stacking factor is 0.6247, with a standard deviation of 0.07289 m^3/stere. This agrees well with the figure determined by Kant [14] for split wood of 0.6337. The stacking factor used in another project report [13] of 0.77 m^3/stere appears rather high.

In all the mensurational work connected with this report, which involves conversion to or from stacked volumes, a factor of 0.624 m^3/stere has been used.

Figure 11 : Frequency distribution of stacked volume conversion factors



6.8 Size distribution of standards in Subri Conversion Technique

The characteristic silvicultural technique adopted on the project of which this inventory forms a part is the Subri Conversion Technique [5]. This involves leaving 30-40 'standards' per hectare of valuable rainforest species, after the balance of the forest has been felled for carbonisation, and agrisilvicultural plantation establishment. The standards form an overstorey over the plantation crop.

During the demarcation of the felled volume sampling area described in Section 3.3, standards were marked in accordance with the normal prescription for the Subri Conversion Technique. These standards were subsequently enumerated and their diameters recorded, on a plot by plot basis, although species was not individually assessed.

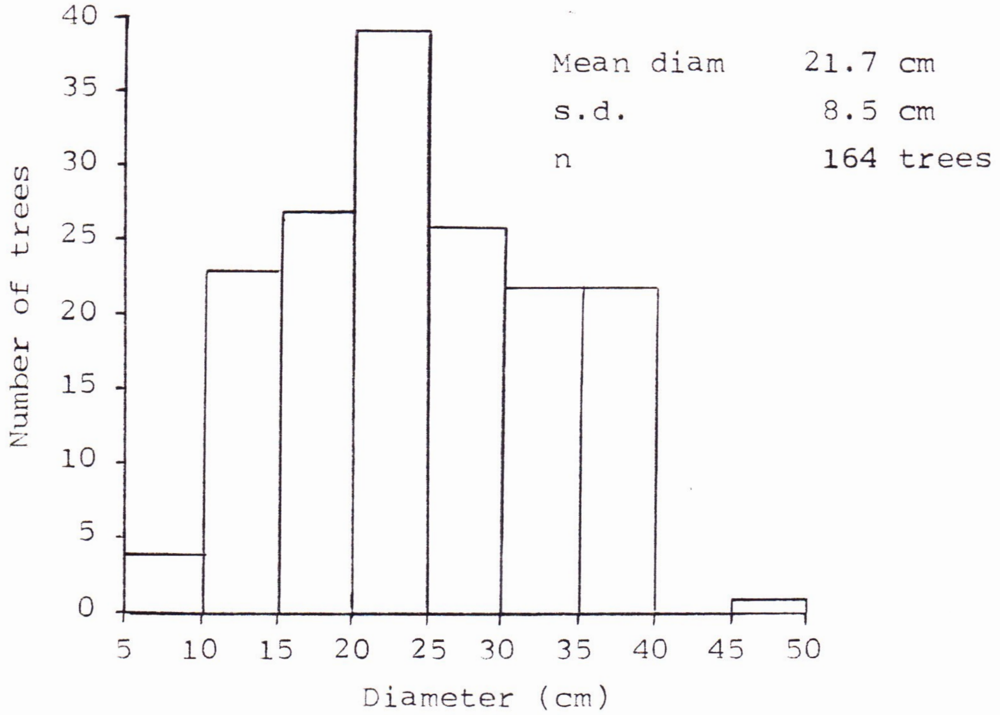


Figure 12 : Size class distribution of standards on felled volume experimental area

Figure 12 above shows the frequency distribution of the diameters of standards on the 5.8 ha felled volume experimental area. The mean diameter of standards was 21.7 cm. The standards averaged 16.7 m^3/ha total volume, comprising 9% of the total volume present prior to felling. The average stocking per ha. of standards was 29.1 trees, with the confidence limits for the mean stocking being between 23 and 34 stems/ha.

The measurements above are compensated for losses during felling, but not those which arose from a serious storm shortly after, which broke a number of crowns on the area. The total volume on the experimental area averaged 224 m^3/ha, which represents a low stocking compared with the majority of the reserve (see figure 10); only about 2½% of all inventory plots had stockings lower than this. Hence the distribution of standards may not be typical of what would occur on better stocked areas.

7. CONCLUSIONS & RECOMMENDATIONS

7.1 General conclusions

The results presented in the last section support the contention of many ecologists that tropical rainforest is one of the most productive ecosystems. The 107,850 ha. covered by the present inventory have an average above-ground woody biomass of 446 m^3/ha. Around 10% of the area has volumes exceeding 600 m^3/ha.

A total volume conversion system such as the Subri Conversion Technique can yield on average around 350 steres/ha of carbonisable wood, plus 50 m^3/ha of bole wood of quality sawtimber species, and 70 m^3/ha of pulpable volume. Volumes on the reserves covered are generally higher than those where project operations are currently focussed, in the South-East of Subri Reserve; possibly this is due to salvage logging on the project site in the early 70's in anticipation of the pulp mill due to be established at Daboase.

Certain species are common and well-represented in all areas. Pre-dominant among these are Dahoma (*Piptadeniastrum africanum*) which is an acceptable timber species with good properties for heavy construction work. *Uapaca guineensis*, also a good sawtimber, *Dialium aubrevillei*, *Heritiera* (*Tarretia*) *utilis*, *Parkia bicolor*, and *Sacoglottis gabonensis* all exceed 10 m^3/ha over Subri River Forest Reserve as a whole. Dahoma amounts on average to 24 m^3/ha over Subri. In Pra Suhien Forest Reserve, Avodire (*Turraeanthus africanus*) is nearly three times as abundant as Dahoma, at 75 m^3/ha. Avodire, apart from being a utility timber and plywood species is very suitable for pulping, and exists in quantity both on Pra Suhien, and the South East of Subri River Reserve, close to the proposed pulp mill at Daboase.

The mensurational results from the inventory show that between 50 and 70% of the volume of indigenous trees is in the branches and buttresses, not normally used by conventional harvesting methods. The general total volume table and bole volume tarifs in Appendix F are useful results; they can be used to estimate volume of standing trees from diameter only, and the volume of stands from a diameter frequency distribution (stand table). The total volume table suffers from the deficiency that it is based on a small sample only (102 trees) which does not allow partitioning of species into form classes. The bole volume tarifs, although based on a large sample (1441 trees), were derived from optical dendrometry, which does not appear to have been carried out as accurately as could be desired.

Species identification by inventory crews was also much less successful than they imagined. Control plot remeasurement of about 10% of the plots showed that only 50-odd species were being identified with over 70% consistency. Many of those which were mis-identified were valuable timber trees.
It is possible that some mis-identification is correct to the generic level, but the system used did not allow this to be quantified.

The sampling method, originally recommended in a consultancy report by Adlard [1], proved robust and effective. Sampling errors for groups of common species were generally below 10% for 30 or more plots. Over Subri River Reserve, total volume in all size classes had a coefficient of variation of less than 1½%. It is possible that plotless angle-count sampling would have been more efficient than the fixed 1 ha. plots used, but bearing in mind the strictures mentioned in [15] regarding the necessity for close supervision to avoid bias, the fixed plots used may well have been the optimum system under the circumstances.

The data processing system developed incorporates modern and reliable microcomputer systems programmed in BASIC. The programs are designed to be used with a minimal knowledge of the internal operations invloved, and can be handled by trained technical officers from the Forestry Department to produce inventory tables. The modular design of the system will allow future addition of alternative modes of analysis, e.g. cluster sampling, or different types of report generation. This system will remain operational after the completion of the UNDP/FAO project, and is a useful secondary benefit from the inventory exercise.

About 15 Technical Officers have received extensive training in mensurational techniques and instrumental methods. One professional officer has been trained in depth in computer data processing and BASIC programming, as well as in multivariate analytical techniques. A computer programmer was also trained, but regrettably resigned his post shortly afterwards.

7.2 Recommendations for future inventory work

The following recommendations relate particularly to future inventory work in Ghana. There is at the moment interest in conducting a National Forest Inventory exercise, possibly with the assistance of external funds.

1. Inventory design The present systematic grid design has advantages in that the coverage of the data is uniform and suitable for mapping forest types and vegetation patterns. The fixed plots used are robust and easily demarcated, although theoretically less efficient than plotless sampling.

   Continuation of the main features of the present design is therefore recommended.

2. Sampling intensity The ½% sample adopted is unnecessarily intense for total volume sampling and aggregate data for groups of 50 or more species. The intensity could be be reduced to ¼%, using a 2 km square grid, without any serious deterioration in the utility of the results.

3. Field equipment Any inventory project requires vehicles, personal clothing for the workforce, shelter, and instruments. None of these are available at present on the local market. The optimum type of vehicle is probably a 3-ton diesel pick-up. The use of off-road

vehicles such as the Land-Rover is not recommended on a routine basis, although they are required for supervisory staff; they should also be diesel powered.

Tents should be of heavy-duty tropicalized design. Plastic sheeting may also be used for shelter; but tents are recommended for more senior staff. Facilities such as camp-beds, lanterns, etc. must also be provided.

4. <u>Volume sampling</u> The sample in the present inventory of 102 felled trees was insuffiicent. At least 2000 trees of all species need to be felled and measured in detail to build volume tables of bole and branchwood. Recovery studies should also be made for sawlogs. Appropriate provision is required for adequate numbers of chainsaws and spare parts. Sampling and analysis should aim to estimate taper functions and species form-groups. Optical sampling is not adequate.

5. <u>Permanent plots</u> Permanent plots should be laid down at an intensity of 1 ha per 5000 ha on a stratified random basis to allow increment estimation. Permanent plots can also function as a training area for tree identification and dendrometry.

6. <u>Tree identification</u> The services of an expert tropical forest dendrologist are required on any future inventory, to train tree spotters, and prepare practical identification guides. The project should be equipped to process colour plates for teaching purposes.

7. <u>Data processing</u> The existing facilities will remain operational for at least 5 years. However, improvements are desirable. The rather idiosyncratic mixed BASIC/ assembler programs should be replaced by some which are more machine independent. The adoption of the UCSD p-system for the RML 380Z's would be of benefit in this respect. A data processing/mensuration consultant is likely to be a continuing necessity for successful inventory operations.

REFERENCES

References are given in the text in square brackets, viz.[2].

1. Adlard P.G. 1978 Proposal for a forest inventory of the Subri area. UNDP/FAO Project GHA/74/013 Field doc. 1.

2. Hall J.B., & Swaine M.D. 1976 Classification & ecology of closed-canopy forest in Ghana. J.Ecol.(64)913-951

3. Taylor C.J. 1960 Synecology & silviculture in Ghana. Nelson, Edinburgh.

4. Alder, D., & Caillez F. 1980 Forest volume estimation and yield prediction. FAO Forestry Paper 22 (2 vols).

5. Masson J.L. 1981 Subri conversion technique. UNDP/FAO project GHA/74/013 field doc. 7.

6. Odoom F.K. 1981 A provisional yield table for *Gmelina arborea* plantations in Subri River Forest Reserve. UNDP/FAO Project GHA/74/013 field doc. 18.

7. Research Machine Ltd 1981 RML 380Z system manual. Research Machines, Oxford.

8. Research Machines Ltd 1980 TXED text editor and formatter reference manual. Research Machines, Oxford.

9. Research Machines Ltd 1980 Extended BASIC version 5 reference manual. Research Machines, Oxford.

10. Zilog, Inc. 1977 Z-80 Assembly language programming manual. Zilog Inc., Cupertino, Calif.

11. Research Machines Ltd 1980 FORTRAN-80 reference manual. Research Machines, Oxford.

12. Alder, D. 1982 SNIFTA nonlinear analysis documentation. Unpublished mimeo.

13. Roetzer, G. 1982 The productive conversion of tropical rainforests : logging and utilization. UNDP/FAO project GHA/74/013 field doc 19.

14. Kant H. 1979 The development of forest energy resources in Ghana : forest engineers report. UNDP/FAO project GHA/74/013 field doc. 2.

15. Sutter, H. 1979 The indicative inventory of reserved high forests in Soutern Nigeria 1973-77. UNDP/FAO project NIR/71/546 Tech Rep 1.