# Woody vegetation cover and wood volume assessment in northern Nigeria.

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SILVICONSULT BT AB

# WOODY VEGETATION COVER AND WOOD VOLUME ASSESSMENT IN NORTHERN NIGERIA

RIM

June 1991

Federal Government of Nigeria
Forestry Management, Evaluation and Coordinating Unit
SILVICONSULT BT AB

# WOODY VEGETATION COVER AND WOOD VOLUME ASSESSMENT IN NORTHERN NIGERIA

A rapid assessment of resources based on interpretation of satellite imagery, low level sample aerial photography, and ground validation.

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## ACRONYMS, ABBREVIATIONS AND UNITS

| | |
|---|---|
| APCU | Afforestation Project Coordination Unit |
| APMEU | Agricultural Projects Monitoring and Evaluation Unit |
| CBH | Circumference at Breast Height |
| DBH | Diameter at Breast Height |
| FDF | Federal Department of Forestry |
| FORMECU | Forestry Management, Evaluation and Coordinating Unit |
| IAR | Institute for Agricultural Research |
| MSS | Multi-Spectral Scanner |
| NAPRI | National Animal Production Research Institute |
| OFI | Oxford Forestry Institute |
| RBDA | River Basin Development Authority |
| RIM | Resource Inventory and Management Limited |
| SE | Standard Error |
| SLAR | Side Looking Airborne Radar |
| sp | Species |
| UTM | Universal Transverse Mercator |
| Vol | Volume |

| | |
|---|---|
| cm | centimetre |
| ft | foot |
| ha | hectare |
| in | inch |
| km | kilometre |
| $km^2$ | square kilometre |
| m | metre |
| $m^3$ | cubic metre |
| mm | millimetre |

## SUMMARY

In response to the escalating cost of firewood and the rising concern about its future availability, the Federal Government commissioned a special study of Household Energy Supply and Demand in the northern part of the country.

As part of this study, Resource Inventory and Management Limited (RIM) was contracted by SILVICONSULT to provide an assessment of present woody vegetation cover and potential wood volume availability in the area to the north of the eleventh parallel and, in the centre of the country, selected areas to the south of that line. The region thus defined covered some 322,000 $km^2$, and included most of Bomo, Sokoto, Kano and Katsina States, as well as the northern parts of Kaduna, Bauchi and Plateau States.

The results of this survey have been incorporated into the report of the SILVICONSULT Household Energy Supply and Demand Study, which examines the relationship between supply and demand in the project area. This work therefore concentrates on estimating wood volume in the region and, to avoid duplication, does not consider the consequences of actual demand.

The survey was conducted between August and November 1990, and relied on the integrated use of low level aerial photography, ground validation, and satellite imagery. Over 5000 photographs were taken and assessed for the proportion of tree canopy cover, from which the canopy area was calculated for each of six land use categories identified from satellite imagery.

In addition, some 6,700 trees of 140 species in nearly 150 sample sites, were measured for canopy and trunk dimension. Using currently available conversion tables, these ground data were then converted to wood volumes per unit area of canopy which, when combined with the estimated area of canopy, allowed the estimation of wood volumes per square kilometre for each land use category.

The area of each land use category in 806 20 x 20 km analysis grids was then measured, and the wood volumes calculated. This enabled the wood volumes to be mapped and analysed by a number of geographical regions, including ecozone, state, and varying distances from selected towns.

The wood volume estimated for the entire study area is 380 million cubic metres, or 11.8 $m^3$/hectare. More than 10% of this figure is attributable to a single species - the baobab - which is rarely used as fuel, suggesting that a more realistic estimate of potential fuel wood for the area is in the region of 335 million cubic metres, or an average of 10.4 $m^3$/hectare.

These averages compare well with other recent field estimates for small areas in the study area, but conceal a wide variability in relation to ecological conditions. Estimated wood volumes in grassland and shrubland are 4 to 6 $m^3$/ha; in cultivation and shrub/grassland are approximately 7 to 9$m^3$/ha; and rise to some 22 and 50 $m^3$/ha in woodland and dense woodland respectively.

This study has been the first of its kind to cover such an extensive land area. It clearly demonstrates the value of the integrated use of satellite imagery, sample photography and selective ground truthing in providing rapid, reliable and cost effective assessments of vegetation cover, wood volume and land use for large areas. The method clearly has relevance and applications for many other regions.

## INTRODUCTION

In northern Nigeria, the cost of firewood in urban areas is escalating; trees are being progressively replaced by either shrubs or bare ground as cultivation expands in concert with the rising human population and increasing food costs. As a result, land degradation is becoming more widespread.

In response to these disturbing trends, the Federal Government's Forestry Management, Evaluation and Coordinating Unit (FORMECU) and the Afforestation Project Coordination Unit (APCU) commissioned SILVICONSULT BT AB to conduct a study of Household Energy Supply and Demand in the region.

A prerequisite of such a study is that it is based on adequate data on both wood consumption and availability. A World Bank report (World Bank, 1984) stated that 'data on tree stocks (are) subject to large margins of uncertainty. Inventories (are) supplemented where possible by aerial photography, though the latter ... is still quite limited in Africa; surveys are often described as 'patchy', and it is not clear whether they comprise statistically representative samples.'

Therefore, as part of the Supply and Demand study, Resource Inventory and Management Limited (RIM) was sub-contracted to provide an objective assessment of present woody vegetation cover and potential fuelwood availability in the area to the north of the eleventh parallel and, in the central part of the country, selected areas to the south of that line.

The resulting study area thus covered most of Borno, Sokoto, Kano and Katsina States, together with the northern sectors of Bauchi, Kaduna and Plateau States, and amounted to a total land area of some 322,000 square kilometres, or about a third of the country (Map 1).

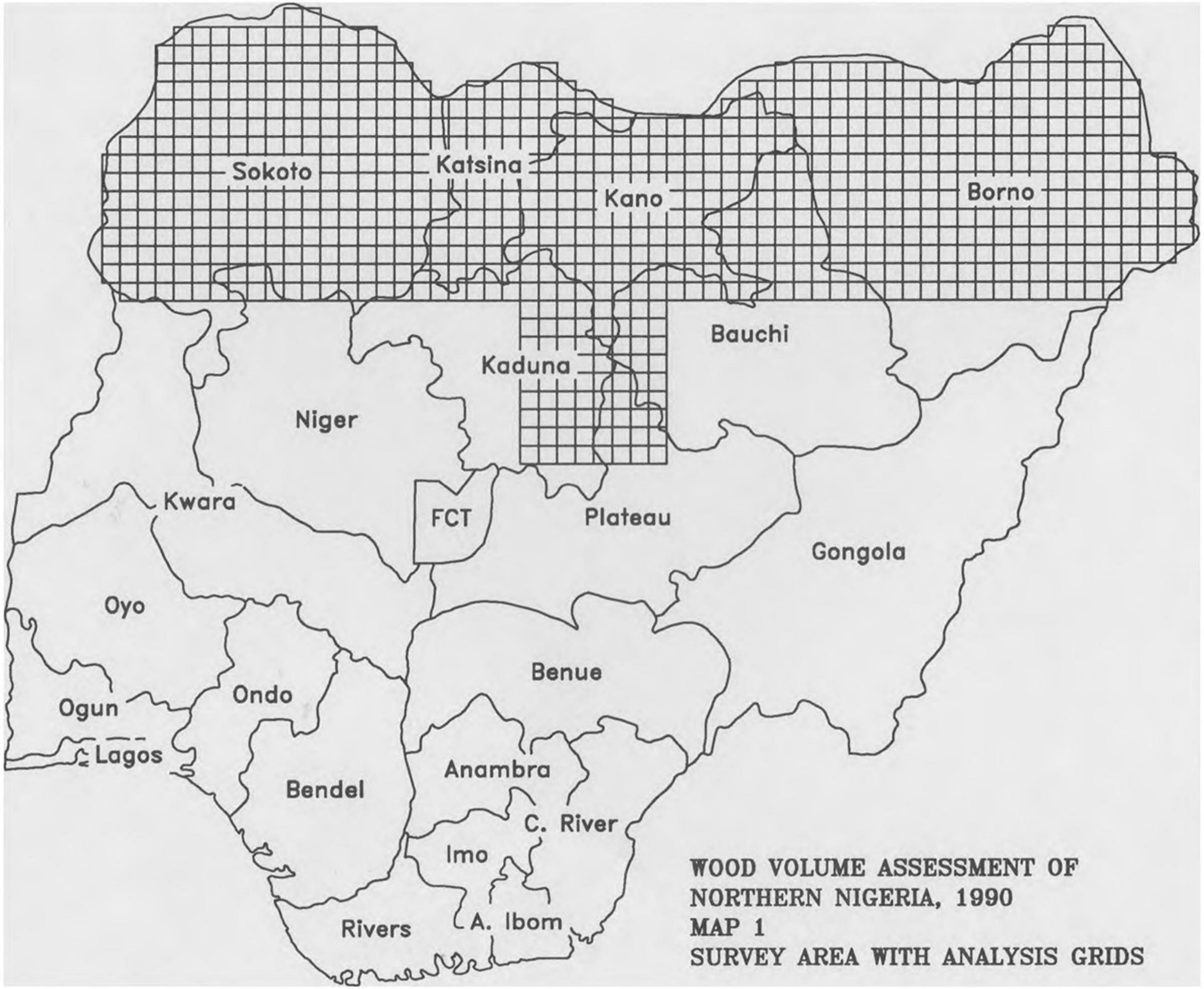
Given the size of the area to be surveyed and the limited time available, a rapid, cost-effective method of information collection was devised, which incorporated the use of satellite imagery, systematic sample low level aerial photography, and ground validation.

## METHODS AND ANALYSIS OVERVIEW

The calculation of wood volumes involves two basic stages: first an estimation of the area of tree canopy; and second the estimation of wood volume per unit area of tree canopy. These two figures can then be multiplied to give a figure for total wood volume. The following paragraphs summarise the techniques used, which are illustrated schematically in Figure 1, below

The estimation of canopy area relies on aerial photography, whereby photographs are assessed for percent canopy cover. From its geographical location, each photograph is assigned to one of six land use strata, as defined from Landsat images and Side Looking Airborne Radar (SLAR) vegetation maps (see below). Consequently, the mean percent canopy cover for each stratum can be calculated. This percentage is then applied to the area of each land use stratum to provide estimates of total canopy area.

The estimation of wood volume per emit area of canopy relies on extensive ground sampling within each land use stratum and ecozone to assess the frequency of each tree species and the dimensions of trunk and canopy for each individual tree. These data can then be used to estimate wood volumes per unit area of canopy, provided that wood volume tables are available for the relevant tree species.


Sokoto
Katsina
Kano
Borno
Bauchi
Kaduna
Niger
Kwara
FCT
Plateau
Gongola
Oyo
Benue
Ogun
Ondo
Lagos
Bendel
Anambra
C. River
Imo
Rivers
A. Ibom
WOOD VOLUME ASSESSMENT OF
NORTHERN NIGERIA, 1990
MAP 1
SURVEY AREA WITH ANALYSIS GRIDS

## FIGURE 1: SCHEMATIC OF METHODOLOGY

**AERIAL PHOTOGRAPHY**

% TREE CANOPY COVER FOR EACH LAND COVER STRATUM AND EACH ECOZONE

↓

**GROUND SURVEY**

WOOD VOLUME PER UNIT AREA OF CANOPY FOR EACH LAND COVER STRATUM AND EACH ECOZONE

↓

**ANALYSIS**

WOOD VOLUME PER UNIT AREA OF LAND FOR EACH LAND COVER STRATUM AND EACH ECOZONE

↓

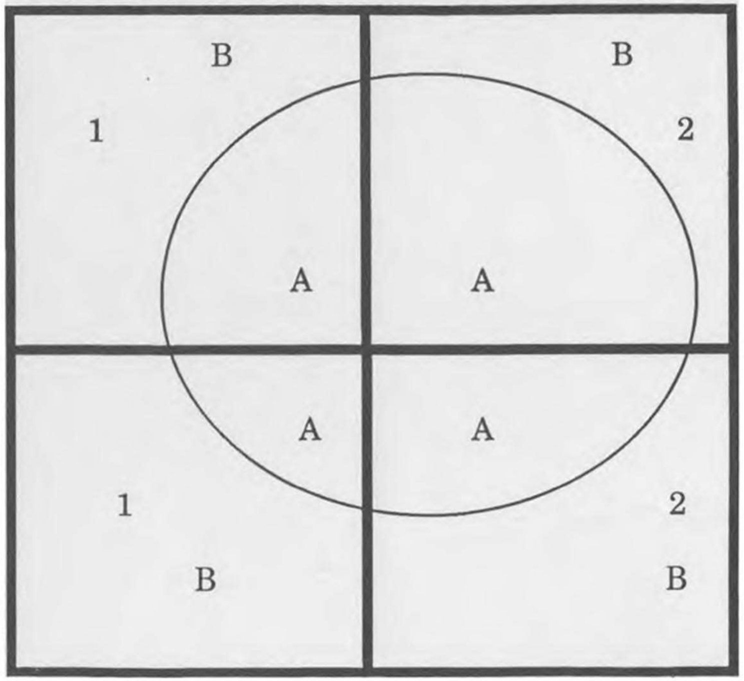
**STRATIFICATION OF SATELLITE IMAGERY**

AREA WITHIN EACH GRID OF EACH LAND COVER STRATUM

**GRID CODING**

ECOZONE CODE (1,2)

FOUR GRIDS WITH MEASURED AREAS OF LAND USE STRATA A & B, ASSIGNED TO ECOZONES 1 OR 2




**WOOD VOLUME OF EACH ANALYSIS GRID KNOWN**

Each sample of 50 trees was assigned to a particular land use stratum according to location, as derived from the Landsat and SLAR information. Each tree sample was also assigned to a specific vegetation mapping unit or ecozone, as defined by White (1983) and modified on the basis of vegetation type and rainfall.

The area of each stratum must be measured within defined geographical regions, such as states or ecozones, before final estimates of wood volume can be calculated. This process could be carried out directly from large scale maps, but fails to provide either satisfactory measures of the error of any estimates made, or readily interpretable distribution maps at any alternative scale. Furthermore, the allocation of particular areas to additional strata is extremely laborious.

A more flexible method is to overlay a series of regular spatial units onto the survey area. As the area of each such unit is constant, the extent of tree canopy and of each land use stratum can be calculated for every one. Each unit can then be assigned to a range of spatial strata, for example, ecozone, at any stage during the analysis, and canopy area for each stratum then calculated accordingly.

In the present work, the overlaid units were defined to coincide with those used in another large scale survey of Nigeria - namely the 20 x 20 kilometre grids used in the National Livestock Survey (RIM, 1991). These grids, which form an integral part of the SLAR maps used in the initial identification of the land use strata, are based on the Universal Transverse Mercator (UTM) cartographic projection.

There are 806 grid squares (each of 400 $km^2$) within the survey area (Map 1), for each of which the absolute area of each land use strata is known. As a result, using the aerial photographs, the area of tree canopy within each grid is also known.

Analysis and mapping have been performed with SPSS (Statistical Package for the Social Sciences) to process the raw data which were entered into ASCII data sets using portable IBM compatible micro computers. The processed data were then concatenated (summarised) into individual data points for each variable within each analysis grid, and mapped using a customised mapping programme (MAPICS), specifically designed for use with aerial survey data (RIM 1986).

## LAND USE STRATIFICATION

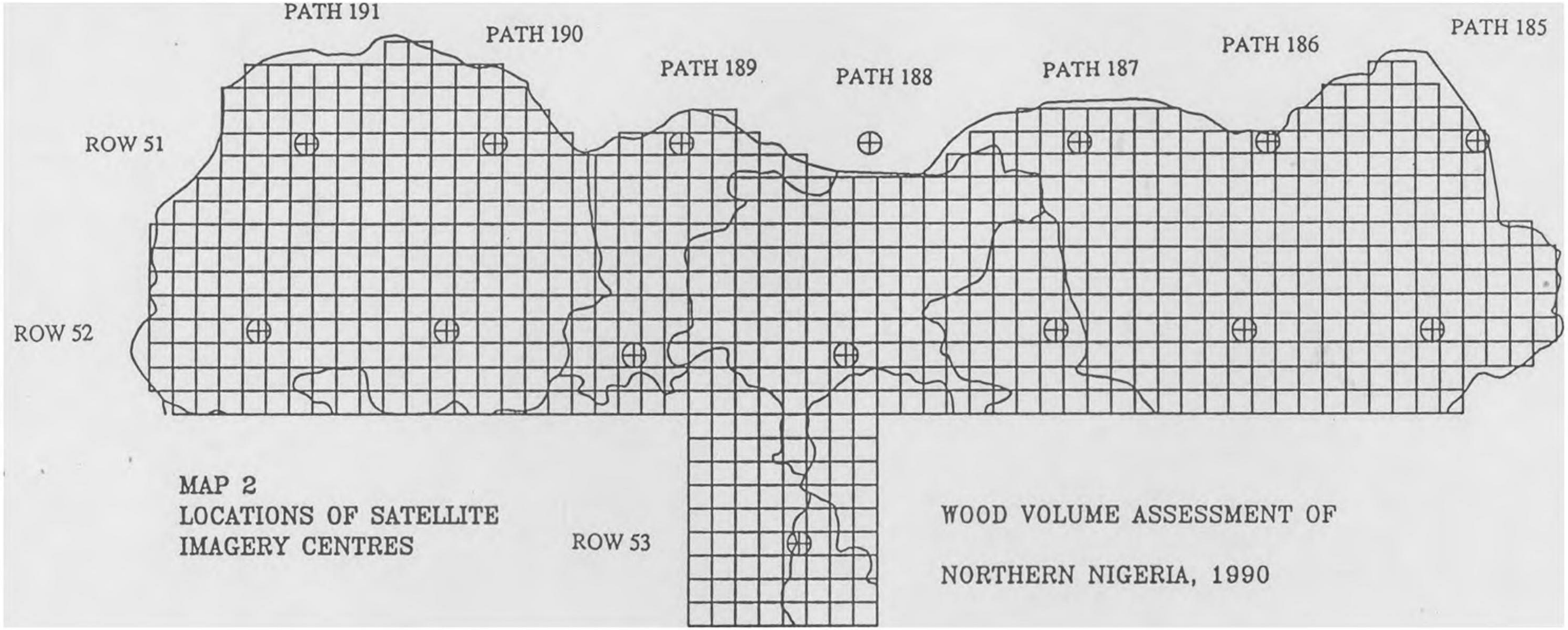
The most recent Landsat coverage available was obtained by SILVICONSULT in the form of Multi-Spectral Scanner (MSS) standard false colour prints at a scale of 1:250,000. Scenes available are identified by date, path and row number in Table 1 below, and by the location of their image centres, as shown in Map 2.

These images covered most of the study area, except for a section of Sokoto State which was unavailable. The required land use stratification of this area was derived solely from SLAR vegetation maps.

The major vegetation and land use strata defined were as shown in Table 2, below.

All scenes were carefully examined and compared with corresponding SLAR Vegetation and Land Use Maps obtained in the late 1970s . Updated boundaries of the major vegetation and land cover strata were traced from the satellite imagery.

These land use strata were initially selected so that they could be reliably differentiated on the satellite images, as well as to reflect meaningful combinations of the vegetation types defined on the SLAR vegetation maps. As a result, once the strata had been identified on the Landsat images, they could be cross checked, and, if necessary, modified using the vegetation maps. In those areas for which satellite images were not available, the SLAR maps could be used on their own to delineate strata that were directly comparable to those defined for the majority of the survey area.




MAP 2
LOCATIONS OF SATELLITE
IMAGERY CENTRES

WOOD VOLUME ASSESSMENT OF

NORTHERN NIGERIA, 1990

Table 1: Landsat Imagery Used To Define Land Use Strata

| Path | Row | Date |
|---|---|---|
| 185 | 51 | 09 Sep 86, 14 Oct 87 |
| | 52 | 14 Oct 87 |
| 186 | 51 | 22 Jan 87 |
| | 52 | 22 Jan 87 |
| 187 | 51 | 26 Nov 86 |
| | 52 | 12 Dec 86 |
| 188 | 51 | 17 Nov 86 |
| | 52 | 17 Nov 86 |
| | 53 | 17 Nov 86 |
| 189 | 51 | 23 Oct 86 |
| | 52 | 11 Jan 87 |
| | 53 | 11 Jan 87 |
| 190 | 51 | 22 Oct 89 |
| | 52 | Unavailable |
| 191 | 51 | 20 Jul 87, 13 Oct 89 |
| | 52 | 03 Sep 86, 14 Nov 89 |

Table 2: Defined Land Use Strata

| Stratum | SLAR Categories Incorporated |
|---|---|
| Cultivation: | Farmland, incorporating farming, intense farming and cultivation categories of 30-60%, 60%+ |
| Grassland: | Grassland (including Dry Grassland and Grassland) |
| Shrub/Grassland: | Grassland with Shrub, Wooded shrub |
| Shrubland: | Shrub and Thicket, Grassland Shrubland Transition |
| Woodland: | Wood/Grass, Transition Woodland and Broad Leaved Woodland |
| Dense Woodland: | Selected Forest Reserves |
| Water: | Lakes |

It should be noted that the boundaries of Forest Reserves were taken directly from the SLAR maps. However, careful observation from the air, during this and previous surveys, has shown that many of those areas defined on the SLAR vegetation maps as Forest Reserve have been severely encroached upon by recent or, indeed, active cultivation (RIM, 1991). Such encroachment was also evident from the satellite imagery: whilst the boundaries of some Reserves were discernible, those of many sites purported to be Reserves were not.

This suggests that the 1975 definitions are unlikely to reflect a land use stratum that can be viewed as having discrete characteristics at present. In addition, the ground validation data suggested great variability within this stratum, which throws doubt on the validity of extrapolating to a survey wide coverage.

As a result, only a selection of Reserves were included within a discrete category, which has been named 'dense woodland', and could be taken as representative of intact Forest Reserves surveywide. This stratum does not therefore incorporate all the putatively reserved areas.

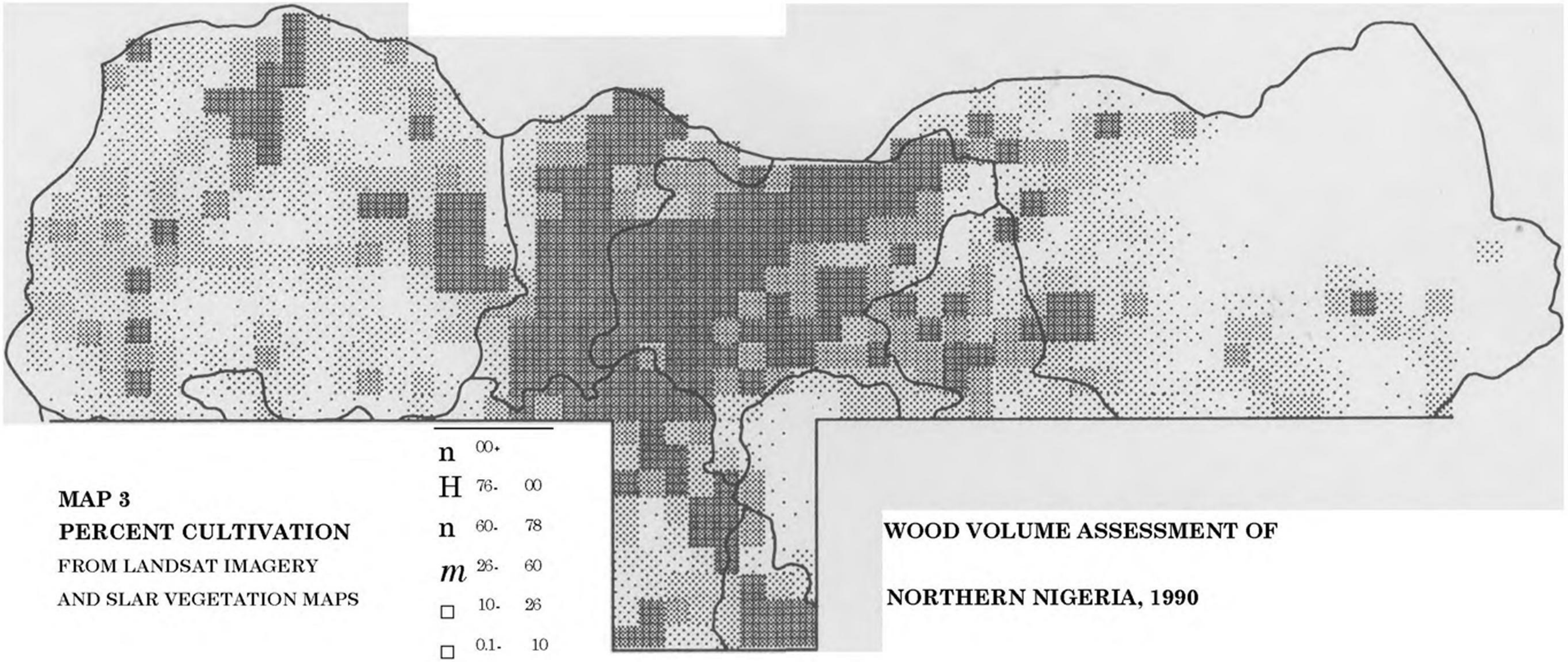
Once the strata had been defined and outlined on a series of 1:250,000 maps, a series of 20 x 20 kilometre grids was overlaid. These grids are based on the UTM projection and were used in the Federal Government's National Livestock Survey (RIM, 1991). The proportion in every cell of each land use category was then measured and transferred to a geographically coordinated computer database. As the area of each cell is a constant 400 square kilometres, the absolute area of each stratum present in each cell could be calculated.

The resulting areas of each stratum within the survey zone are shown in Table 3, below:

Table 3: Measured Area Of Each Land Use Stratum

| STRATUM | AREA ($km^2$) | % TOTAL AREA |
|---|---|---|
| Cultivation | 155,764 | 48.3 |
| Grassland | 7,800 | 2.4 |
| Shrub/Grassland | 65,528 | 20.3 |
| Shrubland | 35,784 | 11.1 |
| Woodland | 49,948 | 15.5 |
| Dense Woodland | 7,416 | 2.3 |
| Water | 160 | 0.1 |

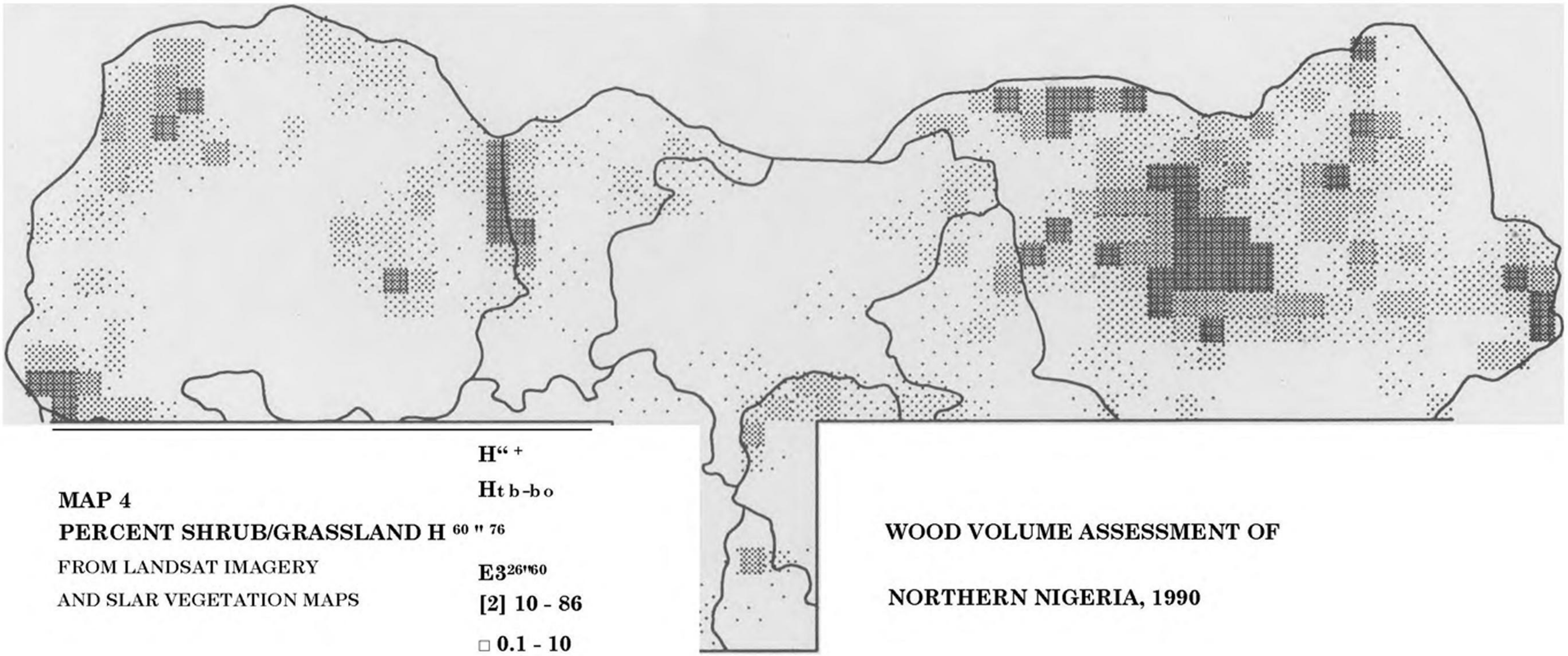
The distribution of the major strata can be seen on Maps 3 to 7. Cultivation is the most abundant of the land use types, covering approximately half of the total area, and is concentrated in the 'Close Settled Zone' stretching from eastern Sokoto to Bauchi State. The distribution of grassland is limited to the extreme eastern and western borders of the region, around Lake Chad, and to the west of the River Niger in Sokoto State. Shrub/grassland, the second most widespread stratum, is most widespread in Borno State and in western Sokoto State. Patches are also to be found in Kaduna and Bauchi States, and more particularly along the border between Katsina and Sokoto States, in the region of Kukar Jangarai Grazing Reserve. Shrubland is more extensive, though it has a broadly similar distribution to grassland. Woodland also shows a relatively disjunct distribution pattern, being concentrated in southern Sokoto and Borno States, western Bauchi State, and along the rivers in Kano State that feed into Lake Chad (Komadugu Yobe and Komadugu Gana).




**MAP 3**
**PERCENT CULTIVATION**
FROM LANDSAT IMAGERY
AND SLAR VEGETATION MAPS

**WOOD VOLUME ASSESSMENT OF**

**NORTHERN NIGERIA, 1990**



H“ +

Ht b-b o

**MAP 4**

**PERCENT SHRUB/GRASSLAND** H 60 " 76

FROM LANDSAT IMAGERY

E3 26"60

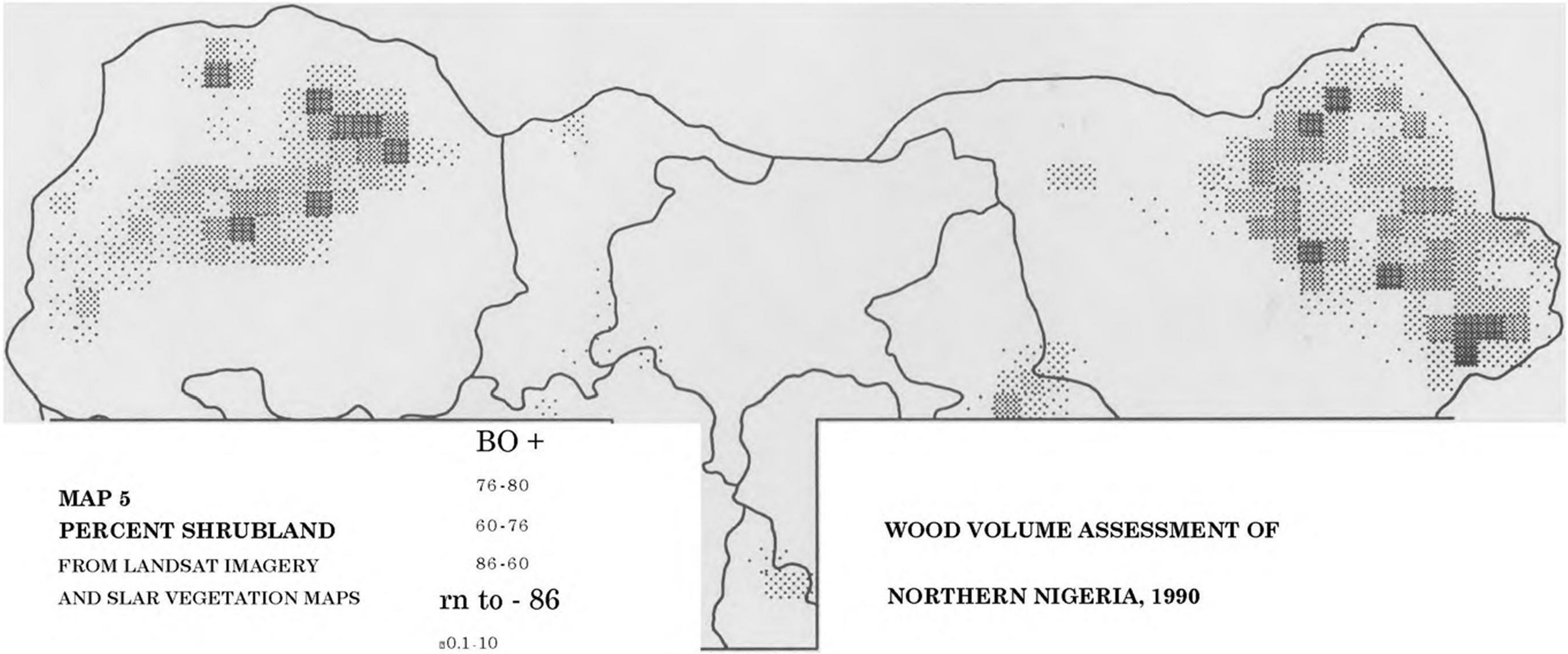
AND SLAR VEGETATION MAPS

[2] 10 - 86

□ 0.1 - 10

**WOOD VOLUME ASSESSMENT OF**

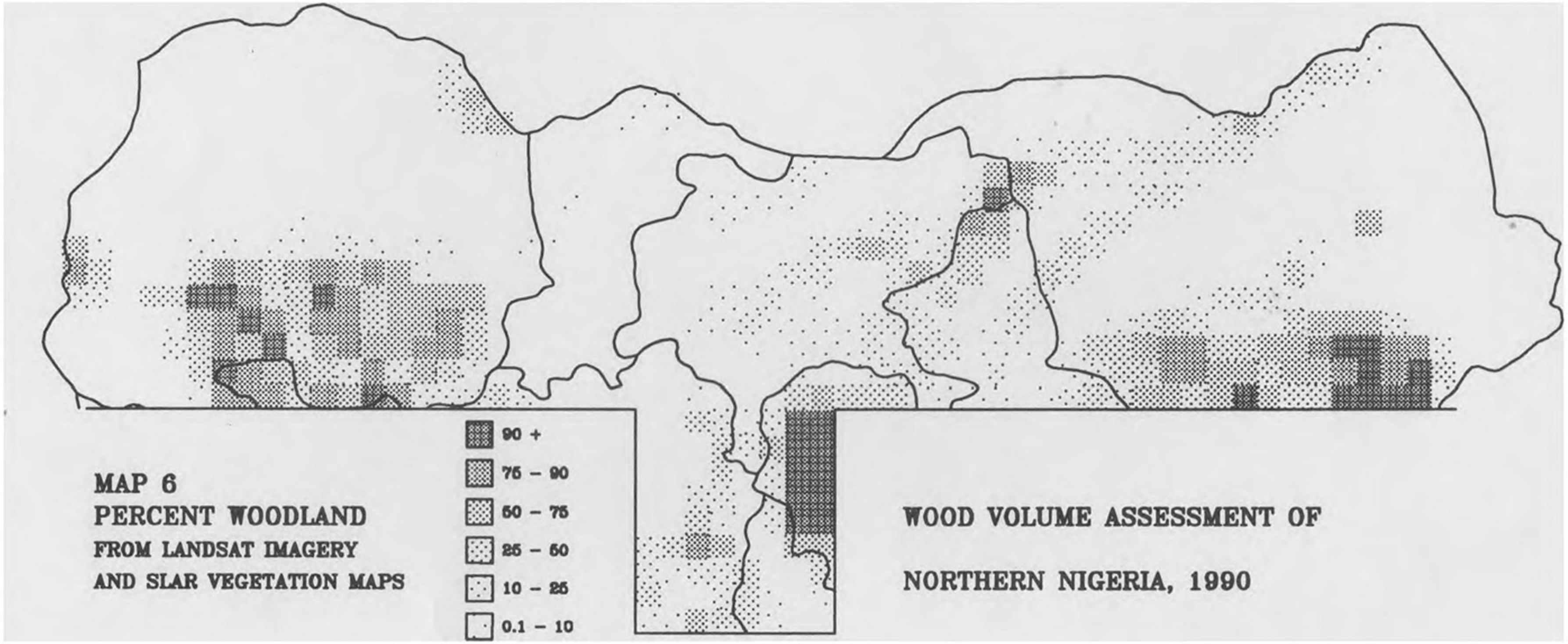
**NORTHERN NIGERIA, 1990**




**MAP 5**
**PERCENT SHRUBLAND**
FROM LANDSAT IMAGERY
AND SLAR VEGETATION MAPS

**WOOD VOLUME ASSESSMENT OF**

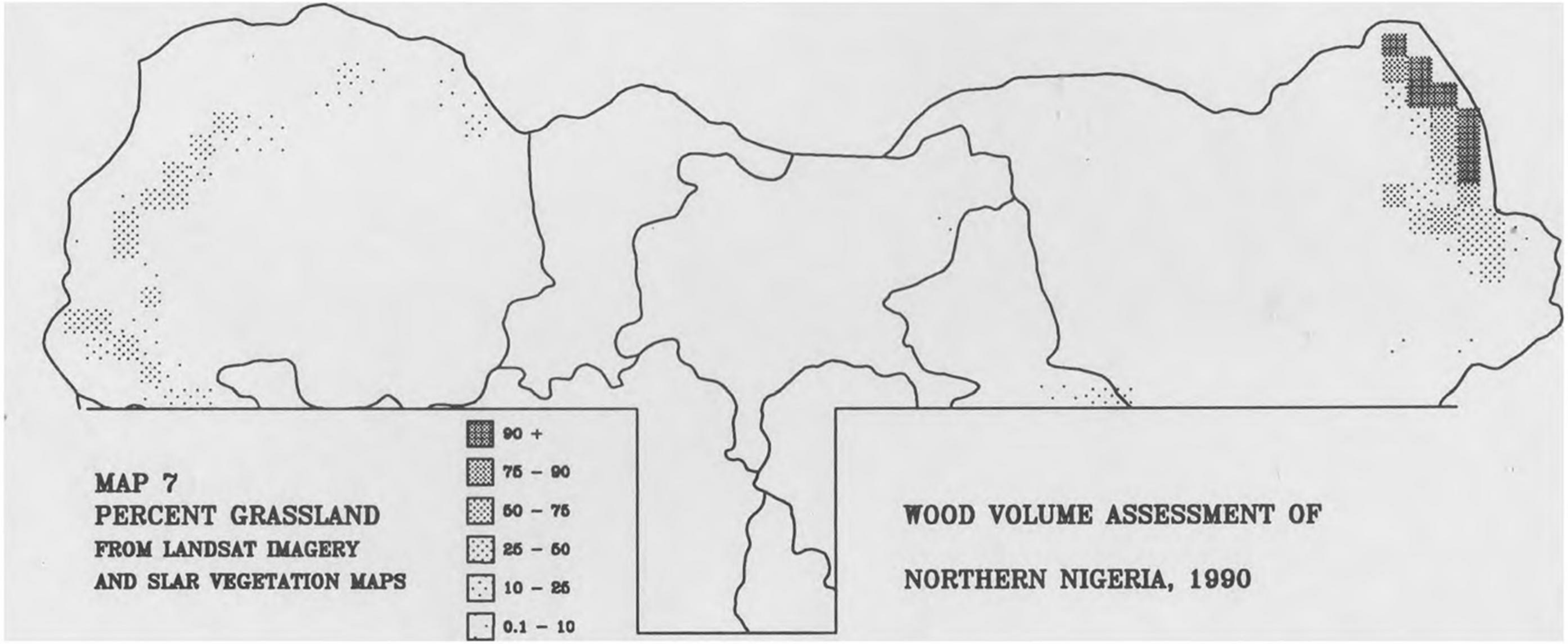
**NORTHERN NIGERIA, 1990**




MAP 6
PERCENT WOODLAND
FROM LANDSAT IMAGERY
AND SLAR VEGETATION MAPS

WOOD VOLUME ASSESSMENT OF

NORTHERN NIGERIA, 1990


MAP 7
PERCENT GRASSLAND
FROM LANDSAT IMAGERY
AND SLAR VEGETATION MAPS
90 +
75 - 90
50 - 75
25 - 50
10 - 25
0.1 - 10
WOOD VOLUME ASSESSMENT OF
NORTHERN NIGERIA, 1990

Of some relevance to the projection of future wood supply is the degree of concordance between the 1975 SLAR maps and the 1990 Landsat Imagery. Whilst it is not part of the present terms of reference to make detailed quantitative comparisons between the two sources of vegetation data, a number of preliminary observations can be made.

The extent and distribution of the broad categories of natural vegetation (woodland, shrubland, grassland etc) appear to have remained fairly constant over the 16 years separating the two maps. Indeed this was one of the determining factors behind the original choice of the land use strata. Similarly some of the more restricted categories, such as riparian woodland, or islands of vegetation dictated by edaphic or topographic variation, seem to have persisted unchanged.

However, the distributions of three land use categories have altered to some degree. Urban areas have expanded: RIM (1991) estimates that the extent of inhabited urban areas in 1990 was, on average, approximately twice that delineated by the 1975 SLAR maps. Also, as discussed above, many Forest Reserves shown on the 1975 maps have not maintained their integrity.

The most marked changes are visible in the extent of cultivation. Though the general distribution patterns are similar, particularly in areas where cropping is widespread, many small scale or localised differences are evident between the two cartographic sources, where new areas have been cleared or, less frequently, where old areas have reverted to natural vegetation.

## AERIAL PHOTOGRAPHY AND PHOTO-INTERPRETATION

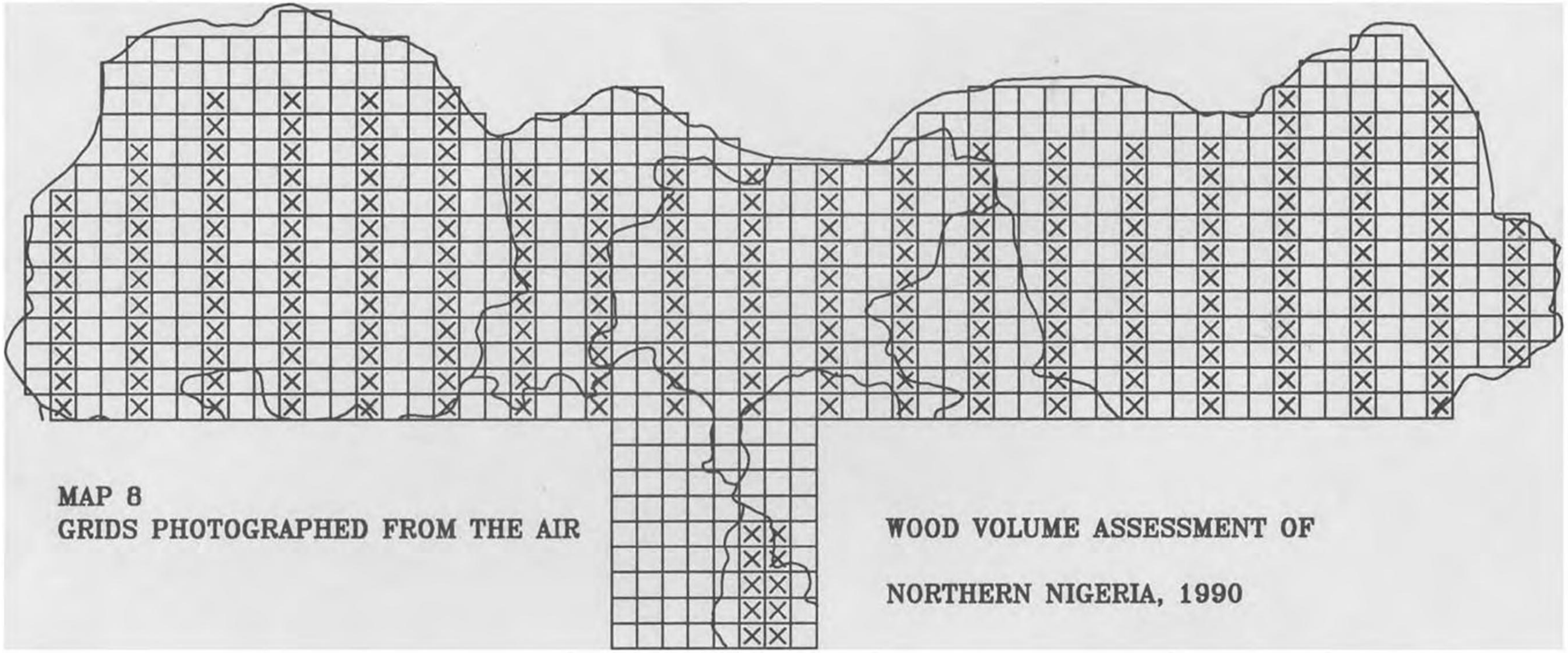
For the purposes of the survey, a locally registered light aircraft was specially equipped with a Tracor computer navigation system, a radar altimeter, and twin 35mm Nikon cameras. The flight crew consisted of a team of three: pilot, navigator and camera operator.

Each camera was fitted with a 24 mm wide-angle lens and a 250 exposure bulk film data-back which recorded date, flight line and time to the nearest second onto each frame of film. Exposure was triggered by an intervalometer. Ektachrome 200 ASA Professional colour slide film was used to obtain high resolution photographs.

The aerial survey took place in the middle of the northern Nigerian crop growing period, in late August 1990. In order to obtain a representative sample of vertical photographs (RIM (1984 a & b); Clarke (1986); Norton-Griffiths (1988)), flight lines were orientated longitudinally so as to traverse the major eco-climatic gradients, and spaced at 60 kilometre intervals (See Map 8). Navigational accuracy was regularly cross-checked by comparing the computer positions with physical features observed on the ground, and a constant flying height was maintained using the radar altimeter.

Over 5,000 vertical photographs were taken at regular intervals along each flight line, corresponding to approximately one per linear kilometre, from a nominal height of 1,500 feet above ground level below the normal wet season cloud base). Photographic frequency was adjusted for each flight line, according to wind speed and direction. It should be noted that the photographs obtained were not of the type often associated with aerial photography (i.e. large format black and white), but were instead 35 mm colour transparencies. These are considerably easier to interpret for vegetation as colour contrasts are more evident.

At regular intervals, and at least once every 20 kilometres, the exact position of the aircraft was marked on the navigation maps, and the precise time recorded. This allowed the accurate location of marker photographs, so that the intervening frames could be assigned to specific positions on the basis of elapsed time between confirmed locations.



**MAP 8**
**GRIDS PHOTOGRAPHED FROM THE AIR**

**WOOD VOLUME ASSESSMENT OF NORTHERN NIGERIA, 1990**

FIGURE 2: PHOTO-INTERPRETATION FRAME

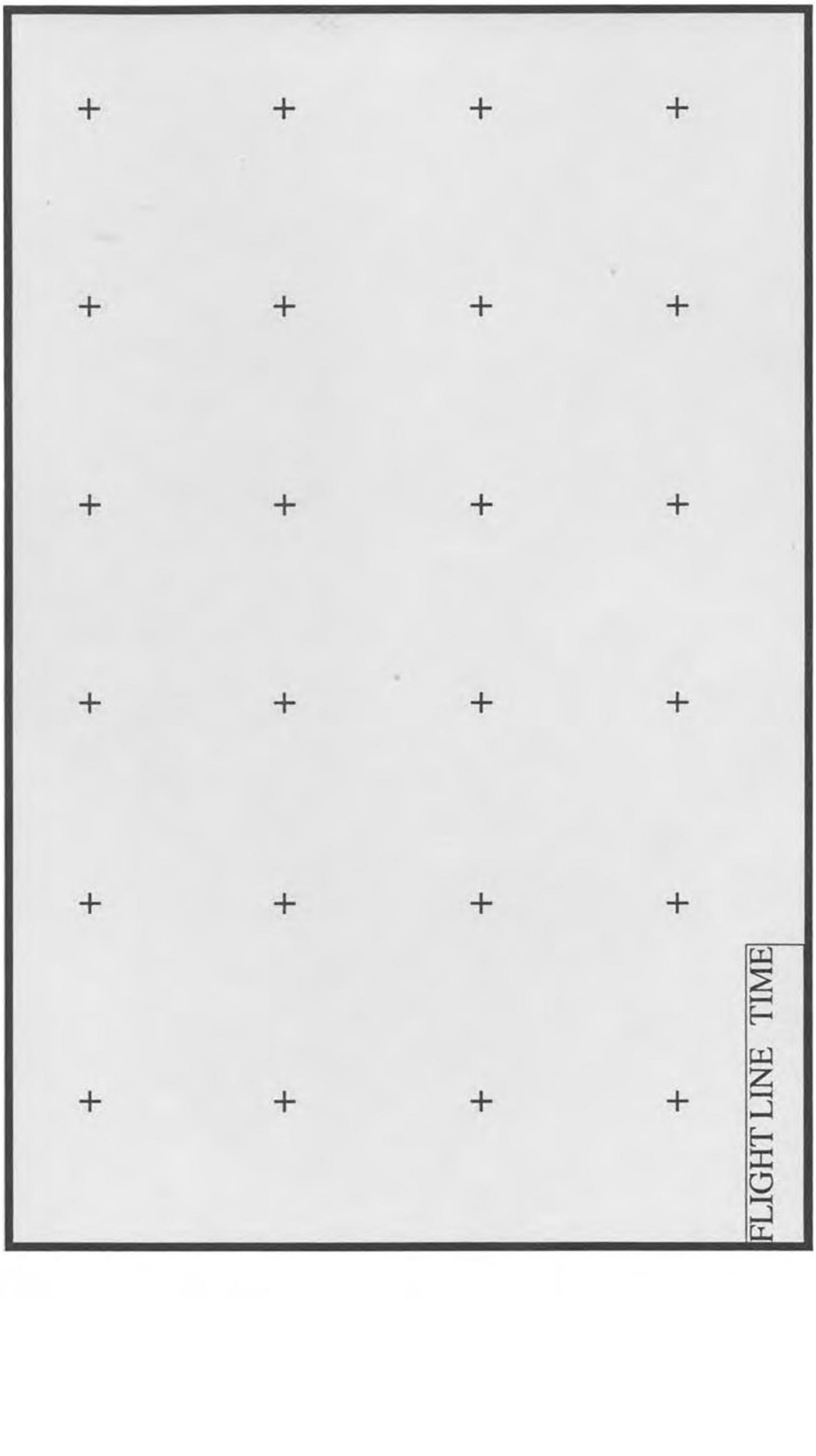


Photo-interpretation was carried out by point sampling of projected images at a scale of 1:1,000. Each slide was projected onto a matt white screen (675 mm by 450 mm) with a 6 by 4 array of 24 cross hair sample points (see Figure 2), which contained sufficient points to form a statistically satisfactory sample of each photograph.

Interpreters, working in pairs in a darkened room, were required to record, for each frame, the contents of the imprinted data box, and to classify each sample point into one of four mutually exclusive land cover categories: Tree Canopy; Shrub Cover; Farmland; and Other (e.g. bare ground, water, grassland, etc). The occurrence of a number of additional features anywhere within a frame was also recorded, including severe erosion, major towns, roads and large rivers.

It is emphasised that these categories do <u>not</u> correspond to the land use strata defined from the satellite imagery. Thus, for example, trees within cultivated land were included within the category 'Tree Canopy'.

Trees and shrubs were differentiated during the photo-interpretation on the basis of height, and contrast: whilst trees cast shadows, shrubs do not, and the two could thus be readily distinguished.

Table 4, below, summarises the results of the photo-interpretation and shows the mean percentage of each land cover category for each land use stratum. As might be expected, tree canopy was found to be most extensive in dense woodland and woodland, and least widespread in grassland. The proportion of cultivation in each stratum also met with expectations: all strata included some farmed land because much of the survey area is, in reality, a fine mosaic of natural vegetation and farming. Such mosaics are generally too fine to be sub-divided on the available satellite imagery, and could only be realistically differentiated in surveys covering very limited areas at very high resolution.

Table 4: Percent Land Cover Estimated From Aerial Photography

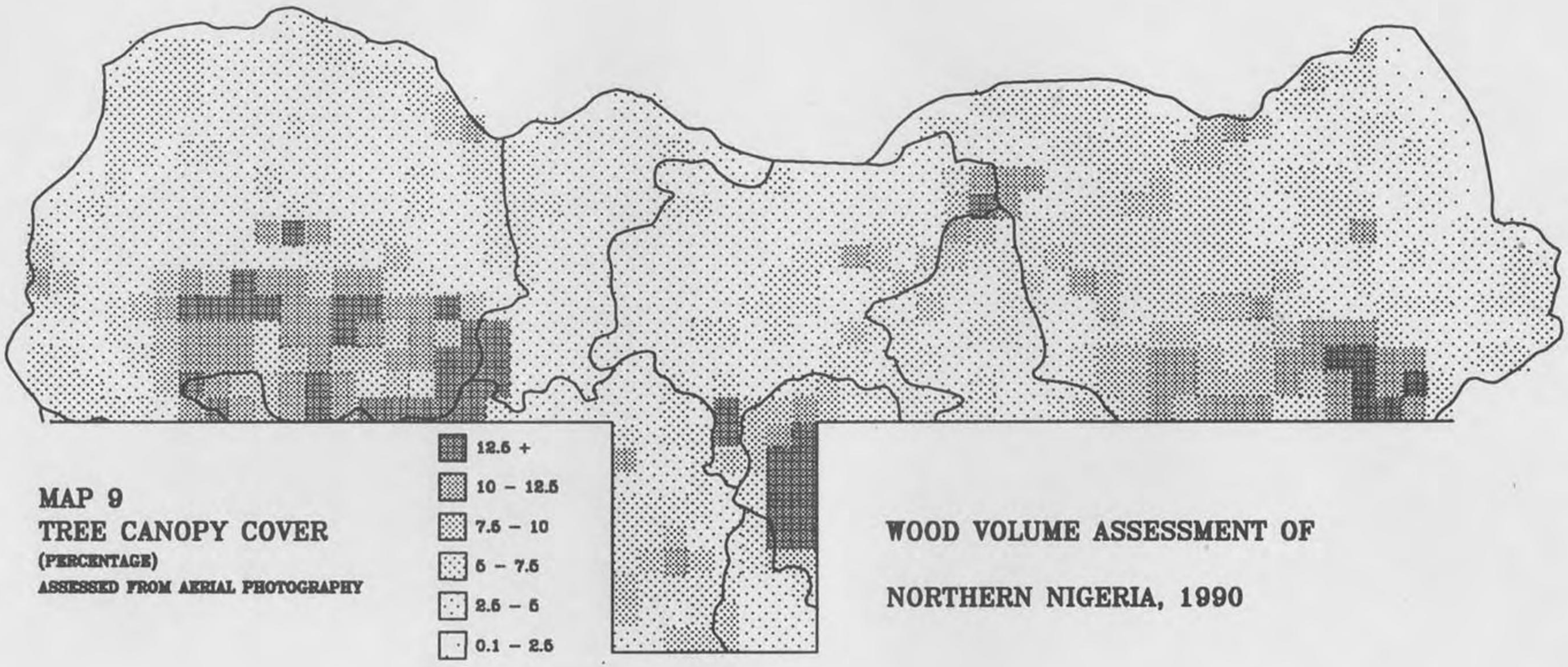
| Stratum | No. Photos | %Tree Canopy | | %Shrub Cover | | %Farmland | | %Other | |
|---|---|---|---|---|---|---|---|---|---|
| DENSE WOODLAND | 57 | 24.49 | (9.73) | 12.50 | (12.5) | 5.63 | (42.4) | 57.38 | (4.35) |
| WOODLAND | 533 | 12.92 | (6.20) | 10.13 | (5.24) | 15.14 | (7.03) | 61.84 | (1.77) |
| SHRUB-GRASSLAND | 1085 | 7.21 | (5.15) | 6.94 | (3.89) | 15.67 | (4.66) | 70.18 | (1.08) |
| CULTIVATION | 2647 | 4.11 | (3.97) | 4.41 | (3.41) | 50.15 | (1.26) | 41.32 | (1.33) |
| SHRUB LAND | 596 | 3.56 | (3.50) | 7.33 | (5.86) | 14.01 | (7.42) | 75.11 | (1.37) |
| GRASSLAND | 99 | 0.93 | (34.5) | 9.43 | (18.7) | 21.13 | (15.5) | 68.52 | (4.72) |
| TOTAL | 5018 | 5.71 | (2.81) | 6.10 | (2.19) | 33.61 | (1.43) | 54.45 | (0.79) |

%SE in Brackets

Maps 9 and 10 show the distribution of the tree canopy cover and farmland within the survey area, as assessed by the application of aerial photography results to the known areas of each land use stratum for each analysis grid, as measured from the satellite imagery.

Tree canopy was most widespread in the woodland regions of southern Sokoto and Borno States, in the areas to the north of the Jos Plateau, and along the series of rivers running into Lake Chad from the west and south, most especially in the environs of Nguru.

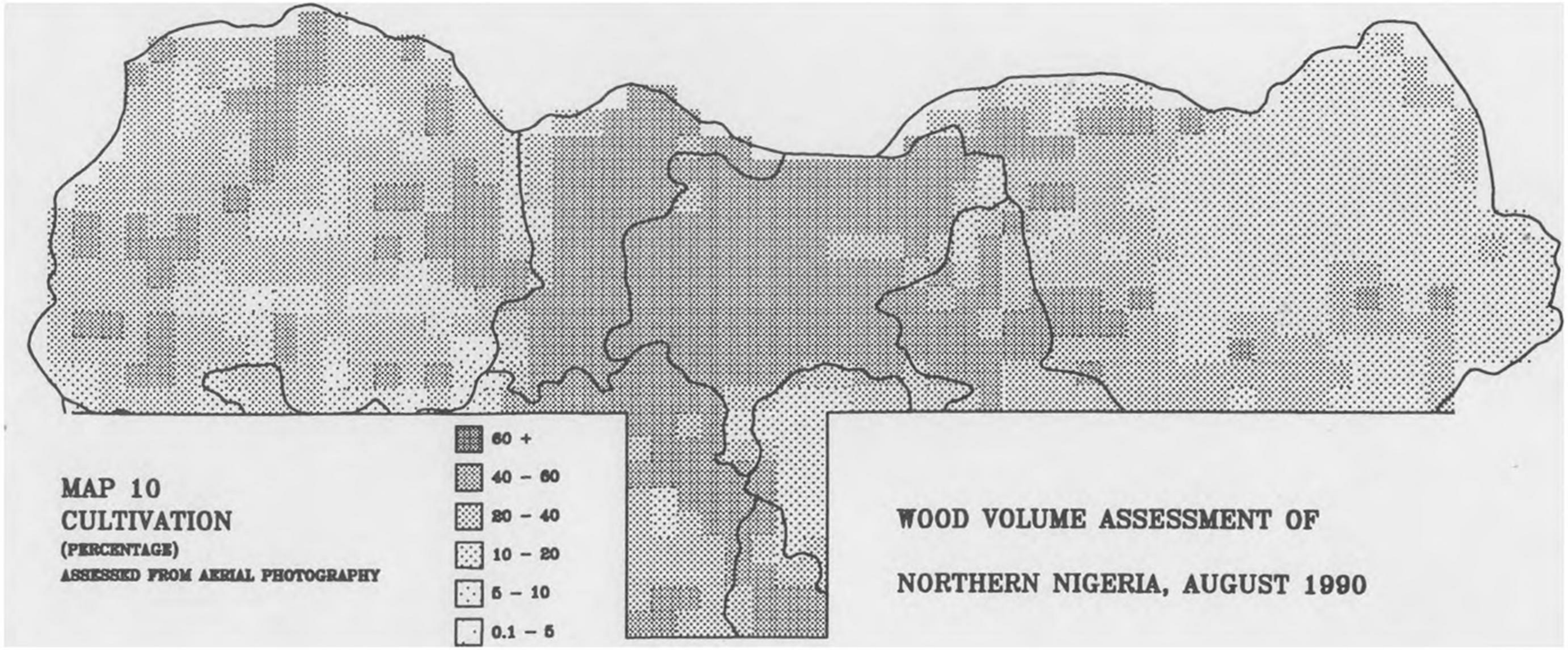
Farmland was particularly prevalent in the close settled belt of Katsina and Kano States, around Gusau and Sokoto towns, and in the parts of Plateau, Kaduna and northern Bauchi States covered by the survey. It was found to be sparse in the north west of Borno State.



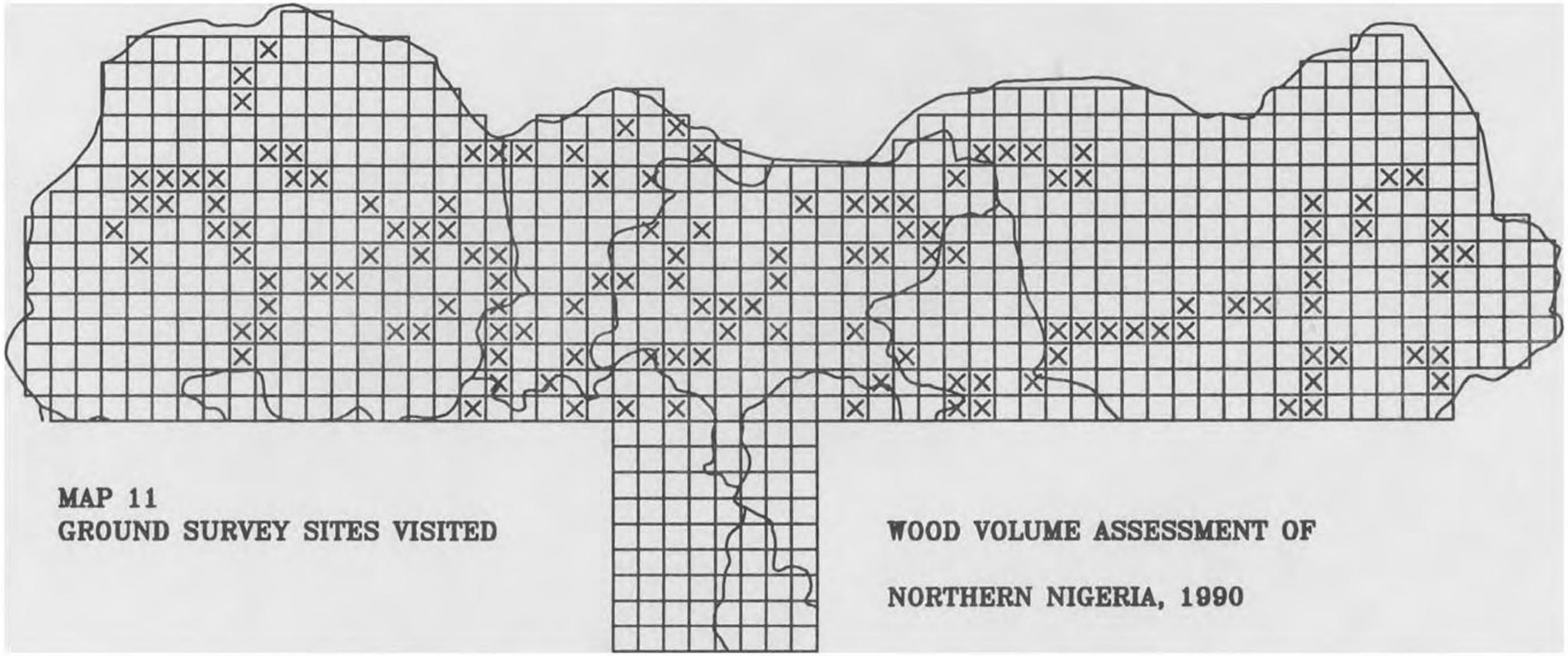

MAP 9
TREE CANOPY COVER
(PERCENTAGE)
ASSESSED FROM AERIAL PHOTOGRAPHY

WOOD VOLUME ASSESSMENT OF

NORTHERN NIGERIA, 1990



MAP 10
CULTIVATION
(PERCENTAGE)
ASSESSED FROM AERIAL PHOTOGRAPHY
60 +
40 - 60
20 - 40
10 - 20
5 - 10
0.1 - 5
WOOD VOLUME ASSESSMENT OF
NORTHERN NIGERIA, AUGUST 1990



**MAP 11**
**GROUND SURVEY SITES VISITED**

**WOOD VOLUME ASSESSMENT OF NORTHERN NIGERIA, 1990**

# GROUND VALIDATION

## Site Selection

Ground validation sites were selected to be representative of the land use strata derived from the satellite imagery. The predominant stratum was identified for each analysis grid and the number of grids in which each stratum was dominant calculated. This gave the approximate proportion of ground sites that should be sampled for each stratum.

To select a specific sample site, a grid containing a high proportion of the particular stratum was first identified and then located on the SLAR maps. The actual location of each sample site within a chosen grid was standardised as much as possible by travelling a specified distance from the grid boundary along a road or track, before turning off (to left or right) for 500 metres. The resulting location of the site was then marked on the map and the stratum assigned accordingly.

An important feature of this process was that the selected site was assigned to a particular land use stratum on the basis of the satellite imagery, and *not* according to the type of vegetation encountered. Thus the ground samples were representative of the stratification which, by its very nature, consisted of mosaics of different vegetation types, amongst which the assigned type was dominant. Had the stratum been assigned on the basis of the vegetation encountered, then the results could not have been extrapolated to the zone identified by satellite imagery, as its resolution was insufficient.

As much as possible, the sites selected for each stratum were spread throughout the survey area (see Map 11), so as to take account of regional variation. This was particularly important for the more widespread strata such as woodland and cultivation.

Of the 146 sites visited, the proportion in each stratum was as follows: cultivation 41%; grassland 4.1%; shrubland 16.4%; woodland 17%; and shrub/grassland 21%. Twenty six of these sites were within the boundaries of forest reserves as identified on the SLAR vegetation maps. However, given the arguments discussed above, it was not considered possible to treat these samples as representative of a discrete and independent sample, and so they were assigned to their parent vegetation strata.

## Parameters Measured

Once a site had been located, 50 trees were measured for the salient characteristics by a team of 4 working in pairs, each following a triangular route from the starting point.

Only trees with a circumference of more than 10cm (DBH 3.2cm) were measured for the required parameters. These were:

Diameter or circumference at breast height (DBH/CBH)
Height to the top of the canopy
Canopy radius or diameter
Degree of lopping or trimming (Score 0-3)

If less than 4 metres, height was measured directly. The height of taller trees was obtained by using a clinometer to measure the angle to the top of the tree from a distance of either 10 or 20 metres from the base of the trunk. These two figures, together with the distance of each observer's eye from the ground, were used to calculate the height of each tree. For those few specimens with multiple stems, each stem was treated separately, and a total cross sectional area calculated, from which an aggregate radius could be extrapolated.

Initially, some preliminary attempts were made to assess regeneration, but these were subsequently abandoned as, in the absence of available sapling specimens to permit reliable identification of the young plants, it was not considered feasible to investigate this phenomenon effectively. However, it is possible that some pointers of relevance may be gleaned from an examination of the DBH frequencies for the commoner species given below.

### Species Recorded

Appendix Table Al.l lists the species recorded by the ground validation studies, together with their frequency, the percentage of the total, and the categories into which they were grouped for calculation of wood volumes (see below). Appendix Table A1.2 gives a list of available local names.

Of the approximately 6,800 specimens measured, more than half belonged to the 11 most common species as shown in the following Table 5. Their DBH frequencies are shown in Table 6a and the accompanying Figure 3. Bole diameter frequencies were heavily skewed to the left so that 85% of the trees had a DBH of less than 40 cm, and about a third less than 15cm. This is a common pattern, reflecting age distributions, but serves to emphasise the fact that the majority of extant tree individuals contribute relatively little to the total available wood volume, given that volume is related to the square of the radius. Table 6b shows additional DBH data for further species which are commonly used for fuelwood (SILVICONSULT, pers comm): a number of other species are also frequently used for fuel, but were not recorded often enough to provide reliable DBH distributions. These include: *Combretum collinum, C. micranthum, Guiera senegalensis,* and *Khaya senegalensis.*

Table 5: Frequency of Most Common Tree Species: All Strata

| SPECIES | NUMBER | % OF TOTAL |
|---|---|---|
| *Balanites aegyptiaca* | 607 | 9.0 |
| *Anogeissus leiocarpa* | 541 | 8.0 |
| *Combretum glutinosum* | 367 | 5.4 |
| *Parkia biglobosa* | 344 | 5.1 |
| *Diospyros mespiliformis* | 311 | 4.6 |
| *Piliostigma reticulatum* | 310 | 4.6 |
| *Tamarindus indica* | 286 | 4.2 |
| *Acacia seyal* | 253 | 3.7 |
| *Combretum nigricans* | 240 | 3.6 |
| *Adansonia digitata* | 232 | 3.4 |
| *Vitellaria paradoxa* | 205 | 3.0 |

Many of these species are utilised for their fruits, so their distribution and abundance has undoubtedly been influenced by man. They are typically found in cropped land, reflecting the pre-eminence of cultivation throughout the area surveyed.

Table 6a: DBH Frequencies Of The Most Commonly Recorded Tree Species

| DBH (M) | | NUMBER OF INDIVIDUALS | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Midpoint | All Spp | Spll | Sp7 | Spl9 | Sp37 | Sp23 | Sp38 | Sp41 | Sp9 | Sp68 | Sp2 | Sp43 |
| 0.10 | 2253 | 166 | 104 | 161 | 24 | 58 | 138 | 16 | 162 | 183 | 42 | 24 |
| 0.30 | 2517 | 300 | 265 | 162 | 52 | 110 | 116 | 90 | 86 | 53 | 42 | 58 |
| 0.50 | 1107 | 122 | 120 | 31 | 79 | 81 | 28 | 84 | 4 | 4 | 18 | 70 |
| 0.70 | 443 | 16 | 36 | 8 | 75 | 38 | 9 | 52 | 1 | | 20 | 35 |
| 0.90 | 209 | 3 | 4 | 1 | 61 | 15 | | 29 | | | 22 | 12 |
| 1.10 | 86 | | 0 | | 32 | 5 | | 8 | | | 12 | 3 |
| 1.30 | 45 | | 2 | | 15 | 2 | | 6 | | | 11 | 2 |
| 1.50 | 25 | | | | 2 | 1 | | 1 | | | 12 | 1 |
| 1.70 | 14 | | | | 1 | 1 | | | | | 10 | |
| 1.90 | 14 | | | | 2 | | | | | | 11 | |
| 2.10 | 8 | | | | 1 | | | | | | 6 | |
| 2.30 | 5 | | | | | | | | | | 5 | |
| 2.50 | 6 | | | | | | | | | | 5 | |
| 2.70 | 4 | | | | | | | | | | 4 | |
| 2.90 | 5 | | | | | | | | | | 5 | |
| 3.10 | 4 | | | | | | | | | | 4 | |
| 3.30 | 2 | | | | | | | | | | 2 | |
| 3.50 | 0 | | | | | | | | | | 0 | |
| 3.70 | 0 | | | | | | | | | | 0 | |
| 3.90 | 0 | | | | | | | | | | 0 | |
| 4.10 | 1 | | | | | | | | | | 1 | |

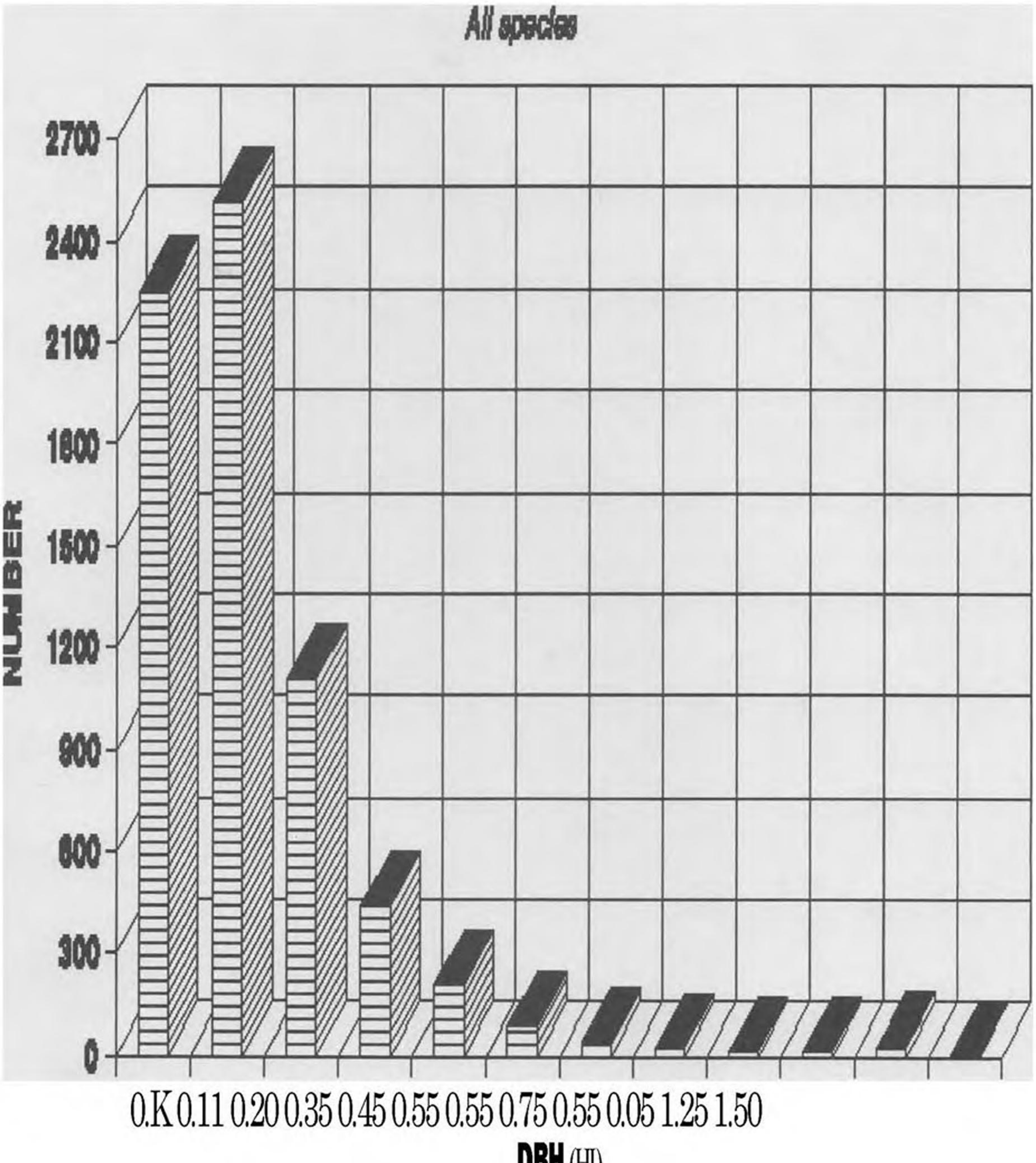
Species Code Number Key:
11 -.*Balanites aegyptiaca T.Anogeissus leiocarpa* 19: *Combretumglutinosum*
37: *Parkia biglobosa* 23: *Diospyros mespiliformis* 38: *Piliostigma reticulatum*
41: *Tamarindus indica* 9: *Acacia seyal* 68: *Combretum nigricans*
2: *Adansonia digitata* 43: *Vitellaria paradoxa*

Table 6b: DBH Frequencies Of Further Species Commonly Used For Fuel wood.

| DBH (M) | NUMBER OF INDIVIDUALS | | | | |
|---|---|---|---|---|---|
| Midpoint | Sp3 | Sp4 | Sp8 | Sp42 | Sp49 |
| 0.10 | 45 | 48 | 58 | 2 | 19 |
| 0.30 | 67 | 52 | 83 | 10 | 58 |
| 0.50 | 43 | 6 | 91 | 11 | 46 |
| 0.70 | 24 | 1 | 4 | 8 | 19 |
| 0.90 | 9 | 1 | 0 | 3 | 4 |
| 1.10 | 3 | | 0 | 3 | 2 |
| 1.30 | 1 | | 0 | 1 | |
| 1.50 | 1 | | 0 | | |
| 1.70 | | | 0 | | |
| 1.90 | | | 0 | | |
| 2.10 | | | 1 | | |

Species Code Number Key:
3: *Acacia albida 4: Acacia nilotica* 8: *Azadirachta indica*
42: *Vitex doniana* 49: *Prosopis africana*

# FIGURE 3: TRUNK DBH FREQUENCY



*Balanites aegyptiaca* is not only the most frequently recorded species overall, but accounts for a significant proportion of the trees in all strata (Tables 7a to e). It is least frequent in cultivation, where it represents 6.3% of the total. Other species with a comparatively uniform distribution include *Tamarindus indica,* another popular fuelwood species (Cline Cole *et al,* 1987).

*Calotropis procera,* a shrub which does not merit inclusion in Keay's 'Trees of Nigeria' (1989), is present in all strata except cultivation and woodland. Though of low value in terms of firewood because much of its stem is composed of a light corky bark, it is of some interest as its presence is indicative of recent soil disturbance, through, for example, either overgrazing, degradation, or cultivation. The present data suggest this shrub is most frequent in grassland, particularly in some areas of Borno State, where it can be found in effectively single species stands.

A number of species appear to be common only in specific strata. These include A. *nilotica* in grassland, as mentioned above, and, most notably, *Adansonia digitata, Parkia biglobosa,* and *Diospyros mespiliformis* which are largely restricted to cropped land. Of the less common species, *Acacia hockii* is especially frequent in shrub/grassland as is *Combretum microcarpa* in shrubland.

Woodland, in particular, was found to contain several common species virtually unique to the stratum. Examples include *Boswellia dalziellii, Lannea humilis* and *Pericopsis laxiflora.*

Oboho (1986) lists *Acacia nilotica, Piliostigma reticulatum, Combretum nigricans, Prosopis africana, Anogeissus leiocarpa* and the shrub *Guiera senegalensis* as species which are both suitable and popular for use as fuelwood. Three of these rank amongst the top 11 most frequently recorded species, and represent about a sixth (17%) of all individuals encountered.

All five of Oboho's tree species listed above are present in the list of the most common tree species in cultivation (Table 7a) and account for nearly a quarter (23.3%) of the trees present, indicating that substantial, if diffuse, fuel wood resources yet remain in cropped land, despite the heavy exploitation that is likely to occur within the stratum. A. *leiocarpa, P. reticulatum* and *C. nigricans* all rank amongst the 15 most common species in shrub/grassland, shrubland and woodland as, in the latter two strata, does *P. africana* (Tables 7c, d and e). These species account for 20.8%, 11.5% and 15.5% of the total number respectively - somewhat lower than their proportions in cultivation - suggesting that they have been selectively preserved by the resident farmers.

A. *nilotica* was found only in grassland (Table 7b), and in very small numbers. Indeed, the abundance of arboreal species in this stratum as a whole is very low and it can be assumed that the fuelwood potential of grassland is extremely limited. However, other Acacias rank relatively highly in all strata, most notably A. *seyal* and, in cultivation, A. *albida.*

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Table 7a: Frequency of Most Common Species: Cultivation

| SPECIES | Code | Frequency | % Total |
|---|---|---|---|
| *Parkia biglobosa* | 37 | 300 | 9.3 |
| *Anogeissus leiocarpa* | 7 | 282 | 8.7 |
| *Diospyros mespiliformis* | 23 | 232 | 7.2 |
| *Piliostigma reticulatum* | 38 | 212 | 6.6 |
| *Adansonia digitata* | 2 | 204 | 6.3 |
| *Balanites aegyptiaca* | 11 | 203 | 6.3 |
| *Tamarindus indica* | 41 | 173 | 5.4 |
| *Combretum glutinosum* | 19 | 145 | 4.5 |
| *Vitellaria paradoxa* | 43 | 136 | 4.2 |
| *Acacia albida* | 3 | 132 | 4.1 |
| *Sclerocarya birrea* | 40 | 116 | 3.6 |
| *Prosopis africana* | 49 | 99 | 3.1 |
| *Azadirachta indica* | 8 | 95 | 2.9 |
| *Acacia nilotica* | 4 | 84 | 2.6 |
| *Lannea acida* | 32 | 81 | 2.5 |
| *Cassia sieberiana* | 18 | 57 | 1.8 |
| *Combretum nigricans* | 68 | 42 | 1.3 |
| *Acacia seyal* | 9 | 38 | 1.2 |
| *Hyphaene thebiaca* | 29 | 37 | 1.1 |
| *Mangifera indica* | 36 | 33 | 1.0 |

Table 7b: Frequency of Most Common Species: Grassland

| SPECIES | Code | Frequency | % Total |
|---|---|---|---|
| *Acacia seyal* | 9 | 28 | 31.8 |
| *Calotropis procera* | 17 | 24 | 27.3 |
| *Balanites aegyptiaca* | 11 | 19 | 21.6 |
| *Acacia albida* | 3 | 7 | 8.0 |
| *Acacia nilotica* | 4 | 4 | 4.5 |
| *Celtis integrifolia* | 94 | 3 | 3.4 |
| *Acacia dudgeonii* | 119 | 2 | 2.3 |
| *Tamarindus indica* | 41 | 1 | 1.1 |

Table 7e: Frequency of Most Common Species: Shrub/Grassland

| SPECIES | Code | Frequency | % Total |
|---|---|---|---|
| *Anogeissus leiocarpa* | 7 | 153 | 11.3 |
| *Balanites aegyptiaca* | 11 | 139 | 10.3 |
| *Acacia dudgeonii* | 119 | 111 | 8.2 |
| *Combretum glutinosum* | 19 | 100 | 7.4 |
| *Sclerocarya birrea* | 40 | 63 | 4.6 |
| *Azadirachta indica* | 8 | 51 | 3.8 |
| *Acacia seyal* | 9 | 52 | 3.8 |
| *Tamarindus indica* | 41 | 47 | 3.5 |
| *Isoberlinia doka* | 30 | 42 | 3.1 |
| *Combretum molle* | 73 | 37 | 2.7 |
| *Combretum nigricans* | 68 | 35 | 2.6 |
| *Sterculia setigera* | 97 | 30 | 2.2 |
| *Piliostigma reticulatum* | 38 | 29 | 2.1 |
| *Acacia hockii* | 127 | 28 | 2.1 |
| *Diospyros mespiliformis* | 23 | 27 | 2.0 |
| *Lannea acida* | 32 | 25 | 1.8 |
| *Calotropis procera* | 17 | 23 | 1.7 |
| *Acacia tortilis* | 142 | 23 | 1.7 |
| *Commiphora africana* | 20 | 21 | 1.5 |
| *Vitellaria paradoxa* | 43 | 20 | 1.5 |
| *Cassia sieberiana* | 18 | 19 | 1.4 |
| *Entada africana* | 64 | 19 | 1.4 |
| *Lannea schimperi* | 35 | 18 | 1.3 |
| *Adansonia digitata* | 2 | 15 | 1.1 |
| *Dalbergia melanoxylon* | 24 | 13 | 1.0 |
| *Cassia singueana* | 70 | 13 | 1.0 |
| *Isoberlinia tomentosa* | 84 | 14 | 1.0 |
| *Mitragyna inermis* | 85 | 14 | 1.0 |

Table 7d: Frequency of Most Common Species: Shrubland

| SPECIES | Code | Frequency | % Total |
|---|---|---|---|
| *Balanites aegyptiaca* | 11 | 166 | 19.0 |
| *Combretum nigricans* | 68 | 123 | 14.1 |
| *Cassia sieberiana* | 18 | 68 | 7.8 |
| *Combretum glutinosum* | 19 | 63 | 7.2 |
| *Acacia dudgeonii* | 119 | 50 | 5.7 |
| *Acacia albida* | 3 | 47 | 5.4 |
| *Acacia seyal* | 9 | 43 | 4.9 |
| *Piliostigma reticulatum* | 80,38 | 43 | 4.9 |
| *Combretum microcarpa* | 81 | 28 | 3.2 |
| *Tamarindus indica* | 41 | 25 | 2.9 |
| *Prosopis africana* | 49 | 24 | 2.7 |
| *Sterculia setigera* | 97 | 16 | 1.8 |
| *Calotropis procera* | 17 | 15 | 1.7 |
| *Maerua oblongata* | 118 | 15 | 1.7 |
| *Anogeissus leiocarpa* | 7 | 14 | 1.6 |
| *Detarium microcarpum* | 26 | 14 | 1.6 |
| *Diospyros mespiliformis* | 23 | 11 | 1.3 |
| *Parkia biglobosa* | 37 | 11 | 1.3 |

Table 7e: Frequency of Most Common Species: Woodland

| SPECIES | Code | Frequency | % Total |
|---|---|---|---|
| *Anogeissus leiocarpa* | 7 | 92 | 7.7 |
| *Acacia seyal* | 9 | 92 | 7.7 |
| *Balanites aegyptiaca* | 11 | 80 | 6.7 |
| *Combretum glutinosum* | 19 | 55 | 4.6 |
| *Mitragyna inermis* | 85 | 50 | 4.2 |
| *Boswellia dalzielii* | 15 | 49 | 4.1 |
| *Vitellaria paradoxa* | 43 | 49 | 4.1 |
| *Diospyros mespiliformis* | 23 | 41 | 3.4 |
| *Isoberlinia doka* | 30 | 41 | 3.4 |
| *Detarium microcarpum* | 26 | 40 | 3.3 |
| *Tamarindus indica* | 41 | 40 | 3.3 |
| *Combretum nigricans* | 68 | 40 | 3.3 |
| *Sterculia setigera* | 97 | 37 | 3.1 |
| *Lannea humilis* | 33 | 34 | 2.8 |
| *Pericopsis laxiflora* | 65 | 32 | 2.7 |
| *Entada africana* | 64 | 27 | 2.3 |
| *Piliostigma reticulatum* | 38 | 25 | 2.1 |
| *Burkea africana* | 14 | 21 | 1.8 |
| *Parkia biglobosa* | 37 | 21 | 1.8 |
| *Terminalia glaucescens* | 82 | 21 | 1.8 |
| *Lannea acida* | 32 | 20 | 1.7 |
| *Isoberlinia tomentosa* | 84 | 18 | 1.5 |
| *Lannea schimpera* | 35 | 15 | 1.3 |
| *Acacia dudgeonii* | 119 | 14 | 1.2 |
| *Prosopis africana* | 49 | 13 | 1.1 |
| *Terminalia avicennioides* | 60 | 13 | 1.1 |
| *Nauclea latifolia* | 106 | 13 | 1.1 |
| *Adansonia digitata* | 2 | 12 | 1.0 |
| *Combretum fragrans* | 129 | 12 | 1.0 |

### Trimming and Lopping

During the course of the ground surveys, each specimen was scored on a scale of 0 to 3 for the degree of trimming (of smaller branches) or lopping (of larger branches and boles) it had suffered. As it can be difficult to conclusively differentiate between the two practices, e.g. between heavy trimming and light lopping, only those which were definitely identifiable as exclusively trimmed were recorded as such. Thus the category referred to below as 'lopping' often incorporates a degree of trimming.

Only 163 (2.4%) of the sampled specimens had been exclusively trimmed to any extent, indicating that the proportion of trees utilised for browse alone was very small. Of these, the most commonly used species was *Adansonia digitata,* of which 12.5% were trimmed; *Anogeissus leiocarpa* (3%); *Balanites aegyptiaca* (2.5%); *Vitellaria paradoxa* (7.3%); and *Combretum glutinosum* (3.8%). The first four of these species were most often recorded as moderately trimmed (score 2), and the last as heavily trimmed (score 3).

Trimming/lopping was much more frequent, and was found, to some extent, in 1551 (23%) of the specimens sampled. Again, the majority of these were moderately lopped. Table 8 below summarises the species most often lopped, together with the proportions of each that were affected. The DBH frequencies of the most frequently lopped species can be found in Table 6 or 6a above.

Table 8: Most Frequently Trimmed/Lopped Tree Species

| Light | | Moderate | | Heavy Lopping | |
|---|---|---|---|---|---|
| *Diospyros mespiliformis* | (7.4) | *Prosopis africana* | (38.5) | *Vitellaria paradoxa* | (11.7) |
| *Piliostigma reticulatum* | (6.9) | *Adansonia digitata* | (29.7) | *Adansonia digitata* | (11.2) |
| *Sclerocarya birrea* | (6.3) | *Anogeissus leiocarpa* | (22.2) | *Tamarindus indica* | (10.1) |
| *Parkia biglobosa* | (4.9) | *Tamarindus indica* | (19.6) | *Anogeissus leiocarpa* | (5.2) |
| *Combretum glutinosum* | (4.7) | *Balanites aegyptiaca* | (18.9) | *Diospyros mespiliformis* | (5.1) |
| *Acacia nilotica* | (3.8) | *Piliostigma reticulatum* | (18.6) | *Parkia biglobosa* | (4.7) |
| *Anogeissus leiocarpa* | (3.0) | *Diospyros mespiliformis* | (16.1) | *Piliostigma reticulatum* | (4.5) |
| *Balanites aegyptiaca* | (2.1) | *Combretum glutinosum* | (14.3) | *Balanites aegyptiaca* | (4.3) |
| | | | | *Combretum glutinosum* | (3.6) |

Percentage Trimmed/Lopped in Brackets

## WOOD VOLUME ESTIMATIONS

### Wood Volume Calculations

There is, regrettably, a dearth of wood volume tables for Nigerian tree species, and very little information is available in either international journals or the grey literature' concerning wood volume tables for any of the species recorded in this survey. A lengthy search of the literature held by the Oxford Forestry Institute, which ranges from the mid 1950s to the present day, and is world-wide in its subject matter, revealed only 29 references which contained mention of relevant species or their con-generics.

Of these equations, 21 were discarded as being unsuitable for use either because the con-generics concerned were of radically different form or habitat preference, or because the formulae cited were incomplete and referred to, for example, bole volume or branch wood volume rather than total wood volume. There thus remained only 8 formulae which were considered to be at all applicable to the present data.

These eight formulae, if applied rigourously to only conspecific or con-generic species, are applicable to a very small percentage of the total data. As the calculation of volumes requires a conversion factor for each specimen recorded, it was necessary to either extend the application of the available formulae to species for which the relevant information was unknown, or to use a general formula which could be considered appropriate for all species.

A compromise solution was adopted to resolve this problem. As many of the recorded tree species as possible were assigned, on the basis of taxonomy or growth form, to groups corresponding to those species for which wood volume formulae were known.

The species groupings applied, the corresponding formulae, and the source references are listed in Appendix Table A1.3, and are summarised in Appendix Table Al.l which lists code number and volume group for every species encountered. Of the 6,800 individual trees measured, approximately 3,700, or somewhat over half, were assigned to species categories for which the available formulae were considered applicable.

To the remainder, a general formula was applied. A number of such formulae are commonly used, foremost amongst which are the volume of a cylinder and that of a modified cone. Given that most of the species encountered have boles which taper to some extent, it was considered most suitable to use the second of these equations, namely: Section Area x Height/2). This formula gives figures equivalent to half a cylinder, but 1.5 times that of a cone. As the height used is that to the top of the canopy, some compensation for branchwood volume is implicit.

A test of the correlation between the values produced by the general formula and by the specific ones, using the specimens for which specific formulae were available, revealed a correlation coefficient of 0.64 which is significant at $p<0.00001$. This strongly suggests that the use of the general formula is statistically justifiable.

The list given in Table 9, below, shows details of the standing wood volumes calculated for the 11 most commonly recorded species, and for an additional 7 species which are frequently used for fuelwood. By definition, these figures reflect, to a degree, the bole diameters of the species concerned: the species with the larger mean wood volumes tend to be those with large boles.

In general, the species with lower wood volumes per individual tend to be more common in shrubland and shrub/grassland: *Combretum nigricans, C. glutinosum, Acacia seyal, Piliostigma reticulatum* and *Balanites aegyptiaca.* The reverse is true of the cultivated and woodland areas, where the wood is confined to relatively fewer, but larger, trees.

The mean wood volume of one of the species - *Adansonia digitata* (baobab) - was found to be considerably greater than that of the others and, given its abundance, contributes more than any other to the total wood volume within the survey area as a whole (12%), and within the cultivation stratum in particular (18.6%).

As this species is rarely used for firewood in northern Nigeria, it was considered necessary to exclude it from the data set when calculating available fuelwood volume. The tables presented in the following pages therefore give two sets of figures: one including baobab, and one excluding it.

Table 9: Wood Volumes ($m^3$) For Species Most Commonly Encountered or Most Frequently Used for Fuel.

| SPECIES | SUM | MEAN | %SE | NUMBER |
|---|---|---|---|---|
| Most Commonly Encountered Species | | | | |
| *Balanites aegyptiaca* | 165.8743 | 0.2733 | 5.4 | 607 |
| *Anogeissus leiocarpa* | 328.2723 | 0.6068 | 7.4 | 541 |
| *Combretum glutinosum* | 70.9426 | 0.1954 | 7.7 | 363 |
| *Parkia biglobosa* | 361.1515 | 1.0499 | 1.9 | 344 |
| *Diospyros mespiliformis* | 287.3347 | 0.9239 | 9.1 | 311 |
| *Piliostigma reticulatum* | 58.4292 | 0.2008 | 9.4 | 291 |
| *Tamarindus indica* | 300.4719 | 1.0506 | 7.8 | 286 |
| *Acacia seyal* | 128.5691 | 0.5082 | 1.0 | 253 |
| *Combretum nigricans* | 19.6559 | 0.0819 | 8.6 | 240 |
| *Adansonia digitata* | 2155.2147 | 9.3299 | 12.1 | 231 |
| *Vitellaria paradoxa* | 177.3875 | 0.8653 | 10.5 | 205 |
| Additional Species Frequently Used for Fuel wood | | | | |
| *Acacia albida* | 143.7863 | 0.7554 | 2.6 | |
| *Acacia nilotica* | 22.9779 | 0.2128 | 22.8 | |
| *Azadirachta indica* | 31.4150 | 0.2053 | 15.9 | |
| *Ceiba pentandra* | 66.5382 | 5.1183 | 42.9 | |
| *Khaya senegalensis* | 21.8430 | 1.6802 | 39.1 | |
| *Prosopis africana* | 81.6813 | 0.5519 | 11.0 | |
| *Vitex doniana* | 48.2015 | 1.2685 | 19.9 | |

The wood volumes calculated for each sampled individual were converted to wood volumes per unit area of canopy, as extracted from the ground survey data. In order to apply these figures to the area of tree canopy in each analysis grid, as estimated from the aerial photographs, it was necessary to calculate the mean volumes per square metre of canopy for each of the land use strata. These are given in Appendix Table A1.3.

However, it is axiomatic that the vegetation associated with, for example, cultivation, in the arid zone is unlikely to be as dense as that in the sub-humid areas. A survey-wide mean would fail to compensate for such regional variation, unless corrected for, in this case, rainfall. Consequently, mean wood volumes per unit canopy area were calculated for each stratum and for a range of vegetation mapping zones defined by White (1983), and modified into ecozones according to rainfall isohyets.

Eight vegetation mapping zones (VZones) were identified as follows:

VZone 1: Sahel *Acacia* wooded grassland and deciduous bushland
VZone 2: Mandara Plateau Mosaic
VZone 3: Jos Plateau Mosaic
VZone 4: Sudanian Woodland with islands of *Isoberlinia*
VZone 5: Undifferentiated Sudanian Woodland (<650mm annual rainfall)
VZone 6: Undifferentiated Sudanian Woodland (>650mm annual rainfall)
VZone 7: Sudanian woodland with abundant *Isoberlinia*
VZone 8: Mosaic lowland rainforest, *Isoberlinia* woodland and secondary grassland

After discussion with SILVICONSULT staff, it was decided that the vegetation mapping zones, whilst suitable for analysis and calculation, were needlessly complex in relation to any presentation of results. Consequently, the VZones were condensed into six ecozones which corresponded precisely with those used in the Household Energy Supply and Demand report. The resulting ecozones (EZones) were defined as follows:

| | |
|---|---|
| EZone 1: | Equivalent to VZone 1 |
| EZone 2: | Equivalent to VZone 5 and that part of VZone 4 with less than 650 mm annual rainfall |
| EZone 3: | Equivalent to Vzone 6, plus VZone 2 and that part of VZone 4 with more than 650 mm annual rainfall |
| EZone 4: | Equivalent to VZone 7 |
| EZone 5: | Equivalent to VZone 3 |
| Ezone 6: | Equivalent to VZone 8 |

These are shown on Map 12, from which it can be seen that most of the survey area is covered by EZones 1 to 4, whilst EZones 5 and 6 are relatively small, and restricted to the southern extension of the survey area.

### Wood Volume Estimates

The calculated mean wood volumes per unit canopy area for each vegetation mapping zone (VZone) within the land use strata are given in Appendix Table A1.4. It is these figures that have been applied to the estimated canopy areas within each analysis grid in order to derive the required wood volumes.

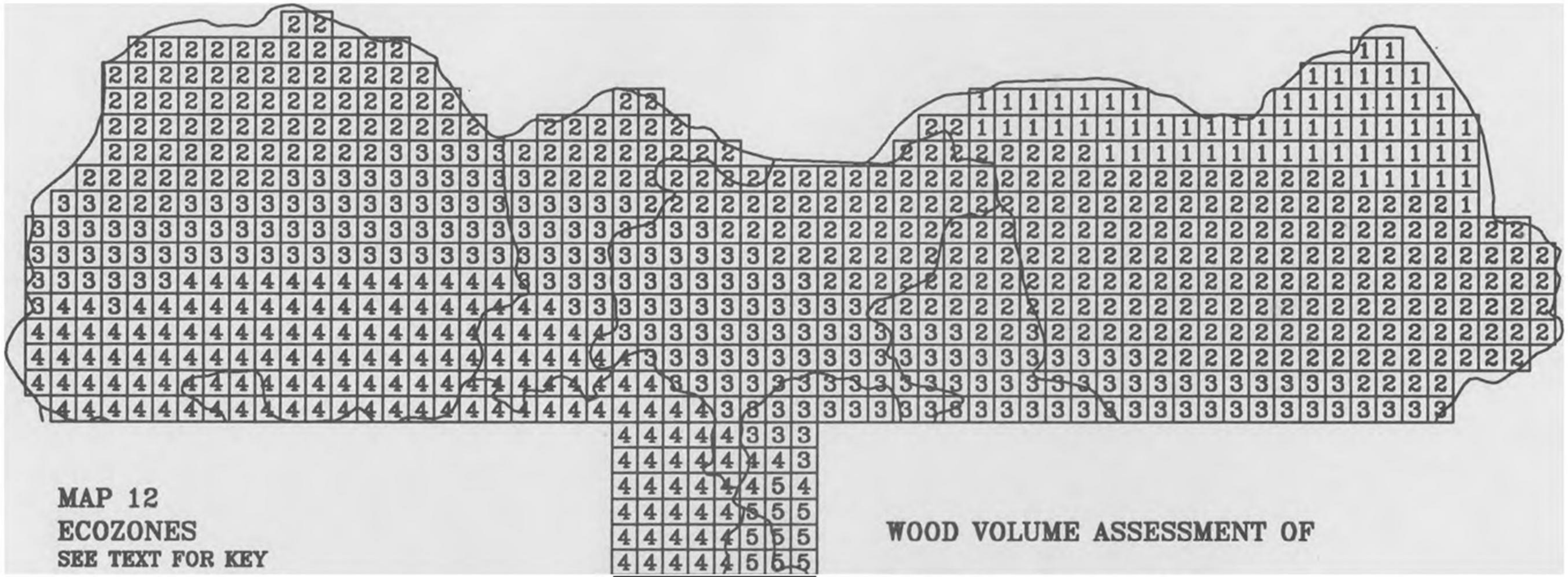
The calculated wood volume for the entire study area is estimated as 380 million cubic metres, which translates to approximately 11.8m$^3$/ha. Excluding baobab, the equivalent total is 335 million m$^3$ (10.4 m$^3$/ha). These figures compare well with those of Cline Cole *et al* (1987, 1988) for the Kano region, which estimated an average wood volume of 8.9 m$^3$/ha excluding baobab, and 12.4 m$^3$/ha including it.

Maps 13 and 14 show the distribution of estimated wood volume with and without baobab respectively. Total wood volume (i.e with baobab) is lowest in the northern parts of Sokoto and Borno states, and generally highest in the areas where woodland is most widespread, and where human habitation is least abundant (RIM, 1991). There is also a concentration of available wood near Nguru where there is abundant surface water, and along the rivers in its vicinity. If baobab is excluded, though the basic distribution pattern remains the same, the estimated wood volume in much of the Close Settled Zone, in Kano and Katsina States, is reduced substantially.

Examined in relation to land use stratum, the total wood volume per hectare varies considerably. Table 10, below, shows a range of 4.13 m$^3$/ha for grassland to 52.58 m$^3$/ha for dense woodland, and a wood volume, excluding baobab, ranging from 4.13 m$^3$/ha to 47.41 m$^3$/ha. Again, these figures compare well with those of the Kano fuel wood study which suggested a range of 4.8 to 41 m$^3$/ha for degraded shrubland and natural forest respectively.

Wood volume densities can thus be seen to be highest in the dense woodland and woodland strata - those with the most widespread arboreal vegetation - and lowest in the more open shrubland and grassland areas. In concert with the distribution of baobab, the exclusion of this species from the calculations has the greatest effect on the figures estimated for cultivation.

Reference to Appendix Table A1.4 shows that, in general, the more heavily wooded strata support somewhat lower volumes per unit area of canopy. This is most probably a reflection of edaphic and competitive conditions which prevail in more dense vegetation.




[redacted]

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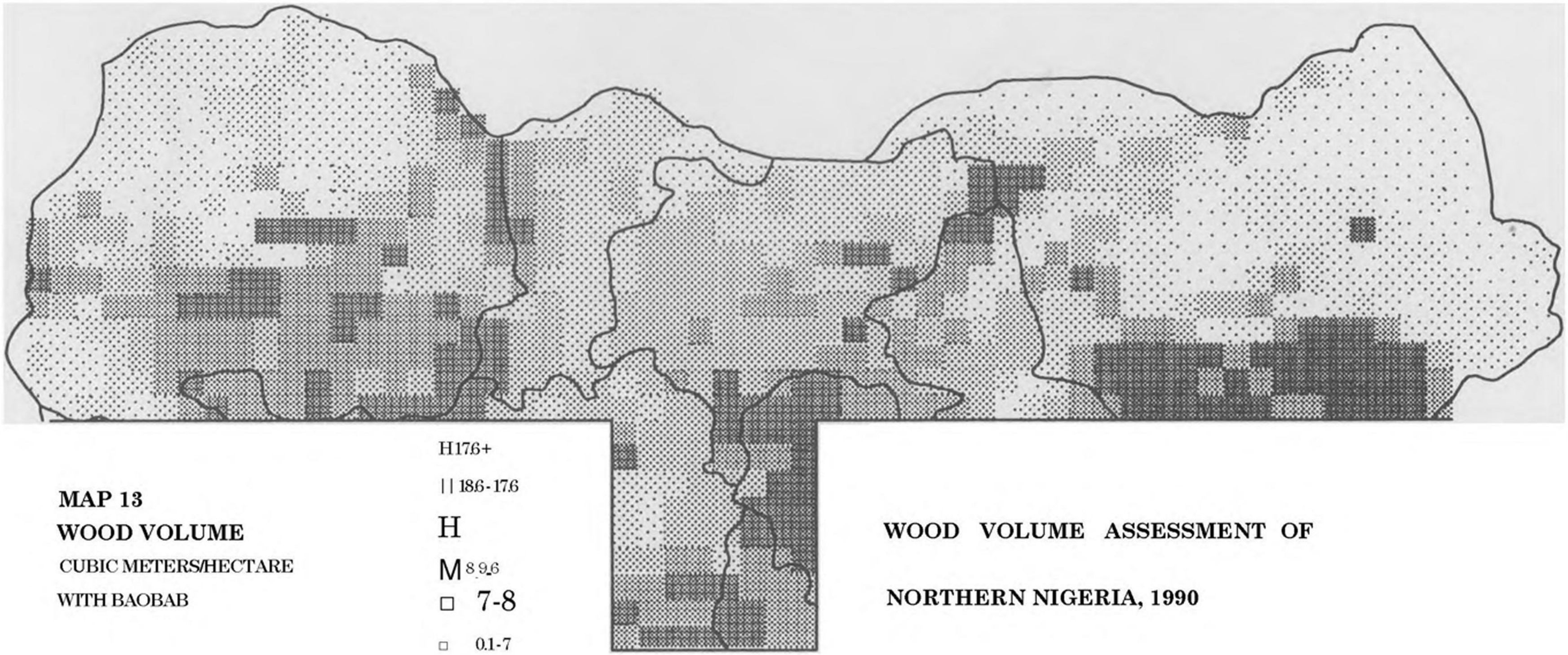
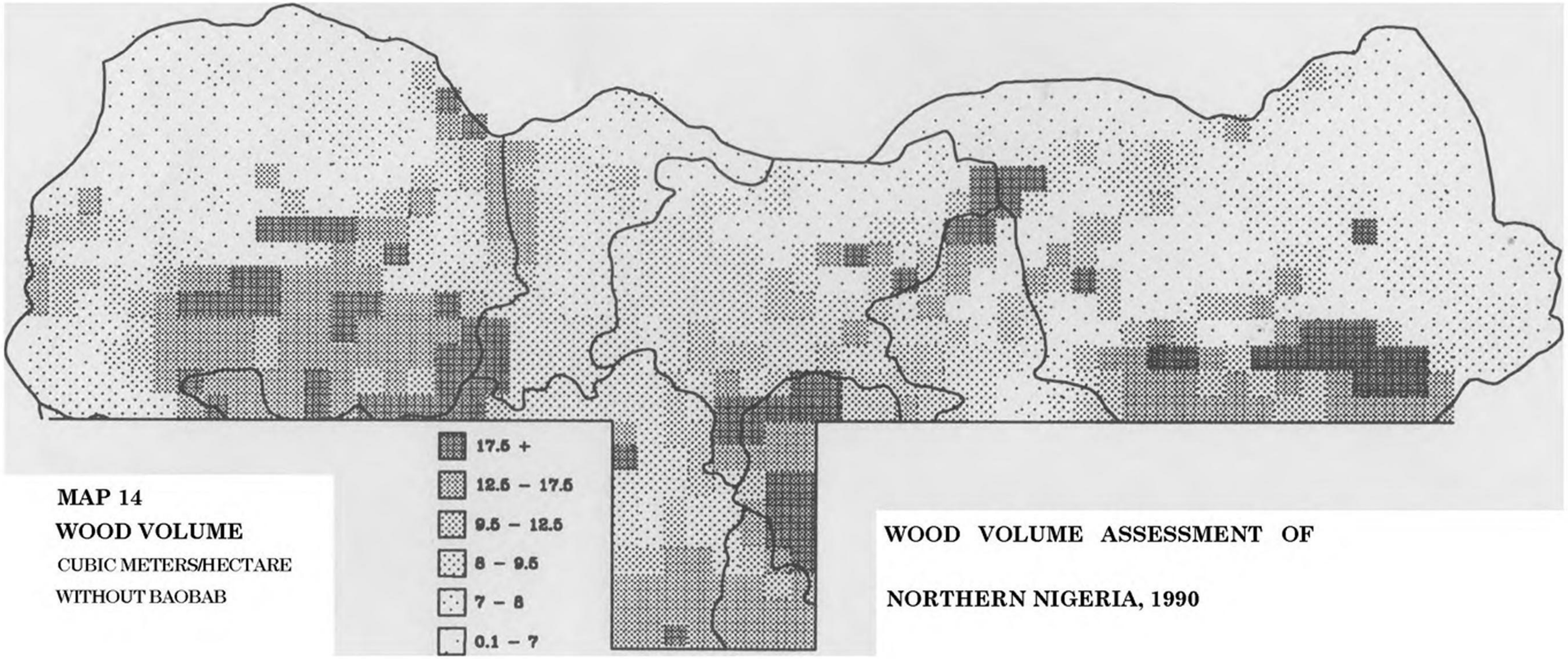
[redacted]

NORTHERN NIGERIA, 1990




**MAP 13**
**WOOD VOLUME**
CUBIC METERS/HECTARE
WITH BAOBAB

**WOOD VOLUME ASSESSMENT OF NORTHERN NIGERIA, 1990**




**MAP 14**
**WOOD VOLUME**
CUBIC METERS/HECTARE
WITHOUT BAOBAB

**WOOD VOLUME ASSESSMENT OF NORTHERN NIGERIA, 1990**

In such ecosystems, both inter- and intra-specific competition for light and nutrients is likely to be comparatively intense, and the opportunity for canopy extension by trees in close proximity to each other will be limited. They will therefore tend to be relatively tall and thin, unlike more open grown specimens.

Table 10: Mean and Total Wood Volumes For Land Use Strata

| STRATUM | With baobab $m^3$/ha | With baobab Total* | Without baobab $m^3$/ha | Without baobab Total* |
|---|---|---|---|---|
| GRASSLAND | 4.13 | 3225 | 4.13 | 3225 |
| SHRUBLAND | 6.17 | 22091 | 6.10 | 21845 |
| CULTIVATION | 9.24 | 143882 | 7.51 | 117100 |
| SHRUB/GRASSLAND | 9.04 | 59286 | 8.61 | 56485 |
| WOODLAND | 22.49 | 112334 | 20.29 | 101347 |
| DENSE WOODLAND | 52.58 | 38988 | 47.41 | 35159 |

* Volume in $m^3$ x 1000

As a result, the relative wood volume densities for each stratum are more a consequence of the comparative extent of tree canopy cover, than of variations in the volume of wood per emit area of canopy.

These data lend credence to a further implication of the figures presented in Table 10, above, namely that cultivation, and the accompanying clearance of natural vegetation, may not inevitably result in a reduction of wood volume. If baobab is excluded, the mean wood volume density for cultivated land is higher than those for grassland and shrubland, and only 13% less than that for shrub/grassland. This suggests that cultivation may actually be associated with higher wood volume (though not probably fuelwood volume) per unit area in those areas where the natural vegetation is more open, and only in regions where woodland predominates does the spread of cropped land substantially reduce the available volume of wood.

Despite the relatively low wood volume density estimated for cultivated land, this stratum is the most widespread within the survey area and, as such, contains the largest absolute volume of wood. The two major potential sources of fuelwood in the survey area are therefore cultivation (38%) and woodland (30%), the former on account of its predominance in terms of area, the latter because of the relatively high density of wood volume it supports. These figures suggest that efforts to conserve or to enhance wood production should be concentrated within these two land use types.

However, whilst the proportion of wood contained within Forest Reserves (as represented by the stratum 'dense woodland', see above) is relatively small, its contribution per unit area is the highest of all the strata. This underlines the importance of such reserves to national wood resources, and highlights the importance of maintaining and, if possible, extending their area. However, it should be noted that a number of these reserves appear, from the air, to have been heavily encroached upon, and so the high wood volume density shown above may not be representative of all Forest Reserves.

Table 11a, below, presents the estimates for wood volume in the various ecozones. The lowest figure is found in the zone with least rainfall and the most open vegetation, in northern Borno; the highest in the wettest and most wooded regions below the eleventh parallel in Plateau State. The three most extensive ecozones support similar and intermediate amounts of wood if baobab is excluded from the calculations.

Table lib presents the estimated wood volumes (excluding baobab) for each of the ecozones within each land use stratum. The wood volume figures for the woodland land use stratum underscore the fact that this stratum is, in fact, a mosaic of different vegetation types. In the drier regions (EZones 1 and 2), the areas defined as woodland from the satellite images and SLAR vegetation maps are generally fairly dense but limited patches, and include habitats such as riparian woodland. There is very little extensive woodland.

Further south, much of the land assigned to the woodland stratum is a more dispersed mosaic of vegetation which is primarily wooded, but also includes numerous small patches of shrubland and cultivation. Thus the mean wood volume per hectare of the wetter woodland strata tends to be lower than that of the dryer areas.

Table 11a: Wood Volume By Ecozone (Without baobab)

| EZone | Area Covered | Wood Volume ($m^3$ x 1000) | $m^3$/ha | % %SE |
|---|---|---|---|---|
| 1 | 24800 | 14610 | 5.89 | 1.9 |
| 2 | 131200 | 118113 | 9.00 | 1.7 |
| 3 | 87200 | 90494 | 10.38 | 1.7 |
| 4 | 65600 | 90413 | 13.78 | 1.9 |
| 5 | 8000 | 12896 | 16.12 | 2.4 |
| 6 | 5600 | 8632 | 15.41 | 1.8 |
| All | 322400 | 335160 | 10.40 | 2.7 |

NB Ecozones defined to compare directly with Household Energy Supply and Demand report

Key:

EZone 1: Sahel *Acacia* wooded grassland and deciduous bushland

EZone 2: Undifferentiated Sudanian Woodland (<650mm annual rainfall), including Sudanian Woodland with islands of *Isoberlinia*

EZone 3: Undifferentiated Sudanian Woodland (>650mm annual rainfall) including Sudanian Woodland with islands of *Isoberlinia*

EZone 4: Sudanian woodland with abundant *Isoberlinia*

EZone 5: Jos Plateau Mosaic

EZone 6: Mosaic lowland rainforest, *Isoberlinia* woodland and secondary grassland

Table lib: Estimated Wood Volumes in Ecozones within each Land Use Stratum (Without baobab)

| EZone | Area ($km^2$) | Wood Vol (m3 x 1000) | $m^3$/ha | %SE |
|---|---|---|---|---|
| Land Use Stratum: Cultivation | | | | |
| 1 | 3348 | 2458 | 7.61 | 14.4 |
| 5 | 4256 | 3124 | 7.34 | 9.4 |
| 2 | 56748 | 37162 | 6.54 | 2.2 |
| 3 | 55788 | 44460 | 7.97 | 1.6 |
| 4 | 32008 | 27239 | 8.51 | 2.7 |
| 6 | 3616 | 2654 | 7.34 | 5.1 |
| Land Use Stratum: Grassland | | | | |
| 1 | 4040 | 1670 | 4.13 | 7.6 |
| 2 | 2372 | 980 | 4.13 | 17.9 |
| 3 | 560 | 231 | 4.13 | 27.9 |
| 4 | 828 | 342 | 4.13 | 27.4 |
| Landsat Stratum: Shrubland | | | | |
| 1 | 6324 | 3735 | 5.91 | 10.5 |
| 5 | 328 | 193 | 5.88 | 42.9 |
| 2 | 20380 | 14647 | 7.19 | 4.9 |
| 3 | 8332 | 3020 | 3.62 | 7.4 |
| 4 | 420 | 248 | 5.90 | 43.2 |
| Land Use Stratum: Woodland | | | | |
| 1 | 2385 | 2385 | 20.28 | 11.9 |
| 5 | 2928 | 5940 | 20.29 | 9.8 |
| 2 | 12972 | 36709 | 28.29 | 6.4 |
| 3 | 11660 | 18190 | 15.60 | 4.4 |
| 4 | 20012 | 35686 | 17.83 | 4.1 |
| 6 | 1200 | 2434 | 20.29 | 14.3 |
| Land Use Stratum: Shrub Grassland | | | | |
| 1 | 9912 | 4360 | 4.40 | 8.6 |
| 5 | 476 | 566 | 11.89 | 54.7 |
| 2 | 38164 | 26941 | 7.06 | 3.2 |
| 3 | 9608 | 18744 | 1.95 | 7.4 |
| 4 | 6584 | 4938 | 7.50 | 9.9 |
| 6 | 784 | 933 | 11.90 | 21.6 |
| Land Use Stratum: Dense Woodland | | | | |
| 2 | 404 | 1672 | 41.38 | 42.1 |
| 3 | 1252 | 5847 | 46.70 | 23.6 |
| 4 | 5748 | 21958 | 38.20 | 11.0 |

Key:

| | |
|---|---|
| EZone 1: | Sahel *Acacia* wooded grassland and deciduous bushland |
| EZone 2: | Undifferentiated Sudanian Woodland (<650mm annual rainfall), including Sudanian Woodland with islands of *Isoberlinia* |
| EZone 3: | Undifferentiated Sudanian Woodland (>650mm annual rainfall) including Sudanian Woodland with islands of *Isoberlinia* |
| EZone 4: | Sudanian woodland with abundant *Isoberlinia* |
| EZone 5: | Jos Plateau Mosaic |
| EZone 6: | Mosaic lowland rainforest, *Isoberlinia* woodland and secondary grassland |

There follow a number of Tables which summarise the assessments of wood volume within requested geographical regions, notably State; varying economic radii from a number of towns defined by SILVICONSULT personnel; and River Basin. For reasons described above, the estimated volume with and without baobab is given for each region.

Each Table shows the total wood volume within each defined region (in $m^3$ x 1000); the average wood volume per hectare for each region; and the % Standard Error (%SE) of the estimate.

The State Tables (Table 12) also include an estimate of the total wood volume present within each State, assuming the volume per unit area is constant throughout the sectors not surveyed. This has not been carried out for Plateau State as the proportion surveyed is considered too small to extrapolate and, in addition, the vegetation of the surveyed portion is unlikely to be typical of the remainder.

As might be predicted, Kano, Katsina and Borno States support the lowest wood volumes per hectare. The first two are both intensively cultivated, contain limited wooded areas, and lie in areas of relatively low rainfall. Borno not only contains a high proportion of grassland and shrub grassland, but also includes substantial areas within the band of lowest rainfall. Sokoto, Bauchi and Kaduna States support intermediate wood volumes per hectare - some 20%-30% higher than the other northern states, encompassing as they do significant regions of comparatively dense woodland in the south of the survey area. Plateau State, the most southerly of those covered, supports the highest wood volume per hectare.

Table 12: Wood Volume ($m^3$ x 1000) by State

a). Without baobab

| State | Area Covered ($km^2$) | Wood Volume | $m^3$/ha | %SE | % of State Covered | Extrapolated Total Volume |
|---|---|---|---|---|---|---|
| Bauchi | 26000 | 32672 | 12.6 | 3.0 | 40.2 | 93600 |
| Borno | 100800 | 92699 | 9.2 | 1.8 | 86.6 | 107042 |
| Kaduna | 22400 | 25932 | 11.6 | 2.4 | 48.6 | 53358 |
| Kano | 42800 | 40823 | 9.5 | 2.9 | 98.9 | 41277 |
| Katsina | 23600 | 21621 | 9.2 | 2.5 | 97.6 | 22153 |
| Plateau | 6800 | 9807 | 14.4 | 0.8 | 11.7 | |
| Sokoto | 97600 | 107579 | 11.0 | 1.8 | 95.2 | 113003 |
| Total | 322400 | 335161 | 10.4 | 0.9 | | |

b) With baobab

| State | Area Covered ($km^2$) | Wood Volume | $m^3$/ha | %SE | % of State Covered | Extrapolated Total Volume |
|---|---|---|---|---|---|---|
| Bauchi | 26000 | 38514 | 14.8 | 2.6 | 40.2 | 95806 |
| Borno | 100800 | 102874 | 10.2 | 1.6 | 86.6 | 118792 |
| Kaduna | 22400 | 28719 | 12.8 | 2.4 | 48.6 | 59092 |
| Kano | 42800 | 50145 | 11.7 | 2.6 | 98.9 | 50702 |
| Katsina | 23600 | 25086 | 10.6 | 2.4 | 97.6 | 25703 |
| Plateau | 6800 | 11409 | 16.8 | 1.0 | 11.7 | |
| Sokoto | 97600 | 118947 | 12.2 | 1.8 | 95.2 | 124944 |
| Total | 322400 | 379807 | 11.8 | 0.9 | | |

The volume estimates within various radii of major towns are shown in Table 13, below. It should be noted that areas outside national boundaries have been excluded, though extrapolations have been made to unsurveyed regions within the country. If required, estimates of complete radii can be calculated using the density ($m^3$/ha) values.

The volume estimates have been provided for each incremental radius so that, for example, the total volume within 200 km of Kano can be found by adding all the columns (0-100, 100-150, and 150-200) together. The information has been deliberately presented in this way so that different cost benefit equations can be applied to each band, as collection and transport costs will vary with distance from the town in question.

Estimated wood volume within 100 km of the towns considered is highest around Jos, as befits a limited area of open plateau surrounded by extensive regions of relatively wet and well wooded land. Wood volume is lowest around the more northern conurbations: Sokoto, Kano and Katsina are all surrounded by areas supporting between 7 and 9 cubic meters of wood per hectare (without baobab). This is not true of Maiduguri, where the equivalent area contains an estimated 11.3 $m^3$/ha of wood. This reflects the presence of relatively dense vegetation in the town's immediate vicinity, and contrasts markedly with the 100-150km radius, wherein the wood volume is considerably more sparse, at an average of 7.6 $m^3$/ha. This figure is similar to that close to Sokoto - an area which also includes comparatively dry and open land.

The wood volume estimates for the various River Basin Development Authorities (Table 14) show relatively little variation for the three Authorities which comprise most of the survey area. The figures for Niger RBDA suggest a somewhat higher wood volume density, though it should be pointed out that the proportion of the region actually surveyed may be too small to provide a reliable estimate. Sectors of two further RBDAs - Upper and Lower Benue - also fall within the survey area. However, the proportion of their total areas which was covered amounts to less than 6%, and accordingly estimates have not been provided.

Table 13: Wood Volume ($m^3$ x 1000) In Areas Around Major Towns (within Nigerian boundaries)

a) Without baobab

| | Radius of Area | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0-100km | | | 100-150km | | | 150-200km | | |
| TOWN | Volume | $m^3$/ha | %se | Volume | $m^3$/ha | %se | Volume | $m^3$/ha | %se |
| Sokoto | 22013 | 7.34 | 4.1 | 25734 | 10.90 | 3.8 | | | |
| Kano | 25945 | 8.26 | 1.5 | 35971 | 10.83 | 3.2 | 48254 | 12.31 | 2.8 |
| Jos | 43786 | 13.94 | 2.8 | 57688 | 14.69 | 6.8 | 59486 | 10.82 | 5.3 |
| Maiduguri | 34937 | 11.27 | 4.1 | 29343 | 7.56 | 2.7 | | | |
| Katsina | 20205 | 9.18 | 1.4 | | | | | | |
| Zaria | 32698 | 10.41 | 3.3 | | | | | | |
| Hadeja | 30479 | 10.30 | 4.2 | | | | | | |

Figures extrapolated outside survey zone, but not outside Nigeria

b) With baobab

| | Radius of Area | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0-100km | | | 100-150km | | | 150-200km | | |
| TOWN | Volume | $m^3$/ha | %se | Volume | $m^3$/ha | %se | Volume | $m^3$/ha | %se |
| Sokoto | 25390 | 8.46 | 4.3 | 28974 | 12.28 | 3.7 | | | |
| Kano | 32509 | 10.35 | 1.6 | 42518 | 12.73 | 3.0 | 55233 | 14.09 | 2.6 |
| Jos | 49219 | 15.67 | 1.8 | 66916 | 17.04 | 6.8 | 72516 | 13.19 | 2.6 |
| Maiduguri | 38192 | 12.32 | 2.8 | 31544 | 8.13 | 2.4 | | | |
| Katsina | 24015 | 10.92 | 1.7 | | | | | | |
| Zaria | 37284 | 11.87 | 3.6 | | | | | | |
| Hadeja | 34937 | 11.80 | 3.1 | | | | | | |

Figures extrapolated outside survey zone, but not outside Nigeria

Table 14: Wood Volume By River Basin

a) Without baobab

| Basin | Area Covered ($km^2$) | % Total Area Surveyed | Wood Volume ($m^3$ x 1000) | $m^3$/ha | %SE |
|---|---|---|---|---|---|
| Sokoto Rima | 100800 | 98.8 | 103356 | 10.25 | 1.7 |
| Hadeja Jamare | 120800 | 92.1 | 116035 | 9.61 | 1.6 |
| Chad | 54000 | 92.5 | 50018 | 9.26 | 2.4 |
| Niger | 35600 | 18.9 | 49015 | 13.77 | 2.3 |
| Upper Benue | 8400 | 5.9 | 12301 | 14.64 | 5.2 |
| Lower Benue | 2800 | 3.2 | 4436 | 15.84 | 0.5 |

Figures within Survey Area only

b) With baobab

| Basin | Area Covered ($km^2$) | % Total Area Surveyed | Wood Volume ($m^3$ x 1000) | $m^3$/ha | %SE |
|---|---|---|---|---|---|
| Sokoto Rima | 100800 | 98.8 | 115938 | 11.50 | 1.7 |
| Hadeja Jamare | 120800 | 92.1 | 136103 | 11.27 | 1.5 |
| Chad | 54000 | 92.5 | 53920 | 9.99 | 2.2 |
| Niger | 35600 | 18.9 | 52804 | 14.83 | 2.2 |
| Upper Benue | 8400 | 5.9 | 15871 | 18.89 | 3.7 |
| Lower Benue | 2800 | 3.2 | 5171 | 18.47 | 0.2 |

Figures within Survey Area only

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## APPENDIX 1: TABLES

Table Al.l: Tree Species Recorded

| Species Name | Code Number | Frequency | % Total | Volume Code |
|---|---|---|---|---|
| *Acacia albida* | 3 | 193 | 2.9 | 1 |
| *Acacia dudgeonii* | 131,119 | 183 | 2.8 | 2 |
| *Acacia hockii* | 127 | 33 | 0.5 | 2 |
| *Acacia macrostachya* | 10 | 5 | 0.1 | G |
| *Acacia nilotica* | 4 | 108 | 1.6 | 2 |
| *Acacia polyacantha* | 128 | 5 | 0.1 | 1 |
| *Acacia Senegal* | 5 | 14 | 0.2 | 2 |
| *Acacia seyal* | 9 | 253 | 3.7 | 1 |
| *Acacia sieberiana* | 47 | 39 | 0.6 | 1 |
| *Acacia tortilis* | 142 | 23 | 0.3 | 2 |
| *Adansonia digitata* | 2 | 232 | 3.4 | 3 |
| *Albizia chevcdieri* | 78 | 13 | 0.2 | G |
| *Anacardium occidentale* | 92 | 3 | 0.0 | G |
| *Andira inermis* | 100 | 1 | 0.0 | G |
| *Annona senegalensis* | 1 | 19 | 0.3 | G |
| *Anogeissus leiocarpa* | 7 | 541 | 8.0 | G |
| *Azadirachta indica* | 8,71 | 155 | 2.3 | 4 |
| *Balanites aegyptiaca* | 11 | 607 | 9.0 | G |
| *Bauhinia rufescens* | 61 | 32 | 0.5 | G |
| *Bombax costatum* | 13 | 25 | 0.4 | 3 |
| *Borassus aethiopum* | 12 | 5 | 0.1 | G |
| *Boscia senegalensis* | 99 | 14 | 0.2 | G |
| *Boswellia dalzielii* | 15 | 51 | 0.8 | 11 |
| *Bride.Ua ferruginea* | 111 | 3 | 0.0 | G |
| *Bridelia micrantha* | 63 | 3 | 0.0 | G |
| *Burkea africana* | 14 | 32 | 0.5 | G |
| *Calotropis procera* | 17 | 67 | 1.0 | G |
| *Cassia are re* | 59 | 1 | 0.0 | G |
| *Cassia siamea* | 134 | 6 | 0.1 | G |
| *Cassia sieberiana* | 18 | 152 | 2.3 | G |
| *Cassia singueana* | 70 | 31 | 0.5 | G |
| *Ceiba pentandra* | 16 | 13 | 0.2 | 3 |
| *Celtis integrifolia* | 53,94 | 10 | 0.1 | 1 |
| *Combretum collinum* | 130 | 5 | 0.1 | 2 |
| *Combretum fragrans* | 129 | 18 | 0.3 | 2 |
| *Combretum glutinosum* | 109,19 | 367 | 5.7 | G |
| *Combretum microcarpa* | 81 | 30 | 0.4 | G |
| *Combretum molle* | 73 | 70 | 1.0 | 2 |
| *Combretum nigricans* | 68 | 240 | 3.6 | 2 |
| *Commiphora africana* | 20 | 44 | 0.7 | 2 |
| *Commiphora pedunculata* | 83,126 | 9 | 0.9 | 2 |
| *Cordia africana* | 133 | 1 | 0.0 | G |
| *Crossopteryx febrifuga* | 69 | 15 | 0.2 | 2 |
| *Cussonia barteri* | 21 | 2 | 0.0 | 3 |

Volume Code refers to groupings in Appendix Table 1.3, G=General Formula

Table Al.l: Tree Species Recorded (continued)

| Species Name | Code Number | Frequency | % Total | Volume Code |
|---|---|---|---|---|
| *Dalbergia melanoxylon* | 24 | 19 | 0.3 | G |
| *Dalbergia sissoo* | 22 | 1 | 0.0 | 20 |
| *Daniellia oliveri* | 25 | 17 | 0.3 | 1 |
| *Detarium microcarpum* | 26 | 67 | 1.0 | G |
| *Dichrostachys cinerea* | 45 | 5 | 0.1 | G |
| *Diospyros mespiliformis* | 23 | 311 | 4.6 | G |
| *Entada africana* | 64 | 66 | 1.0 | 2 |
| *Erythrophleum africana* | 137 | 1 | 0.0 | 1 |
| *Eucalyptus camaldulensis* | 72 | 30 | 0.4 | 1 |
| *Ficus platyphylla.* | 27 | 28 | 0.4 | 1 |
| *Ficus* sp *1.* | 87 | 6 | 0.1 | 1 |
| *Ficus* sp2. | 120 | 2 | 0.0 | 2 |
| *Ficus* sp3. | 121 | 2 | 0.0 | 1 |
| *Ficus sycomorus* | 122 | 5 | 0.1 | 1 |
| *Ficus thonningii* | 123 | 4 | 0.1 | 1 |
| *Gardenia* sp. | 46 | 13 | 0.2 | G |
| *Gardenia erubescens* | 90 | 2 | 0.0 | G |
| *Gardenia ternifolia* | 139 | 2 | 0.0 | G |
| *Gmelina arborea* | 51 | 1 | 0.0 | 22 |
| *Greuiia mollis* | 105 | 1 | 0.0 | 1 |
| *Guiera senegalensis* | 28 | 2 | 0.0 | G |
| *Holarrhena floribundia* | 89 | 5 | 0.1 | 11 |
| *Hymenocardia acida* | 136 | 1 | 0.0 | G |
| *Hyphaene thebaica* | 29 | 43 | 0.6 | G |
| *Isoberlinia doka* | 30 | 89 | 1.3 | 1 |
| *Isoberlinia tomentosa* | 84 | 44 | 0.7 | 1 |
| *Khaya senegalensis* | 31 | 13 | 0.2 | G |
| *Lannea acida* | 32 | 132 | 2.0 | 11 |
| *Lannea barteri* | 52 | 1 | 0.0 | 11 |
| *Lannea humilis* | 33 | 36 | 0.5 | 11 |
| *Lannea kerstingii* | 34 | 9 | 0.1 | 11 |
| *Lannea schimperi* | 35 | 56 | 0.8 | 11 |
| *Lonchocarpus sericeus* | 96 | 2 | 0.0 | 11 |
| *Maerua oblongata* | 118 | 15 | 0.2 | G |
| *Mangifera indica* | 36 | 35 | 0.5 | G |
| *Maytenus senegalensis* | 113 | 3 | 0.0 | G |
| *Mitragyna inermis* | 85,86 | 97 | 1.4 | 11 |
| *Monotes kerstingii* | 102 | 13 | 0.2 | 11 |
| *Moringa oleifera* | 50 | 16 | 0.2 | 1 |
| *Nauclea latifolia* | 106 | 14 | 0.2 | G |
| *Ochna afzellii* | 116 | 1 | 0.0 | G |
| *Ormocarpum bibracteatum* | 114 | 2 | 0.0 | 11 |
| *Ozoroa (Heeria) insignis* | 74 | 4 | 0.1 | G |
| *Parinari curatellifolia* | 66 | 10 | 0.1 | G |
| *Parkia biglobosa* | 37 | 344 | 5.1 | 1 |
| *Pavetta* sp. | 56 | 1 | 0.0 | G |
| *Pericopsis laxiflora* | 65 | 44 | 0.7 | G |
| *Persea americana* | 67 | 1 | 0.0 | G |

Volume Code refers to groupings in Appendix Table 1.3, G=General Formula

Table AI.1: Tree Species Recorded (continued)

| Species Name | Code Number | Frequency | % Total | Volume Code |
|---|---|---|---|---|
| *Phoenix dactylifera* | 62 | 2 | 0.0 | G |
| *Piliostigma reticulatum* | 80,38 | 310 | 4.6 | G |
| *Piliostigma thonningii* | 39 | 8 | 0.1 | G |
| *Prosopis africana* | 49 | 148 | 2.2 | 11 |
| *Pterocarpus erinaceus* | 110 | 11 | 0.2 | G |
| *Sclerocarya birrea* | 40 | 191 | 2.8 | 1 |
| *Sterculia setigera* | 97 | 103 | 1.5 | 3 |
| *Stereospermum* sp. | 54 | 9 | 0.1 | 11 |
| *Strychnos* sp. | 55 | 18 | 0.3 | G |
| *Swartzia madagascariensis* | 108 | 4 | 0.1 | 11 |
| *Syzigium guineense* | 141 | 1 | 0.0 | 11 |
| *Tamarindus indica* | 41 | 286 | 4.2 | 11 |
| *Terminalia avicennioides* | 60 | 25 | 0.4 | G |
| *Terminalia glaucescens* | 82 | 24 | 0.4 | G |
| *Terminalia laxi flora* | 77 | 1 | 0.0 | G |
| *Terminalia macroptera* | 125 | 3 | 0.0 | G |
| *Uapaca togoensis* | 104 | 1 | 0.0 | G |
| *Vitellaria (Butyrospermum) paradoxa* | 43 | 205 | 3.0 | 11 |
| *Vitex doniana* | 42 | 38 | 0.6 | 11 |
| *Vitex simplicifolia* | 91 | 5 | 0.1 | 11 |
| *Xeroderris stuhlmannii* | 98 | 5 | 0.1 | 11 |
| *Xeromphis (Randia) nilotica* | 75 | 10 | 0.1 | G |
| *Ximenia americana* | 57 | 4 | 0.1 | G |
| *Ziziphus mauritania* | 124 | 25 | 0.4 | G |
| *Ziziphus spina-christi* | 44 | 21 | 0.3 | G |

Volume Code refers to groupings in Appendix Table 1.3, G=General Formula

Table A1.2: Authorities and Available Hausa Names.

| Scientific Name | Hausa Name |
|---|---|
| *Acacia albida* Del. | Gawo |
| *Acacia nilotica* (Linn.) Willd. ex Del. | Gabaruwa |
| *Acacia polyacantha* Willd. | K'aro* |
| *Acacia Senegal* (Linn.) Willd. | Dakwara |
| *Acacia seycd* Del. | Dushe |
| *Acacia sieberiana* | Fara Kaya |
| *Adansonia digitata* Linn. | Kuka |
| *Albizia chevcdieri* Harms. | Katsari |
| *Anogeissus leiocarpa* (DC.) Guill. & Perr. | Marke |
| *Azadirachta indica A.* Juss. | Nim |
| *Balanites aegyptiaca* (Linn.) Del. | Aduwa |
| *Bauhinia rufescens* Lam. | Tsattsagi |
| *Bombax costatum* Pellegr. & Vuillet | Gurjiya |
| *Borassus aethiopum* Mart. | Giginya |
| *Boswellia dalzielii* Hutch | Hano, Ararra'bi |
| *Bridelia ferruginea* Benth. | Kirni |
| *Calotropis procera* (Ait.) Ait. | Tumfafia |
| *Cassia arere* Del. | Marga |
| *Cassia singueana* Del. | Rumfu |
| *Ceiba pentandra* (Linn.) Gaertn. | Rimi |
| *Celtis integrifolia* Lam. | Zuwo |
| *Combretum collinum* Fres. | Kantakara, Taramniya |
| *Combretum fragrans* F. Hoffm. | Zindi** |
| *Combretum molle* R. Br. ex G. Don | Wuyan damo |
| *Commiphora africana* (A. Rich.) Engl. | Dashi |
| *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth. | Shaffa |

* May also apply to other 'gum' trees ** Kanuri
Source: Cline Cole *et al* (1987)

Table A1.2: Authorities and Available Hausa Names (continued).

| Species Name | Hausa Name |
|---|---|
| *Daniellia oliveri* (Rolfe) Hutch. & Dalz. | Maje |
| *Dichrostachys cinerea* (Linn.) Wight & Arn. | 'Dundu |
| *Diospyros mespiliformis* Hochst. ex A. DC | Kanya |
| *Entada africana* Guill. & Perr. | Tawatsa |
| *Ficus platyphylla* Del. | Gamji |
| *Ficus sycomorus* Linn. | 'Baure |
| *Ficus thonningii* Blume | Ce'diya |
| *Gardenia erubescens* Stapf. & Hutch. | Gau'de |
| *Gmelina arborea* Roxb. | Melaina |
| *Guiera senegalensis* J.F. Gmel | Sahara |
| *Hymenocardia acida* Tul. | Jani |
| *Khaya senegalensis* (Desr.) A. Juss | Madaci |
| *Lannea acida* A. Rich. | Faru |
| *Lannea barteri* (Oliv.) Engl. | Faru |
| *Mangifera indica* Linn. | Mangwaro |
| *Moringa oleifera* Lam. | Zogale |
| *Parkia biglobosa* (Jacq.) Benth. | 'Dorawa |
| *Pericopsis laxiflora* (Benth.) van Meeuwen | Mak'arfo |
| *Piliostigma reticulatum* (DC.) Hochst. | Kargo |
| *Piliostigma thonningii* (Schum.) Milne-Redhead | Kargo |
| *Prosopis africana* (Guill. & Perr.) Taub | K'irya |
| *Pterocarpus erinaceus* Poir | Madobiya |
| *Sclerocarya birrea* (A. Rich.) Hochst. | Danya |
| *Sterculia setigera* Del. | Kukkuki |
| *Stereospermum* sp. | Sansami |
| *Strychnos* sp. | K'ok'iya |
| *Swartzia madagascariensis* Desv. | Bayama |
| *Tamarindus indica* Linn. | Tsamiya |
| *Terminalia glaucescens* Planch, ex Benth. | Baushe |
| *Terminalia macroptera* Guill. & Perr. | Kwandari(ya) |
| *Vitex doniana* | 'Dinya |
| *Ximenia americana* Linn. | Tsada |
| *Ziziphus mauritania* Lam. | Magarya |
| *Ziziphus spina-christi* (Linn.) Desf. | Kurna |

Source: Cline Cole *et al* (1987)

Table A1.3: Wood Volume Groupings And Equations

GROUP 1
Species included: 3,9,25,27,30,37,40,47,53,72,84,87,94,105,121,122
123,128,137.

Formula: Vol= (419.21176DBH+10.664)/0.028317
originally in imperial units for *Acacia albida*

Reference:Khan, M.A.W. (1966)

GROUP 2
Species included: 4,5,20,64,68,69,73,83,119,120,121,126,127
129,130,142.

Formula: Vol= 0.4034(DBH2)H + 0.006
for *Acacia nilotica*

Reference: Chaturvedi, A.N. (1983)

GROUP 4
Species included: 8,71

Formula: Vol= $(((39.37G)^{1\text{-}694}$ * $(3.2808H)0\text{-}^{9}979)/e^{7}\text{-}4i)$*0.02382
originally in imperial units for *Azadirachta indica*

Reference: Gravsholt, S., Jackson, J.K. and Ojo, G.O.A. (1967)

GROUP 11
Species included: 15,32,33,34,35,41,42,43,49,50,52,54,85,89,91,96,98
102,108,114,141

Formula: $VoMG^{1\text{-}345})\hat{}^{0\text{-}716})$

Reference: Temu, A.B. (1981)

GROUP 20
Species included: 22

Formula: Vol=0.2307 + 2.4833D2H

Reference: Chaturvedi, A.N. (1973)

GROUP 22
Species included: 51

Formula: Vol=0.007893 + 0.3515D2H

Reference: Sharma, R.P. and Jain, R.C. (1977)

GENERAL FORMULA
Vol = (Section Area x Height)/2

Table AI.4: Calculated Wood Volume Per Square Metre Of Canopy by Land Use Stratum and Vegetation Mapping Zone

| | WITH BAOBAB | | WITHOUT BAOBAB | |
|---|---|---|---|---|
| | Vol/m$^2$ | No. Trees | Vol/m$^2$ | No. Trees |
| CULTIVATION | | | | |
| TOTAL | 0.0218 | 3230 | 0.0176 | 3027 |
| VZone 4 | 0.0207 | 600 | 0.0177 | 557 |
| VZone 5 | 0.0197 | 1390 | 0.0156 | 1311 |
| VZone 6 | 0.0257 | 852 | 0.0197 | 780 |
| VZone 7 | 0.0229 | 388 | 0.0204 | 379 |
| GRASSLAND | | | | |
| TOTAL | 0.0447 | 87 | 0.0447 | 87 |
| VZone 5 | 0.0447 | 87 | 0.0447 | 87 |
| SHRUBLAND | | | | |
| TOTAL | 0.0168 | 872 | 0.0166 | 871 |
| VZone 5 | 0.0202 | 572 | 0.0202 | 572 |
| VZone 6 | 0.0103 | 300 | 0.0096 | 299 |
| SHRUB/GRASSLAND | | | | |
| TOTAL | 0.0180 | 1353 | 0.0165 | 1338 |
| VZone1 | 0.0061 | 72 | 0.0061 | 72 |
| VZone 4 | 0.0273 | 272 | 0.0229 | 268 |
| VZone 5 | 0.0096 | 598 | 0.0096 | 593 |
| VZone 6 | 0.0353 | 261 | 0.0326 | 255 |
| VZone 7 | 0.0104 | 150 | 0.0104 | 150 |
| WOODLAND | | | | |
| TOTAL | 0.0173 | 1200 | 0.0157 | 1188 |
| VZone 4 | 0.0218 | 50 | 0.0139 | 49 |
| VZone 5 | 0.0227 | 350 | 0.0219 | 348 |
| VZone 6 | 0.0165 | 250 | 0.0115 | 241 |
| VZone 7 | 0.0138 | 550 | 0.0138 | 550 |
| ENTIRE SURVEY AREA | | | | |
| TOTAL | 0.0199 | 6742 | 0.0173 | 6511 |
| VZone 1 | 0.0061 | 72 | 0.0061 | 72 |
| VZone 4 | 0.0227 | 922 | 0.0191 | 874 |
| VZone 5 | 0.0189 | 2997 | 0.0169 | 2911 |
| VZone 6 | 0.0230 | 1663 | 0.0186 | 1575 |
| VZone 7 | 0.0166 | 1088 | 0.0156 | 1079 |

Key:
VZone 1: Sahel ***Acacia*** wooded grassland and deciduous bushland
VZone 2: Mandara Plateau Mosaic
VZone 3: Jos Plateau Mosaic
VZone 4: Sudanian Woodland with islands of ***Isoberlinia***
VZone 5: Undifferentiated Sudanian Woodland (<650mm annual rainfall)
VZone 6: Undifferentiated Sudanian Woodland (>650mm annual rainfall)
VZone 7: Sudanian woodland with abundant ***Isoberlinia***
VZone 8: Mosaic lowland rainforest, ***Isoberlinia*** woodland and secondary grassland

It should be noted that a figure for dense Woodland has not been calculated in the light of the arguments presented in the main text, and the mean figure for each ecozone has been applied to the estimated areas for this stratum instead. Also, as the extent of grassland within different EZones was insufficient to calculate separate values for each ecozone, a mean figure for the whole stratum has been used

## APPENDIX 2: TERMS OF REFERENCE

1. Using satellite imagery provided by SILVICONSULT, and the most recent land use information available, including Side Looking Airborne Radar maps published by the Federal Department of Forestry, stratify the project area into major land cover strata.

2. Fly low level transects at 1,000-2,000 feet above ground level and obtain sample vertical aerial photography over these strata.

3. Interpret these photographs in order to quantify the parameters, selected after discussions to be held with SILVICONSULT staff, which will be used in conjunction with the ground studies to estimate ligneous biomass in each major stratum.

4. Select suitable ground survey sites in the strata within the project area to determine characteristics of tree species and forest types in relation to ligneous biomass, and assess the degree of regeneration taking place.

5. Integrate satellite imagery, aerial photography, and ground survey information to produce a quantitative assessment of the distribution and abundance of potentially available fuelwood resources.

6. Submit a report describing methodology and results obtained.

## APPENDIX 3: PERSONNEL

| | |
|---|---|
| Dr William Wint | Analyst, Editor |
| Dr Brian Harris | Senior Forester |
| Dr David Bourn | Coordinator |
| Mr Adrian Rayson | Photographer |
| Capt. Alan Price | Pilot |
| Ms Kath Morris | Naivgator, Photo Interpreter |
| Ms Liz Woolley | Data Processor |
| Mr Isahku Maitumbi | Photo Interpreter |
| Ms Polly MacDonald | Photo Interpreter |
| Mr A.O. Ohaeri | Assistant Forester |
| Mr S.O. Magaji | Assistant Forester |
| Mr M. Ayuba | Assistant Forester |
| Mr K. Ohaeri | Ground Enumerator |
| Mr I. Ohaeri | Ground Enumerator |
| Mr D. Magaji | Ground Enumerator |