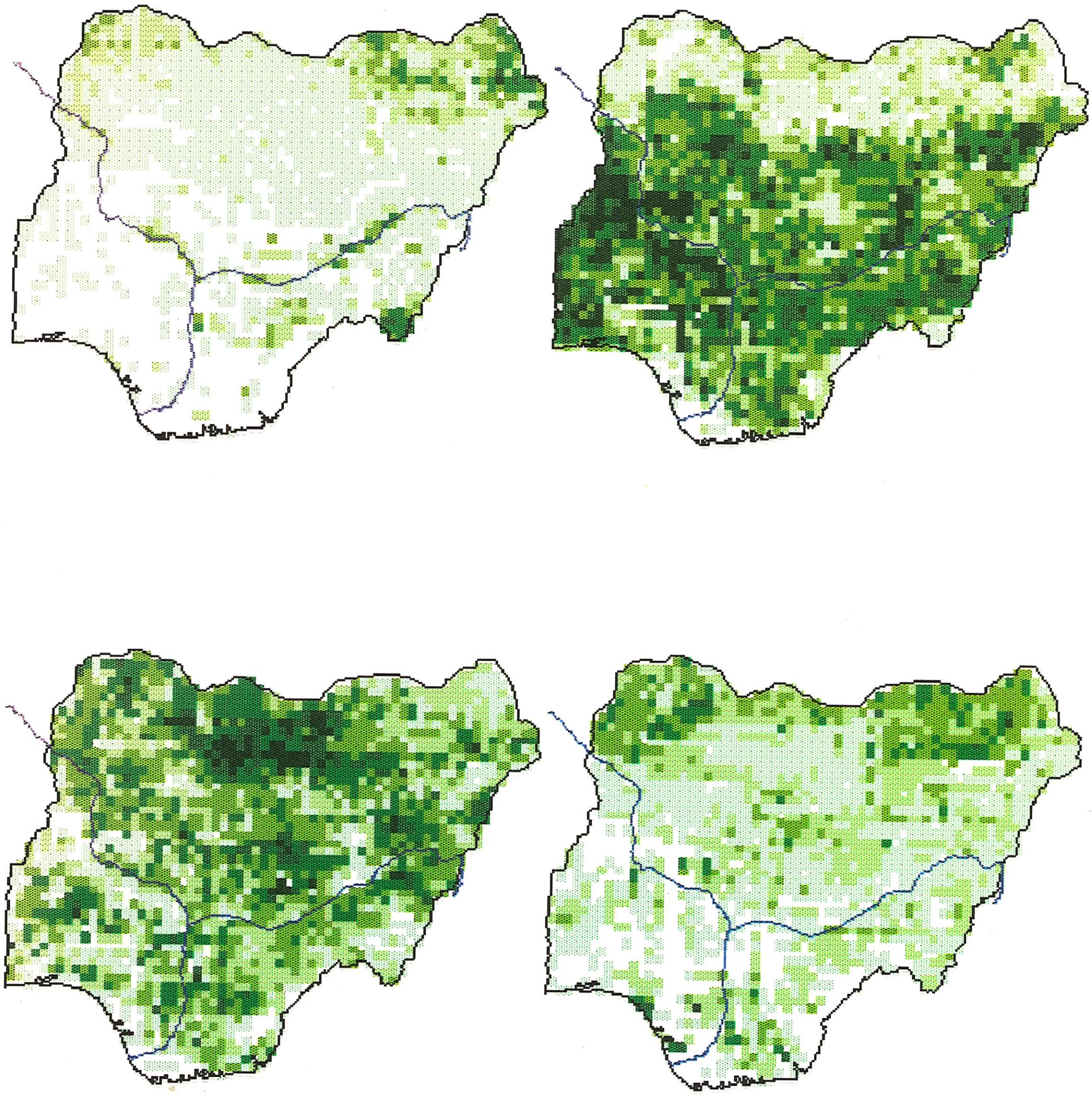
Federal Environmental Protection Agency
Abuja, Nigeria

LAND USE CHANGE IN NIGERIA, 1976 - 1990



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SUMMARY

Evaluation of the sources and sinks of greenhouse gases in Nigeria calls for a national assessment of vegetation and land use, and for an estimate of current rates of change. Compatible sets of vegetation and land use information are required from two periods, sufficiently far apart for differences between them to be greater than the errors inherent in their estimation.

Various classifications of Nigerian vegetation have been published since the 1950s, but most are too broad and generalised for the present task. An important exception is the set of maps published by the Federal Department of Forestry, which provides a detailed assessment of vegetation and land use for the whole country during 1976/77, based on Side Looking Airborne Radar (SLAR). A more recent dataset, compatible in spatial terms comparable in the parameters assessed, was obtained during the course of the Nigerian National Livestock Resources Survey in 1990, which included assessment of vegetation and land use, based on low level Systematic Reconnaissance Flights (SRF).

The 1990 aerial survey data are based on visual estimates of five major land use categories: Grassland, Scrubland, Woodland, Forest and Cultivation, within each of 2280 survey grids covering the entire country. Comparison with photographic assessments, and between repeated visual surveys, confirms the reliability of such estimates.

Two preliminary steps are required to match and compare the data sets: recording the amount of each SLAR vegetation category within each aerial survey grid; and then matching the SLAR categories with the aerial survey data. The first stage was effected by overlaying the aerial survey grids onto each of the 69 SLAR vegetation maps, sub-dividing each into 100 sub-units, and recording the predominant vegetation category within each sub-unit, and calculating the percentage of each grid cell covered by each vegetation category. Matching the SLAR and aerial survey data was achieved by a combination of regression and distribution analyses. Land use change was calculated by subtraction of the two sets of matched figures.

The results show a rise in cultivation levels of approximately 2.1% compound per annum, and a fall in the extent of natural vegetation types: grassland by 2.3% p.a.; scrub by 1.1% p.a., woodland and mangrove forest by 0.6% p.a., and closed canopy forest by 2.1% p.a.. Settlement also increased substantially, at an estimated compound annual rate of 6.9%. Projections, using these estimated rates of change, indicate that by the year 2020: just over half the country will be cultivated; less than a third will be covered by woodland; and settlement will amount to about 5% of the country's land area.

The report also considers the composition and wood volume content of the major land use types, using data from an independent photographic survey of woody vegetation cover over the northern third of the country in 1990. Whilst these figures are only directly relevant for northern Nigeria, they provide some indicative information necessary for calculation of overall carbon balance.

Application of a novel technique of land use assessment, based on Fourier analysis of time series data derived from Advanced Very High Resolution Radiometer (AVHRR) satellite imagery, is also evaluated. This methodology is still in an early stage of development, but can be used for estimating land use cover, where reliable calibration data are available. Further refinements are required, however, before it can be used to inter-annual comparison.

The report concludes with a brief review of future vegetation and land use monitoring requirements, with recommendations for further study.

ACKNOWLEDGEMENTS AND PERSONNEL

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ACRONYMS

AVHRR	Advanced Very High Resolution Radiometer
ERGO	Environmental Research Group Oxford Limited
FEPA	Federal Environmental Protection Agency
FAO	Food and Agriculture Organisation of the United Nations
ha	Hectare
ILCA	International Livestock Centre for Africa
JOG	Joint Operations Graphics
km	Kilometre
m	Metre
NDVI	Normalised Difference Vegetation Index
NOAA	National Oceanographic and Atmospheric Administration (USA)
p.a.	*per annum*
RIM	Resource Inventory and Management Limited
SE	Standard Error
SLAR	Side Looking Airborne Radar
SRF	Systematic Reconnaissance Flights
SPSS	Statistical Package for the Social Sciences
UTM	Universal Transverse Mercator

LAND USE CHANGE IN NIGERIA: 1976 - 1990

1. INTRODUCTION AND BACKGROUND

The study of the sources and sinks of greenhouse gases in Nigeria calls for a national assessment of vegetation and land use, and also for an estimate of the degree to which land use patterns are changing. Estimation of current rates of change require comparison of two sets of vegetation and land use data covering the whole country, so that an annual rate can be calculated. The Terms of Reference for this component of the study are embodied in a research proposal submitted to and approved by the Federal Environmental Protection Agency (FEPA), Nigeria, and are given in Appendix 1.

1.1. Vegetation Classification

Nigeria's natural vegetation reflects the country's diversity of climate and topography - rainfall, relative humidity and length of the dry season are the most important determinants of vegetation type. The major vegetation categories range from the dense mangrove forests of the Niger Delta and the rain forests of the south, to the arid grassland of the north, with extensive woodlands in between, and montane grasslands on the highlands of the Jos and Mambila Plateaux. Natural vegetation is locally variable, with abrupt transitions between these broadly defined categories.

Various classifications of Nigerian vegetation have been published since the 1950s. All comment on the influence of man-induced changes to the natural environment which have created a number of transitional or derived vegetation types. Remnant species, generally those of economic importance, are often the only relics left of natural ecosystems. Vegetation tends to consist of local mosaics of natural and transitional species, interspersed with areas of cultivated or fallow land. Cultivation and the associated transitional ecotypes are now the dominant form of vegetation and land use in many areas.

The various classification schemes used reflect changing perceptions of their significance and value. The earlier trend was to consider vegetation in isolation from cultivation and other aspects of human intervention. As it has become clearer that most landscapes in Nigeria are, in some way, anthropogenic, current descriptions generally consider vegetation and land use together.

Keay (1959) described many of the vegetation classes that are still used today, including mangrove, freshwater swamp, and wet and dry forest types. The last two of these are structurally very similar, though they differ floristically. Mature wet forest has become more scarce in Nigeria, although dry forest, mostly under the protection of forest reserves, is present in many parts of the south. The Niger Delta area is characterised by extensive mangrove and freshwater swamp forests, the latter type being an "edaphic variant of rain forest" (Keay, 1959) confined to the banks of the Delta's numerous waterways. The mangrove ecosystems of Nigeria have been described in considerably more detail by Wilcox and Powell (1985).

Keay's southern guinea savannah, or transition woodland, denotes areas comprising both forest and savannah type vegetation. Widespread throughout the Middle Belt and beyond, for example around Minna and Makurdi, this type of woodland readily transforms into grassland. Further north, the denser, two-storey, broad-leaved woodland, or northern guinea savannah, is common. Sahel savannah, an open thorn woodland dominated by *Acacia* species, is confined to north-east Borno State. A composite of this latter type and Guinea Savannah, described as Sudan Savannah, is prevalent in the northern States, though it has frequently been much modified and degraded.

An ecological zonation of natural vegetation, reflecting the situation in the late sixties and early seventies, is the National Atlas of Nigeria (Federal Surveys, 1978). The stratification follows Keay (1959), but refines the zonal nomenclature: coastal; mangrove; aquatic grassland and herbaceous swamp; swamp forest and riparian forest; sub-montane forest; moist lowland forest; dry forest woodland; wooded tropical steppe; edaphic and biotic savannah. More recently, Keay (1989) has published an updated "Nigerian Trees" that gives currently accepted botanical nomenclature.

In his "Vegetation Map of Africa", White (1983) identifies 11 different vegetation categories within Nigeria, all being variants of his forest, woodland and wooded grassland types (with the exception of those in upland areas). Forest vegetation is characterised by multi-storey woody species, in excess of 10 m in height, with interlocking crowns, usually non-fire-tolerant, and with little or no grass beneath. Woodland comprises open stands of trees standing at least 8 m tall, and giving a canopy of 40% or greater. Savannah is dominated by grass with fire-tolerant woody growth present. Grassland and wooded grassland are distinguished as having less than 10% and 10-40% woody vegetation, respectively.

Several wider regional zonations have also been put forward, such as the "eco-climatic zonation" developed by FAO and used by ILCA (1979). Though defined in agro-climatic terms of plant-growing period, it is also a very general indicator of vegetation zones. The Humid Zone, where annual rainfall exceeds 1,500 mm, corresponds approximately to the forest zone, whilst the Sub-humid and Semi-arid Zones, having 1,000-1,500 mm and 500-1,000 mm average annual rainfall respectively, partially reflect the limits of Keay's northern and southern guinea savannahs. The Arid Zone, with less than 500 mm rainfall per year, occupies a relatively small part of the country, and is restricted to its northern extremes.

A more complex classification of Nigerian vegetation is the set of 69 Vegetation and Land Use maps, derived from Side looking Airborne Radar (SLAR) imagery, obtained during the mid-seventies, which have been published at a scale of 1:250,000 by the Federal Department of Forestry. Some 65 different vegetation and land use types, collected into 10 major formations, are identified.

1.2. Cultivation

Most farming in Nigeria is still in the hands of the "traditional" sector, incorporating a wide range of subsistence farming systems and generally including both arable and pastoral elements. Broad descriptive studies of farming systems are more generally available than detailed discussions of cropping patterns. Although there are some major plantations in the south and a number of large-scale modern farms throughout the country, these represent only a small fraction of the total agricultural output.

Despite the image of traditional farming as small-scale and low-yielding, in reality it has responded effectively to the evolution of a modern economy and an increasingly urbanised population. For this reason, farming systems in rural areas blend purely subsistence activities with a range of market-oriented strategies, most notably, the tillage of larger areas to produce surplus staples and the development of swamp, fadama and irrigation systems for horticultural products.

All types of intensive production, particularly flood-retreat cultivation, swamp cultivation and irrigated horticulture, have undergone a dramatic expansion in recent years to feed the expanding urban populations. This has been correlated with a gradual transformation of land tenure systems from community or inalienable ownership with no rights to individual sales, to personal ownership with the exchange of land for cash or goods.

All farming systems exist in a dynamic relation with the surrounding natural vegetation. Forest trees are a source of firewood, browse, fruits and other economic products, and particular trees may be owned in otherwise untilled land. As the farms expand further into the bush, farmers must compensate for the loss of economic products, especially through conservation of economic trees; hence the establishment of extensive areas of "farmed parkland" in many regions.

1.3. Vegetation Assessments

The assessment of land use change requires that compatible sets of information are available from two periods sufficiently far apart for differences between them to be greater than the errors inherent in their estimation. With the growth in human population over the past century there has been a progressive expansion of farmland at the expense of natural vegetation, but this has not been well documented. Cultivation levels in the Middle Belt are thought to have increased, and there has almost certainly been a reduction in forest cover in the south. Any vegetation and land use changes related to human population increase, generally assumed to have been in the region of 2-3% per year, are therefore likely to have increased (or decreased) by about a third over a period of fifteen years.

The vegetation classifications discussed in the preceding section are, with one exception, rather broad in spatial terms, lack detail, and are unsuitable for the present task. The exception is the SLAR cartography published by the Federal Department of Forestry, which provides a detailed assessment of vegetation and land use patterns for the whole country during 1976/77. More recent national coverage is difficult to come by. Imagery from LANDSAT, NOAA and SPOT satellites is available for the 1980's, though the current state of knowledge concerning its interpretation is neither detailed nor precise enough to warrant its use for the estimation of land use change in any but the most general terms (see Appendix 2). There is, however, one important dataset available from the National Livestock Resources Survey of 1990, conducted on behalf of the Federal Department of Livestock and Pest Control Services, in which land use was estimated during the course of a low level aerial survey of the whole of Nigeria (RIM, 1992).

The 1976/77 SLAR data and the 1990 low level aerial survey data are compatible in spatial terms, and far enough apart in time, for them to be compared and any changes detected. Details of these two vegetation estimates are given in the following section.

2. THE DATA USED TO ESTIMATE LAND USE CHANGE

2.1. The 1990 Aerial Survey Data.

The major vegetation types were assessed by low level aerial survey using Systematic Reconnaissance Flights (SRF), during the 1990 Nigerian National Livestock Resources Survey. This survey technique covers an entire survey area systematically and uniformly, and thus avoids the potential disadvantages of stratified survey methodologies. Estimates were made visually for each of 2280 twenty by twenty kilometre grid cells based on the UTM projection, covering the whole country (Figure 1). Details of the methodology and results can be found in RIM (1992).

2.1.1. Vegetation Categories Assessed from the Air

Nine major vegetation categories were scored in each survey grid, as shown in Table 1. A number of these categories are amalgamations of several vegetation types. For example, scrub/shrubland includes the coastal regions with scrub vegetation, as well as the more common shrubland of the Semi-arid zone. Other categories are described in the Table. It should be noted that the distinction between forest and woodland is based on canopy density, rather than eco-climatic zone or species composition.

Thus woodland is defined as land with between 5-95% tree canopy cover; and forest as land with closed canopy woody vegetation cover.

Figure 1: 1990 Aerial Survey Sampling Grid

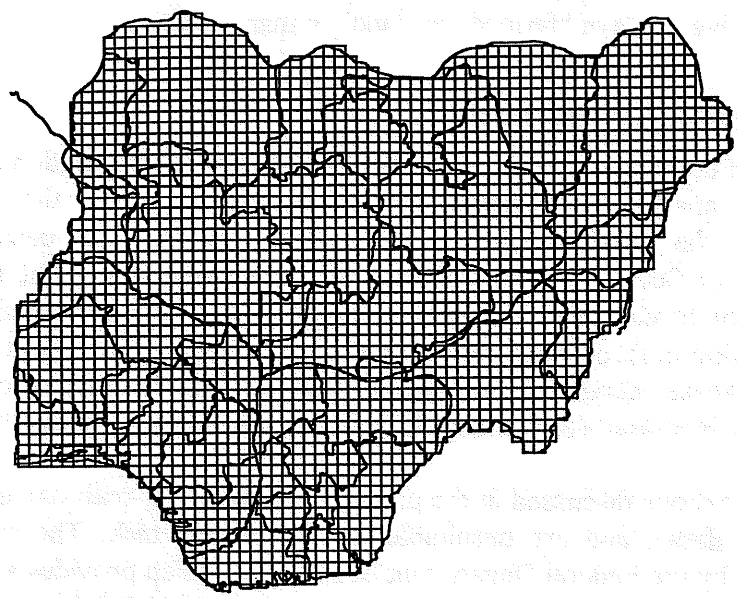


Table 1: 1990 Aerial Survey Vegetation and Land Use Categories

Category	Comments
Bare Ground	Land with no visible vegetation
Grassland	Open Grassland, with less than 1% woody vegetation cover. Includes: *Firki* (Depressions with grass present in late dry season, characteristic of the north-east); and flood plains.
Scrub/Shrubland	Land with woody vegetation that is primarily shrubs, rather than trees Includes: coastal scrub; and old fallow reverting to natural vegetation.
Woodland	Open canopy woodland, dependent on canopy cover rather than species composition. Includes: open woodland (with between 5 and 50% tree canopy cover); and dense woodland (with between 50 and 95% tree canopy cover).
Forest	All closed canopy forest. Includes: riverine forest; and layered (generally primary) forest.
Mangrove	Estuarine, coastal and deltaic mangrove forest.
Open Water	Lakes, rivers, reservoirs, pools and flooded areas.
Cultivation	Cultivated land and recent fallow.
Settlement	Large villages and towns.

2.1.2. Natural Vegetation Estimates, 1990

The extent of the major vegetation categories recorded from the air during 1990, together with the percentage Standard Error (SE) of the estimate and the maximum levels recorded, are summarised in Table 2.

Grasslands covered only 3% of the total land area of Nigeria. They were most common in Borno State (12%), around Lake Tchad and south of its affluents. Extensive grasslands were also found in

Taraba State, on the Mambila Plateau and the Benue flood plains, between Numan and the Taraba River; on the Jos Plateau; and in Benue State. *Firki*, a specific type of clay grassland plain characteristic of northern and north-eastern Borno State were locally very extensive. Because of their water retaining capabilities, these areas constitute an important late dry season grazing resource.

Scrub/shrubland covered 11% of the country, largely in Borno, Kebbi and Sokoto States. Following land clearance, it has replaced forest in parts of the south. Palm-dominated scrub/shrubland was recorded in much of the coastal strip. Scrub/shrubland was also found on the periphery of extensive cultivation in the north, reflecting the effects of agricultural expansion through woodland clearance.

Table 2: Means of Aerial Survey Vegetation Categories

Air Vegetation Category	SPSS Name	Mean %	SE	Max. %
Grassland	GRASS	3.40	0.11	88
Bare Ground	BARE	3.14	0.11	90
Floodplain	FPLAIN	0.72	0.06	48
Firki	FIRKE	0.46	0.03	60
Open Cultivation	OPENCULT	3.60	0.15	85
Cultivation with Trees	PARK	14.32	0.26	95
Cultivation with Palm Trees	PALMPARK	0.77	0.07	52
Recent Cultivation or Fallow	DEADCULT	12.18	0.19	95
Closed Canopy Forest	FOREST	3.96	0.16	99
Layered Forest	LAYFOR	0.94	0.08	95
Riverine Forest	RIVFOR	1.01	0.04	60
Open Woodland	OPENWOOD	17.83	0.29	98
Dense Woodland	DENSEW	23.47	0.33	99
Scrub/Shrubland	SCR	10.88	0.19	92
Mangrove	MANG	1.01	0.05	97
Visible Water	OPENWAT	1.49	0.03	80
Settlement	SETTLE	0.81	0.02	80
Summary Categories:				
All Cultivation	ALLCULT	30.88	0.31	98
All Forest	ALLFOR	5.91	0.17	100
All Woodland	ALLWOOD	41.30	0.37	100
All Forest and Woodland	FORWOOD	47.21	0.33	100

Tree cover was assessed as either woodland or closed canopy forest. Woodland occupied 41% of the country, extending southwards from 11°15'N, to the Atlantic coast in the south-west, and to the edges of the Delta in the south-east. Substantial areas of this woodland appeared to be relatively undisturbed.

Woodland was sub-divided into open and dense types. Open woodland predominated in a band between 10°N and 11°N, extending in a spur south through the Yankari Game Reserve to the south-eastern edges of the Jos Plateau, and from northern Ondo into Kwara State. There was extensive dense woodland to the north of the Mambila Plateau, in south-western Plateau State, most of Kwara State, the southern half of Niger State, western Oyo and Ogun States, and in southern Sokoto State, east of Zuru.

Closed canopy forest covered only 6% of the country, and was concentrated in the southern states. This category consisted mostly of primary forest. Cross River was found to be the most heavily forested state, and contained layered forest, though there was evidence of substantial encroachment. Layered forest also occurred on the south-western escarpment of the Mambila Plateau, although it was threatened by extensive dry season fire penetration. During the 1990 dry season, several hundred square kilometres had been set alight in the area around Baissa.

Bare ground accounted for 3% of the total land area, most of which was found along the northern border of the country, and on the Mambila Plateau. Erosion was most evident in central Sokoto State along a band from Birnin Kudu, via Sokoto town to Gusau; in north-western Kaduna State, west of Birnin Gwari; on the Mambila and Jos Plateaux; north of Yola, and to the north and east of the confluence between the Benue and Taraba Rivers; around the meeting point of Bauchi, Yobe and Jigawa States; and in northern Katsina State, especially in and around Kukar Jangarai Grazing Reserve.

2.1.3. Cultivated Land Estimates, 1990

Two elements of cultivation were assessed from the air: land within the cultivation cycle, i.e. predominantly or recently cultivated or fallow; and the extent of land actually being cropped. The former was assessed in the dry season, the latter in the wet, when active cultivation could be identified more accurately.

Land within the cultivation cycle was assigned to one of three broad categories:

a) parkland - cropped land studded with trees, such as the locust bean tree (*Parkia biglobosa)*, and the baobab (*Adansonia digitata)*;
b) palm parkland - cropping containing remnant or planted palm trees; and
c) open cultivation - farmland with few or no trees.

Parkland was by far the most widespread of the three, and was found throughout the country except for central and northern Borno State, on the Mambila and Jos Plateaux, and in the Niger Delta. Palm parkland was largely restricted to the southern third of the country (the Humid Zone), though outliers were found on some of the major water courses in the north. Open cultivation, although widespread, was comparatively rare, and was limited to the Jos and Mambila Plateaux, along the stretches of the Benue River, and to parts of the far north.

Some 31% of the Nigerian land area was within the cultivation cycle, 70% of which was under active cultivation during the 1990 wet season, i.e. 23% of the country as a whole.

2.1.4. Visible Water Estimates, 1990

Visible water sources (lakes, pools, rivers and large wells) were recorded during both wet and dry season aerial surveys. There was water in almost every grid cell during the wet season, with the exception of parts of northern Borno and north-western Sokoto States, where the rains had been poor and patchy.

During the dry season, water was observed in half the survey grids. In Borno, although surface water was visible in the Komadugu Gana and Yobe Rivers, water was sparse over much of the State, and some grids were more than 50 km from the nearest observed water. Bauchi, Sokoto, Kebbi, and Katsina States were also comparatively dry, with no water recorded in around 60% of the grids.

When expressed as a percentage of the land area open water accounted for approximately 1.5% of the country. It should be emphasised that this figure is likely to be well in excess of that indicated by the SLAR maps which do not show flooded areas or pools.

2.1.5. Aerial Survey Data Accuracy

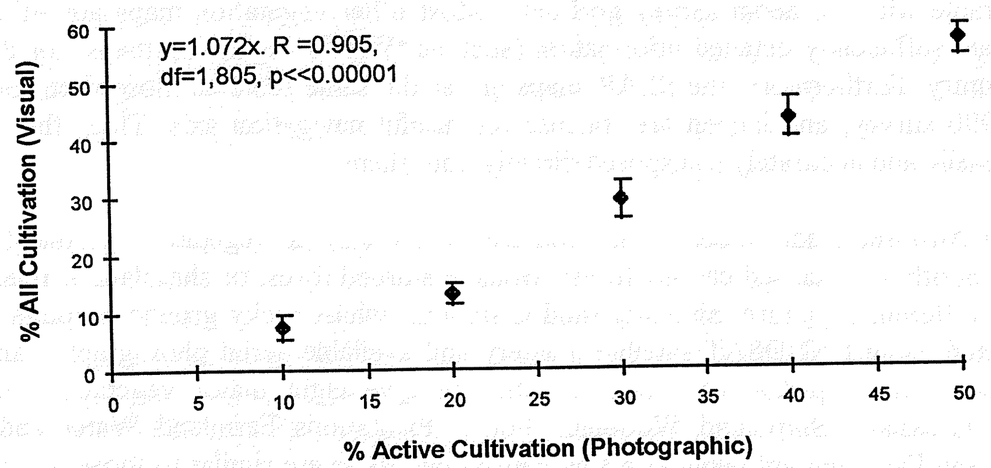
The accuracy of the visual vegetation estimates may be assessed either by comparing repeated measures of the same parameter, or by comparing the visual estimates with those derived from a different methodology.

A number of repeated visual estimates have been made by ERGO survey staff. For example, in the Bahr el Ghazal Region of Tchad, woody vegetation was assessed in 1991 at 14.3%, and in 1993 at 13.6%. In Gongola State, Nigeria, percentage grassland was estimated in 1983 and 1984 at 14% and 17%, respectively, and in Niger State, Nigeria, cultivation was estimated in 1989 and 1990 as 20 and 21%, respectively. These comparisons provide reasonable grounds for believing that these vegetation and land use parameters are sufficiently precise to be meaningful.

During the course of 1990, active cultivation in Northern Nigeria was assessed visually, and through the interpretation of aerial photographs together with concurrent LANDSAT satellite imagery. Active cultivation differs from the category 'Cultivation' shown in Table 1 above because it does not include fallow or recent cultivation.

A comparison of the results from both techniques is illustrated in the graph below. As can be seen, the mean percentages assessed are almost identical, and the regression line between the two shows a highly significant and linear correlation. This suggests, once again, that visual estimates of land use are accurate and reliable.

Figure 2: Comparison of Visual and Photographic Cultivation Estimates

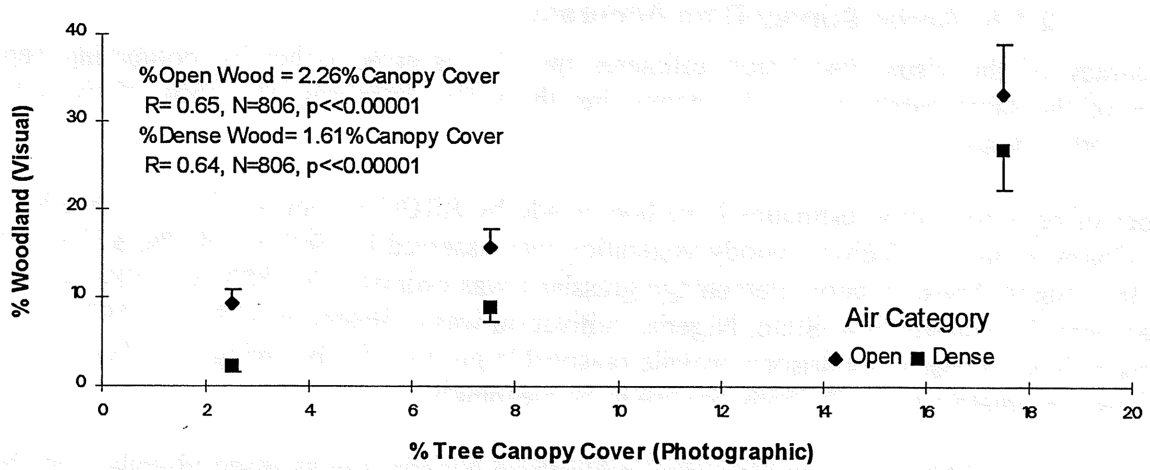


Mean %:- Visual = 32.5, SE = 1.14. Photographic = 32.05, SE = 0.47. T= - 0.72, ns

The photographic survey of 1990 also assessed the percentage tree canopy cover within each photograph. This measure differs from the percentage of open or dense woodland assessed visually, but comparison of the two sets of data can be made to ensure that there is a linear relationship between the land use categories and the canopy cover. The same comparison can also be used to calculate the average percentage canopy cover that each visual vegetation category represents.

Figure 3 demonstrates a clear linear relationship between photographic and visually assessed parameters, and the slopes of the two fitted regression lines suggest an average canopy cover of approximately 40% for open woodland, and 60% for dense woodland. Given that the visual estimates also assessed closed canopy forest and the non-wooded vegetation categories, this implies that open woodland represents 5-50% canopy cover, and dense woodland 50-95% canopy cover.

Figure 3: Comparison of Visual and Photographic Woodland Categories



2.2. The SLAR Vegetation and Land Use Maps

Side Looking Airborne Radar imagery was obtained during 1976/77. Sixty-nine maps were produced, covering the whole country, at a scale of 1:250,000, with the colour coded vegetation categories overprinted onto Joint Operations Graphics (JOG) air navigation maps showing major roads, towns and rivers.

The SLAR maps therefore represent one of the few sets of information with a high enough resolution to be comparable with the aerial survey grid data. Most other vegetation maps are either too large scale to contain sufficiently detailed information (such as White's vegetation maps), or do not cover the entire country. Furthermore, the SLAR maps are at the same scale as those used for navigation during the 1990 survey, and indeed are, themselves, useful navigation aids. Thus, the 1990 survey grids can be easily and accurately transposed directly onto them.

Side Looking Airborne Radar assesses the 'texture' of the surface vegetation, so that for example, grassland is smooth, as is closed canopy forest, whilst disturbed forest or shrubland is relatively rough and returns a different signature. Similarly sand is smooth, whilst rocky ground is rough. These data were interpreted using LANDSAT satellite imagery and available aerial photography, and extensive ground truthing over a period of several months, to give eight major vegetation and land use 'formations' - Grassland, Shrubland, Woodland, Forest, Plantations, Farmland, Water, and Mangrove. If Plantations and Farmland are taken as a single grouping, these are similar to those recorded visually by the aerial survey in 1990, and, indeed, were a major determinant of the 1990 category definitions.

Each such formation is subdivided into a number of 'sub-formations', so that the total number of categories is in excess of sixty. These are given in Table 2, below. Each category is either 'pure' or else a mosaic of different vegetation types: for example 'Farmland 30 - 60%' is a 'pure' category, whilst 'Farmland, mosaic - farmland/oil palm forest/immature forest' is a mixture of farmland, oil palm forest and immature forest.

The relative proportions of each mosaic element are unspecified, as is the composition of the non-farmland element of the pure Farmland categories. As a result, the extent of the major groupings shown in Figure 5 is likely to be misleading. For example, not all the Farmland grouping is actually cropped land. The composition of the various mosaic vegetation categories is therefore somewhat complex and is discussed in following sections.

Table 3: SLAR Vegetation and Land Use Categories

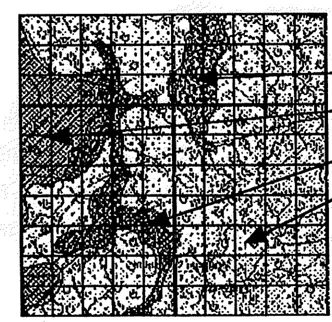
COMPLEX, GRASSLAND, shrub	GRASSLAND, aquatic grassland
COMPLEX, SHRUBLAND AND THICKET, thorny/non thorny	GRASSLAND, dry
FARMLAND	GRASSLAND, dry grassland
FARMLAND, > 60%	GRASSLAND, grassland
FARMLAND, 30- 60%	GRASSLAND, grassland with scattered trees
FARMLAND, derived savannah zone	GRASSLAND, montane
FARMLAND, forest zone	GRASSLAND, mosaic - aquatic
FARMLAND, mosaic - farmland/immature forest	GRASSLAND, mosaic - grassland/farmland
FARMLAND, mosaic - farmland/immature forest /rubber forest	GRASSLAND. mosaic - upland wooded shrub grassland /riparian forest
FARMLAND, mosaic - farmland/oil palm	GRASSLAND, shrub
FARMLAND, mosaic - farmland/oil palm forest/immature forest	GRASSLAND, shrub grassland
FARMLAND, mosaic - farmland/riparian forest	GRASSLAND, wooded shrub
FARMLAND, mosaic - farmland/rubber forest	GRASSLAND/SHRUBLAND TRANSITION, dense shrub grassland
FARMLAND, mosaic - farmland/swamp forest	MANGROVE
FARMLAND, mosaic - farmland/Wooded Shrub Grassland + patches of Woodland	PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, crop plantations
FOREST, immature	PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, forestry plantation
FOREST, mature	PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, irrigation project
FOREST, mature disturbed	PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, livestock project
FOREST, mosaic -mature disturbed/farmland/oilpalm	PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, mech farm project
FOREST, mosaic - mature disturbed/immature	PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, rainfed fm project
FOREST, mosaic - mature disturbed /oil palm/farmland	PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, shelter belt
FOREST, mosaic - oil palm /swamp	SHRUBLAND AND THICKET, non-thorny
FOREST, mosaic - swamp/rubber	SHRUBLAND AND THICKET, thorny
FOREST, mosaic - swamp/rubber/farmland	SHRUBLAND AND THICKET, thorny/non-thorny
FOREST, oil palm	STANDING WATER, lake
FOREST, raffia palm	WATER
FOREST, riparian	WOODED SHRUB GRASSLAND/WOODLAND TRANSITION
FOREST, rubber	WOODLAND
FOREST, swamp	WOODLAND, broad-leaved
GRASSLAND, aquatic	WOODLAND, broad-leaved/riparian forest
GRASSLAND, aquatic/farmland	WOODLAND, mosaic -broad leaved /riparian forest
	WOODLAND, woodland/riparian forest

3. SLAR VEGETATION CODING AND DATA PROCESSING.

3.1. Data Coding and Processing

Once the aerial survey grid had been transposed onto the SLAR maps, each cell was sub-divided into 100 sub-units, each representing 4 square kilometres. Every sub-unit was allocated to a single SLAR vegetation category (Figure 4). If more than one category was present in a sub-unit, then the sub-unit was assigned to the majority category recorded. Settlement, which on the SLAR maps was not given a vegetation type, was assigned to the vegetation category within which it fell, but was also recorded as a separate entity.

Figure 4: SLAR Coding for Grid Cell: 33 15



Slar Category	No Sub-Unit
Mosaic Farmland/Riparian Forest	5
Farmland > 60%	11
Riparian Forest	8
Wooded Shrub Grassland/Woodland Transition	76

Some of the aerial survey grid cells, such as those on international borders, or on the coast have less than 100 sub-units containing vegetation information. For these, the total number of sub-units that were actually scored was recorded, so that the category scores could be converted into percentage cover values for each grid cell.

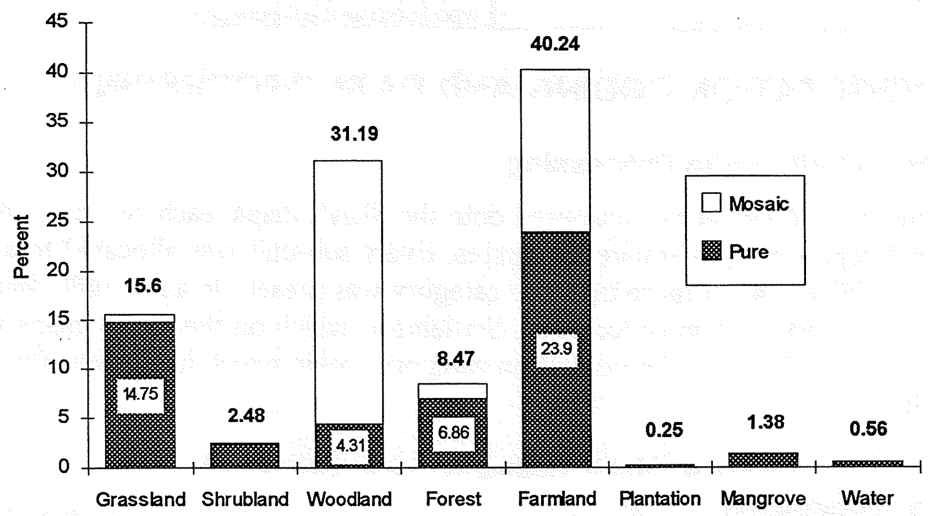
The data were entered into Excel spreadsheets, one per SLAR map. Checks were included within the spreadsheet to ensure that the total number of sub-units assigned to vegetation categories matched the number of sub-units scored. The completed data sheets were printed and compared with the original record sheets, and corrected where necessary.

The raw data were then transferred to a statistical analysis package - SPSS (Statistical Package for the Social Sciences), and the grid cell totals were rechecked. The data from each SLAR map were then added together to make a single data file containing the SLAR data for the whole country. This file contained 2280 rows, one for each aerial survey grid cell, comprising the survey grid co-ordinates, a column for each vegetation category, and the numbers of sub-units scored per grid cell. To this, the aerial survey vegetation data were matched by grid cell co-ordinates.

3.2. The Processed SLAR Data

The averages for each SLAR vegetation category are shown in Appendix Table A3.1. Figure 5 shows the extent of the eight major vegetation formations. Whilst these figures give some indication of the relative extent of the various land use types, they should not be used to calculate precise levels, as the groups are amalgamations of pure and mosaic categories. Thus each group may contain a proportion of the one or all the others. The mosaic categories are particularly significant in the Farmland and Woodland groups, as shown in the Figure.

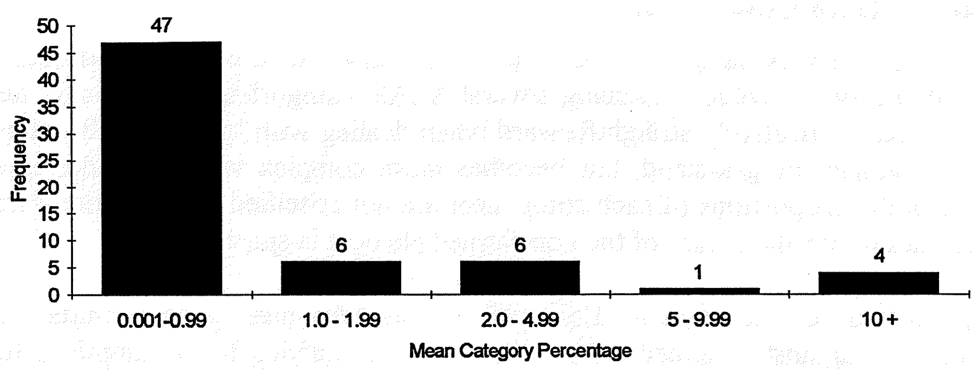
Figure 5: Extent of the Major SLAR Vegetation Groups



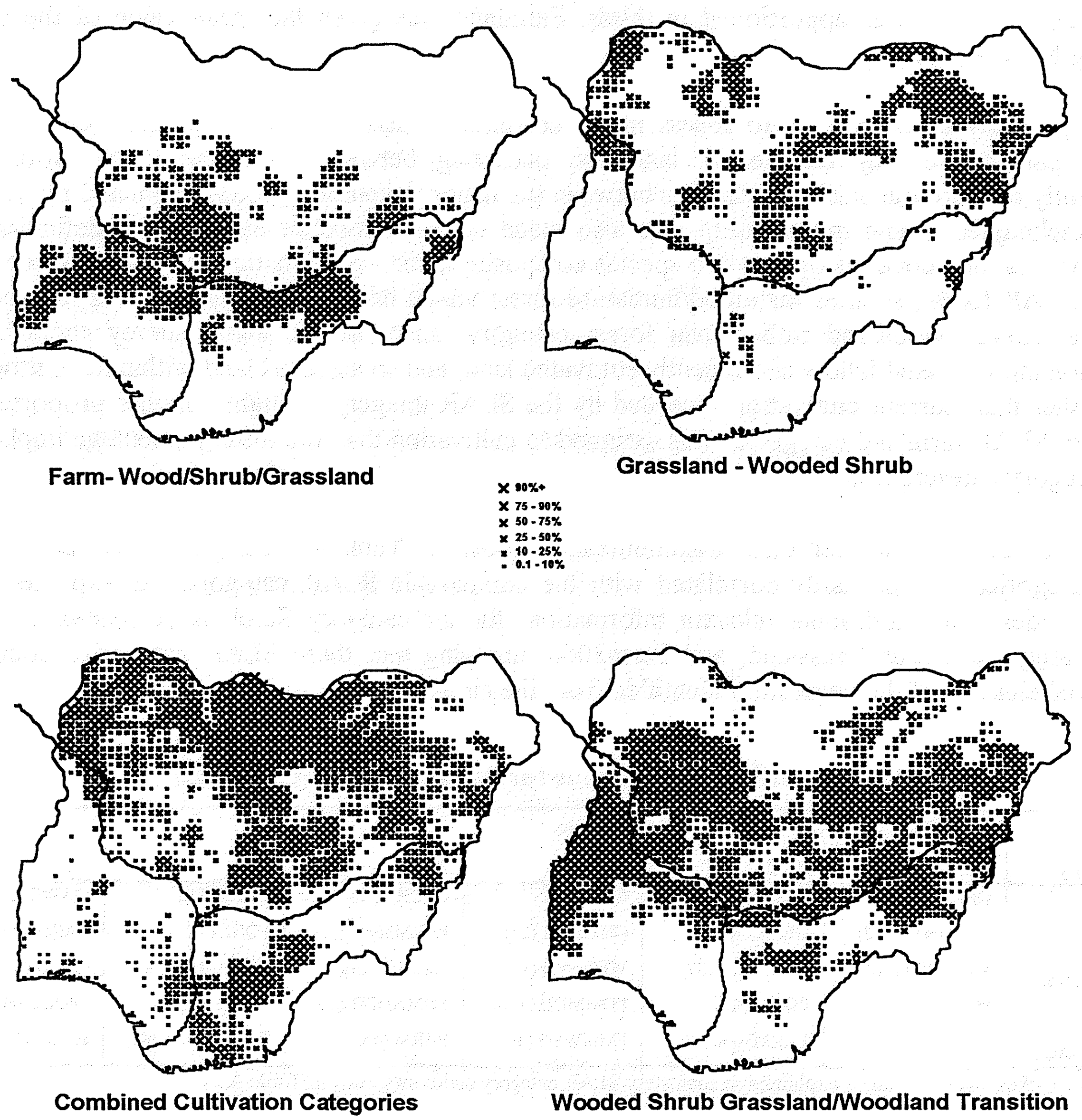
Of the 64 individual categories, most are present in small amounts, when viewed from a national perspective. Only five occupy more than 10% of the country, 11 more than 2%, and 17 more than one percent, whilst 47 cover less than one percent of the country's land area (Figure 6). However, as one percent is equivalent to 9,200 square kilometres, even these relatively small categories, if they are concentrated in a single area, are locally significant.

The four most widespread SLAR vegetation types are Wood/Shrub/Grassland-Woodland Transition (26.63%); Farmland - Wood /Shrub/Grassland Mosaic (10.41%); and the 'pure' Farmland categories (Farmland; Farmland, savannah zone; Farmland, forest zone; Farmland, 30-60%; and Farmland 60%+) which combined account for 24.18%; and Grassland with Wooded Shrub (8.73%). In 1976/77, these four categories made up 69.95% of Nigeria's land area. Their distributions are shown on Map 1.

Figure 6: Frequency Distribution of SLAR Category Mean Percentages



Map 1: Most Widespread SLAR Categories



4. DATA MATCHING AND ANALYSIS

4.1. SLAR Data Conversion

As the SLAR data comprise 64 categories, whilst the aerial survey data consist of substantially fewer, the comparison of the two involves matching several SLAR categories with a single aerial survey parameter. This process is relatively straightforward when dealing with 'pure' SLAR categories, such as broad leafed woodland, or grassland, but becomes more complex when considering the mosaic categories for which the proportions of each component are not specified, or the 'pure' farmland ones where neither the nature nor the extent of the non-farmed element is specified.

The matching process used was iterative. Essentially, it involved making some initial assumptions, examining the outcome against a defined set of criteria, then modifying the assumptions to revise the outcome so that it conformed more closely to the evaluation criteria. The initial set of assumptions used to quantify the SLAR mosaics was the simplest available - if a mosaic category consisted of two vegetation types, it was assigned to each of the parent major groups equally; if the mosaic was made up of three types, it was apportioned in thirds. Farmland was given the mean value of the stated cropping for that category.

Regression analyses were used to assess major correlates, based on the assumption that, from a national perspective, any changes in land use occurring between 1976 and 1990 would not significantly obscure the basic correlations between the major vegetation groups estimated by the two survey techniques. Some modification was also made to accommodate the different definitions of woodland - canopy cover as opposed to species composition and eco-climatic conditions. Hence open canopy SLAR forest, such as disturbed/immature forest which has an open canopy, was assigned to the aerial survey woodland rather than forest category. Also, as the aerial survey estimates of cultivation incorporated fallow and recently cultivated land, and so assessed land within the cultivation cycle rather than current cultivation recorded by the SLAR imagery, a slightly higher proportion of the 'pure' SLAR farmland categories was assigned to cultivation than the mean percentage implied by each category's description.

Multiple regression confirmed these assumptions, as shown in Table 4 which shows that each of the aerial categories was primarily correlated with the comparable SLAR categories as expected. The table provides some additional relevant information: the air category Scrub is correlated with the SLAR categories Shrub/Grassland, and Farm3060, implying that these SLAR categories contain a substantial element of the vegetation identified from the air as Scrub.

Table 4: Multiple Regressions for Air and SLAR Categories

Air Category	SLAR Category Positive Correlates 1st	2nd	3rd	4th	5th	6th
Grass	GRMON (12)	GRDRGR (21)	GRAQ (28)	GRSHGR (34)	GRSH (39)	GRWDSH (43)
Scrub	SHTHNTH (12)	GRSH (18)	GRWDSH (24)	FARM3060 (27)	FORAF (28)	FARM60 (28)
Woodland	WSGWDTR (25)	FMMWSG (37)	WDBLVD (41)	FMMIFO (43)	FMMIRBFO(45)	GRWDSH (46)
Forest	FOMAT (23)	FOSW (42)	FOMMDIM (54)	FOMADIST (59)	FMMIFO (60)	GRMUWSRF (61)
Cultivation	FARM60 (33)	FARM3060 (42)	FMMWSG (44)	FARM (45)	FARMSAVZ (47)	PLIR (47)

Figures in Brackets are % variance explained at each step. SLAR category codes as shown in Table A3.1.

The reverse regressions can be used to identify the aerial categories most closely associated with unspecified SLAR vegetation types, which may pinpoint the composition of the non-farmed element of the 'pure' SLAR farmland types. The results suggest that this should be assigned, in decreasing significance to Scrub, Woodland and Grass. Table A3.2 shows the conversion factors used.

4.2. Estimation of Land Use Change

Using the conversion factors given in Table A3.2, the calculated mean percentages for the SLAR categories concatenated into the five aerial survey vegetation categories are as follows:

Table 5: Amalgamated SLAR Vegetation Percentages

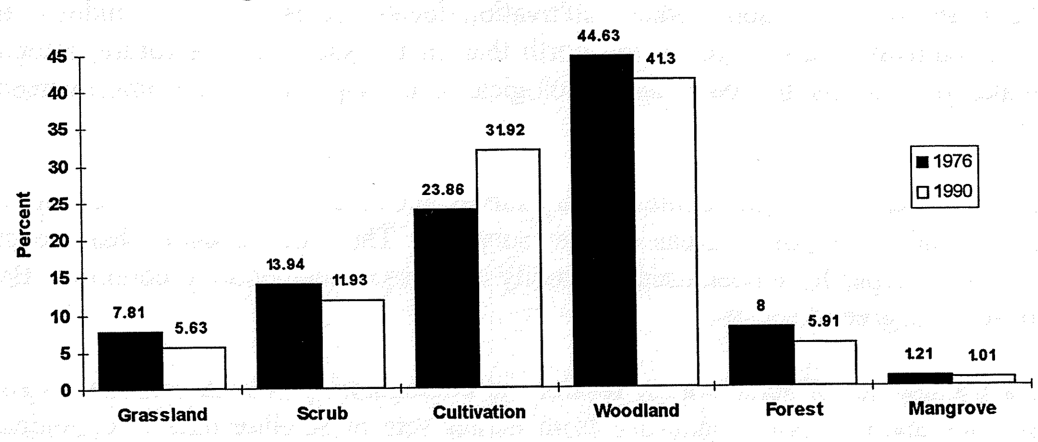
Amalgamated SLAR Category	SPSS Name	Mean%	SE	Max.%
Forest Plantation	ALLPLFO	1.18	0.05	98.00
Active or Recent Cultivation*	ALLFARM	23.86	0.19	80.00
Grassland	ALLGRASS	7.81	0.09	99.44
Scrub	ALLSCRUB	13.94	0.11	100.00
Woodland	ALWOOD	44.63	0.22	100.00
Mangrove	MAN	1.01	0.05	98.00
Forest	ALFOREST	8.00	0.14	100.00
Open Water	ALLWATER	0.55	0.03	65.00

*Includes Plantations and Projects

Table 6: Aerial Survey Vegetation Cover

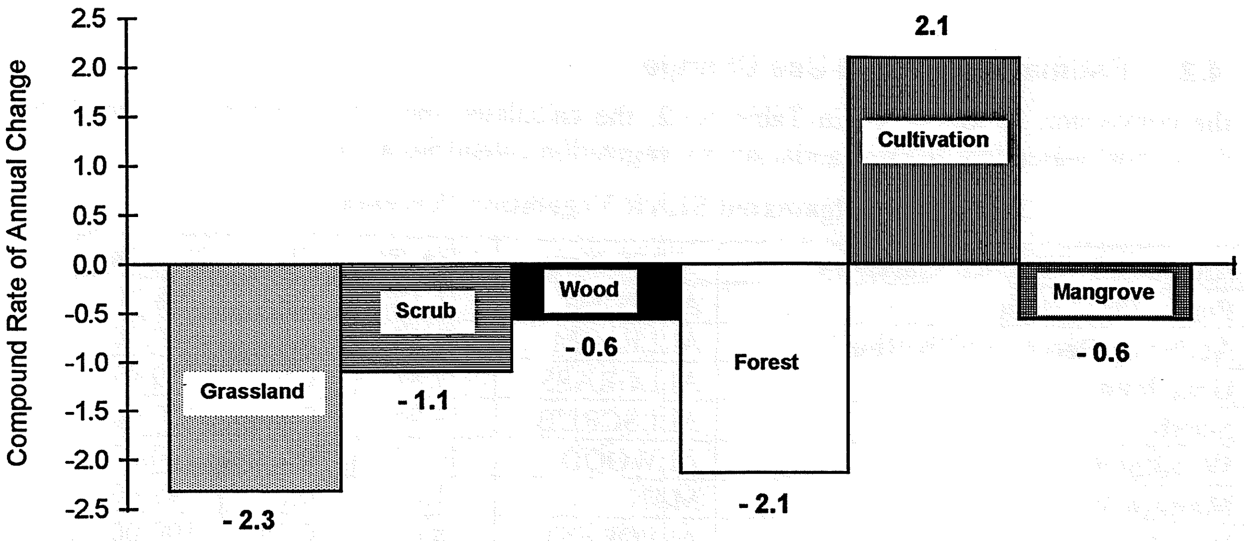
Aerial Survey Category	SPSS Name	Mean%	SE	Max.%
Active or Recent Cultivation	ALLCULT	31.92	0.32	98.00
Grassland	AIRGRASS	5.63	0.13	92.00
Scrub	ALLSCRUB	11.93	0.20	92.67
Woodland	ALLWOOD	41.30	0.37	100.00
Mangrove	MANG	1.01	0.05	97.00
Forest	ALLFOR	5.91	0.17	100.00
Open Water	OPENWAT	1.49	0.03	80.00

Figure 7: Percentage Vegetation, 1976/1990



When compared with the means for the aerial survey categories shown in Table 6, above, the land use changes can be calculated. The results, illustrated in Figure 7, show a rise of 7.46% in cultivation levels, at the expense of all other land use categories. This represents an increase of approximately 30% from the 1976/77 baseline figure and corresponds to a compound increment of 2.1% per year (Figure 8) - close to that estimated for the country's human population growth rate.

Figure 8: Compound Annual Rate of Change in Percentage Vegetation, 1976 - 1990



As specified in the proposal (Appendix 1), an alternative technique using satellite imagery to estimate land use change was investigated for the period 1981-1991. This technique is still being developed. The results of these analyses are summarised below, whilst details of methods and procedures are described in detail in Appendix 2.

At this stage in its development it seems clear that satellite imagery may be used to classify vegetation type into the broad categories used here, given a suitable 'training set' of data. A comparison of the present set of aerial survey data and the predictions derived from satellite imagery shows a good correspondence for all vegetation types except cultivation, which is predicted with some degree of accuracy in some areas, but not in others.

One of the reasons for this is that cultivated land shows the characteristics of many different vegetation types during the agricultural growing period (e.g. from bare ground to shrub type vegetation); another reason is that the type of crop being grown differs from one region to the other. Predictions based on an analysis of cultivation throughout the country will be dominated by those areas in the north of the country where cultivation levels are highest and, indeed, the current descriptions of cultivation are better in the north than in the south. In the future, attempts will be made to make predictions for each agro-ecological zone separately, and improvements can be expected.

Progress has also been made using contemporary survey and satellite data to predict from the satellite data alone the land-use types in areas not yet surveyed. Thus, the satellite characteristics of the Nigerian vegetation types have been used to classify land-use in neighbouring countries: Benin, Togo, Ghana, with some degree of success.

The use of a training set of aerial survey results and contemporary NOAA satellite AVHRR data to make predictions about previous land-use from earlier sets of satellite data is complicated by the average changes in the vegetation index (recorded by the satellite) caused by annual variation in rainfall (and, to a lesser extent, by changes in sensor and orbital characteristics). To date, it has only been possible to assess the extent of this problem (for details see Appendix 2) but not yet to overcome it. Nevertheless it should eventually be possible to allow for inter-annual variation in the mean satellite characteristics of each vegetation type, and so to use satellite data to monitor and quantify rates of vegetation and land-use change.

4.3. Settlement and Water

Settlement was estimated at 293,440 hectares in 1976, as opposed to 748,275 hectares, or more than two and a half times as much in 1990. This change implies an annual compounded rise of 6.9%.

The estimated means for the amount of water in 1976 and 1990 are 0.55% and 1.49% respectively, which suggests an increase over the fifteen year interval of slightly less than 1%. This figure is, however, likely to be misleading as the later estimate includes pools and flooded areas which were not distinguished by the radar imagery.

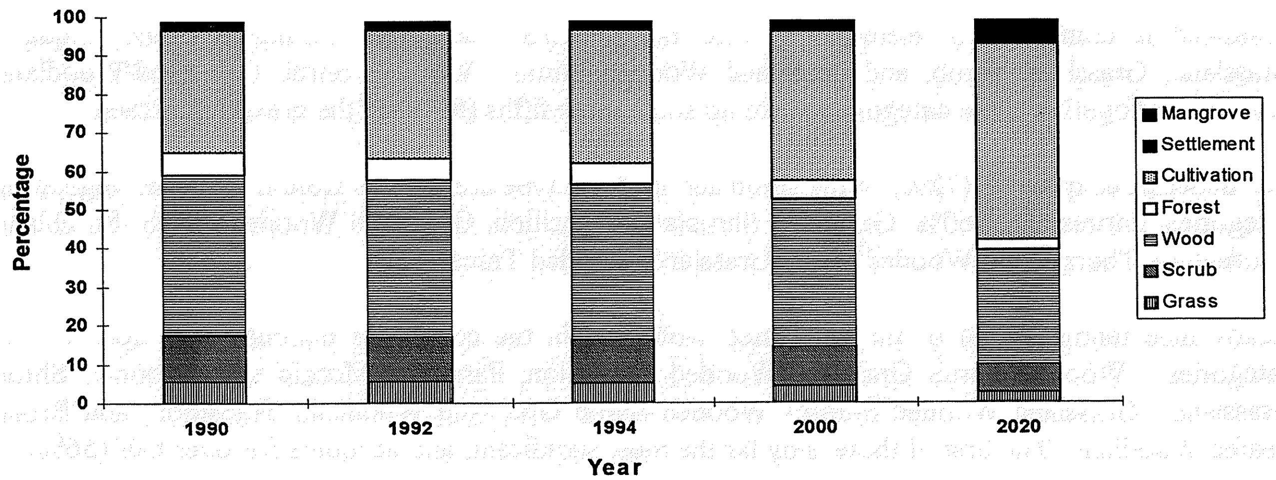
4.4. Projections

Based on the calculated compound rates of change, estimated land use percentages can be calculated for the present (1994) and future years. See Table 7 and Figure 9. These projections have been made assuming that the percentage of water remains constant at the 1990 level, and indicate that by the year 2020, just over half the country will be cultivated, rather less than a third will be covered by woodland, and settlement is likely to cover almost 5% of the land area. The more open land use types, as well as the forest and mangrove categories will become increasingly scarce.

Table 7: Projected Land Use Percentages

	1990	1992	1994	2000	2020
Grassland	5.63	5.36	5.10	4.38	2.37
Scrub	11.93	11.64	11.34	10.02	7.27
Woodland	41.3	40.75	40.16	38.36	29.75
Forest	5.91	5.65	5.39	4.67	2.63
Cultivation	31.92	33.20	34.49	38.58	50.65
Mangrove	1.01	1.00	0.98	0.94	0.73
Settlement	0.81	0.92	1.05	1.55	5.12

Figure 9: Projected Land Use Percentages



5. INTERPRETATION OF LAND USE CHANGE ESTIMATES

The rates of land use change estimated above require further careful interpretation to assess their effect on overall carbon balance. Two relevant sets of information are available. The first is the species composition data contained in the SLAR maps, which may be extracted for those SLAR categories contributing most significantly to the calculated land use types. The second is the wood volume estimates available from the 1990 survey of woody vegetation cover of northern Nigeria (RIM, 1991), which may be used as a basis for calculating standing woody biomass, providing that suitable conversion tables can be found.

5.1. Composition of the Amalgamated Land Use Types

A first step in the assessment of species composition of the various land use types is to establish which of the SLAR vegetation categories contribute most to each one. Table A3.3 shows the percentages of the various individual SLAR categories within the amalgamated land use types used for the land use change estimates. From these the most significant SLAR vegetation categories can be extracted for each major land use type, as summarised in Table 8, and the species composition ascertained in due course.

Table 8: SLAR Categories with Major Contributions to Amalgamated Land Use Types

	Amalgamated Land Use Category				
SLAR Category	Cultivation	Grassland	Shrubland	Woodland	Forest
Grassland Aquatic		13.8			
Grassland Shrub		14.2			
Grassland Wooded Shrub		16.8	20.7	10.0	
Grassland Wooded Shrub - Wooded Shrub Grassland Woodland Transition			9.1		
Grassland/Shrubland Transition, Dense shrub Grassland			9.1		
Shrubland Thorny/Non Thorny			15.2		
Farmland 30 - 60 %	22.8	14.2	17.6		
Farmland >60 %	39.2				
Farmland Mosaic with Wooded Shrub Grassland	16.1			11.9	
Wooded Shrub Grassland Woodland Transition				56.1	
Broad Leafed Woodland				9.2	
Mature Forest					13.5
Oil Palm Forest					10.1
Riparian Forest					13.4
Swamp Forest					30.1
Total % Contribution	78.1	59.0	71.7	87.2	67.1
National % Cover 1976	23.86	7.81	13.94	44.63	8.00

The major component SLAR categories of cultivation (including Plantations) are Farmland 30 - 60%, Farmland > 60%, and Farmland Mosaic with Wooded Shrub Grassland, which together account for approximately four fifths (78%) of the calculated total.

Grassland is comprised of elements of four major SLAR categories: Farmland >60%, Aquatic Grassland, Grassland Shrub, and Grassland Wooded Shrub - Wooded Shrub Grassland/Woodland Transition. Together these categories make up some three fifths (59%) of the grassland present.

Just under three quarters (72%) of the shrubland land use type are derived from five SLAR vegetation categories: Farmland 30-60%, Grassland Shrubland Transition, Grassland Wooded Shrub, Shrubland Thorny/non Thorny, and Wooded Shrub Grassland/Wooded Transition.

Nearly nine tenths (87%) of the calculated woodland in the country is matched with four SLAR categories - Wooded Shrub Grassland/Wooded Transition, Farmland Mosaic with Wooded Shrub Grassland , Grassland Wooded Shrub - Wooded Shrub Grassland Woodland Transition, and Broad Leafed Woodland. The first of these is by far the most significant, and accounts for over half (56%) of the total.

Four SLAR categories - Mature Forest, Oil Palm Forest, Riparian Forest, and Swamp Forest - together make up over two thirds of the Forest and se type, the last accounting for about a third (30%) of the total.

The three most substantial elements of the calculated Forest Plantation category are all mosaics containing significant proportions of rubber. They account for 83% of the total, which is equivalent to 1% of the land surface. These outweigh the species specific plantations which, in 1976, made up 9.7% of the total vegetation type, or 0.17% of the country's area.

5.2. Wood Volumes of the Major Vegetation Categories

5.2.1. Amalgamated Land Use Types

Using the results from the 1990 Wood Volume survey for northern Nigeria (RIM, 1991), it is possible to provide an indication of the standing wood volumes for four of the five major vegetation types, the exception being Forest, which is not present in sufficient quantity in the north to allow for the relevant calculations. These figures are derived from the relationship between the extent of each vegetation type in each grid, and the wood volume present in that grid, as described by the equations shown in Table 9. These equations can then be used to derive wood volume figures assuming total cover of each vegetation type.

Table 9: Wood Volume Estimates for Vegetation Types, Northern Nigeria

Vegetation Type	Equation* y = wood volume x = % vegetation type	Wood Volume cubic metres / hectare
Grassland	$y = 12.02\ (0.988^{x})$	3.45
Scrub	$y = 12.564\ (0.9921^{x})$	5.68
Woodland:		
Open	$y = 10.425 + 0.9x$	19.43
Dense	$y = 9.5469e^{(0.0123x)}$	32.66
All	$y = 8.6116e^{(0.0088x)}$	20.76
Cultivation	$y=11.635 + 0.013/x$	11.64

* All statistically significant to $p < 0.0000$

It is emphasised that the figures in Table 9 do not take into account shrubs, assume a correspondence between the 1990 and 1976 data and will be relevant only to the northern third of the country, However, some additional information may be extracted if the values for woodland are split into two categories: Open and Dense; and the latter used for the central and southern regions.

5.2.2. SLAR Vegetation Categories

In similar fashion to that just discussed for the amalgamated land use types, wood volumes can be calculated for those SLAR categories that are their major components, as shown in Table 10, below. Again, it must be emphasised that these values can only be used directly for the north of the country, do not include any wood volume attributable to shrubs, and that the calculations assume a continuing correspondence between the 1990 and 1976 distributions.

Table 10: Wood Volume Estimates for SLAR Vegetation Categories, Northern Nigeria

SLAR Category	Equation*	Wood Volume m^3/ha
Grassland, Aquatic	$y = 10.735e^{(-.0113x)}$	3.47
Grassland, Shrub	$y = 11.087e^{(-0.0077x)}$	5.13
Grassland, Wooded Shrub	$y = 11.63 + 0.072x - 0.001x^2$	8.82
Farmland 30-60%	$y = 11.952 + 0.022x - 0.0006x^2$	8.13
Farmland >60%	$y = 12.315 - 0.0204x$	10.28
Farmland Mosaic/Wooded Shrub Grassland	$y = e^{(2.704 - 0.0004/x)}$	14.93
Wooded Shrub Grassland/Woodland Transition	$y = 9.1674 + 0.211x - 0.0008x^2$	22.23
Broad Leafed Woodland	$y = 17.531 + 0.9094\ln(x)$	21.02

* All statistically significant to $p < 0.0000$. y = wood volume x = % vegetation type

6. RECOMMENDATIONS FOR FURTHER STUDY

6.1. Future Environmental Monitoring

Nigeria is a large and populous country with a wide range of environments. The impact of human population growth and agricultural expansion is transforming patterns of vegetation and land use throughout the country. This study has clearly demonstrated the scale of changes that have taken place at the macro level during the period 1976-90. Nationally, cultivation has increased at a rate of some 2% per annum, with commensurate reduction in the extent of forest, woodland, scrubland and grassland.

With the constraints of time and information available, it has not been possible to provide a detailed account of local changes in vegetation and land use within specific regions or zones. That was not the intention of this particular study. However, it is apparent that the patterns of vegetation and land use have not changed uniformly across the country. Some areas, such as parts of the central Middle Belt, have experiencing relatively rapid rates of agricultural expansion, as they have been opened up by growth of the road network, whilst in remoter, more inaccessible regions vegetation and land use patterns have remained virtually unchanged.

In the establishment of a national environmental monitoring system, some way of representing the country's ecological diversity and wide range of agro-climatic conditions must be found. Rates of change will vary from area to area according to circumstance, and priorities for monitoring and protection will differ from place to place. What is of major cause for concern in one area, may be of little consequence elsewhere.

The importance of up-to-date and reliable cartographic information for development planning, resource assessment and environmental monitoring cannot be overemphasised. Most maps published by the Federal Survey Department are based on photographic coverage obtained 20-30 years ago. A comprehensive revision of Nigerian cartography is now long overdue, and a recently approved project to produce new vegetation and land use maps of the country should make a significant contribution in this regard.

As far as the prospects for monitoring future vegetation and land use change in Nigeria are concerned, there are two approaches to be considered, one which looks at the "big picture" and provides a general National perspective, and the other which takes a more detailed view of representative parts of the country. The two approaches are complementary and not mutually exclusive, and there is considerable advantage to be gained from the adoption of both, and running the two lines of enquiry in parallel.

For a regular general overview, the daily, one kilometre resolution coverage of the NOAA series of satellites, operated by the American National Oceanographic and Atmospheric Administration is readily available and widely used. The Advanced Very High Resolution Radiometer (AVHRR) Normalised Difference Vegetation Index (NDVI) has become a standard measure for monitoring seasonal change and annual differences in vegetation cover.

For more detailed monitoring studies of specific areas, the higher resolution but less frequent coverage of LANDSAT, SPOT or Russian satellites is more appropriate. A variety of products are available with resolutions down to a few meters. With such detailed imagery, many scenes are required to cover the whole country, and it is therefore impractical to monitor very large areas on a regular basis. An obvious solution is to stratify the country into its four major agro-ecological zones: Arid, Semi-Arid, Sub-Humid and Humid, and select a sub-set of scenes within each as a representative sample, weighted to reflect land area occupied.

6.2. Development of Methodologies

"Remote sensing is not a panacea for resource development and management problems. However, it can provide the data which are the basic tools for sound resource inventorying , monitoring and management" (Bale et al., 1974; quoted by Prince, Justice and Los, 1990).

Some of the techniques outlined in this report have obvious potential for long term monitoring of vegetation and land use change, and assessment of plant biomass. In particular, attention is drawn to the use of time series NOAA AVHRR data, which shows great promise (Rogers and Williams, 1994), and is described in Appendix 2 of this report. Further research and development work is still required to establish characteristic profiles for specific land cover types. Interpretation will be much improved when more up to date vegetation and land use maps of Nigeria become available, and can be used for calibration purposes.

This raises an issue of fundamental importance to remote sensing applications, but one which is often overlooked. Namely, that the reliability of satellite imagery interpretation depends on the quality and reliability of available ground truth information. Validation studies are an essential component of any remote sensing exercise. Without adequate ground truth, interpretation is uncertain and prone to error. Validation studies can take many forms: on the ground, or in the air; by visual observation, photography or video; by spot, quadrat or transect sample; to mention but a few. What is important is that accurate and up to date information is obtained to ensure reliable interpretation.

With regard to the assessment of woody vegetation cover and wood volume assessment for northern Nigeria (RIM, 1991), referred to in the previous section, extensive validatory field work was carried out both from the air and on the ground during 1990. However, this study was restricted to northern arid and semi-arid zones. Further investigations are therefore required to establish zonal crown canopy/wood volume/plant biomass relationships for the Sub-humid and Humid zones.

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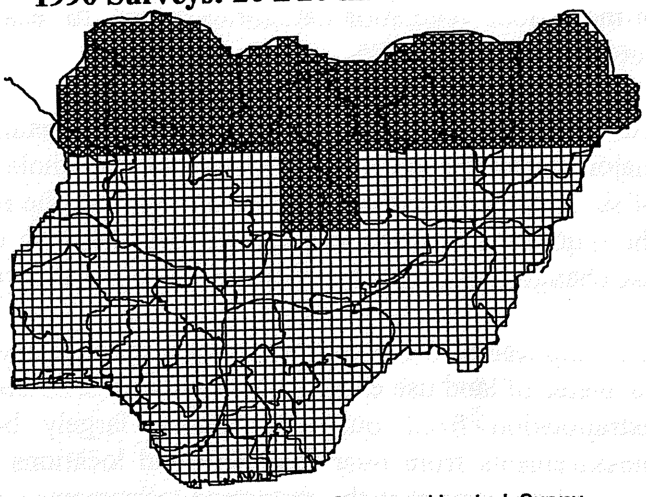
APPENDIX 1: PROPOSAL FOR EVALUATING LAND USE CHANGE IN NIGERIA.

This proposal is submitted in response to a series of discussions with Gerald Leach, Stockholm Environment Institute. As part of a greenhouse gas emissions study in Nigeria, an estimation of the current rate of vegetation and land use change is required. Such estimation demands that two sets of land use estimates covering the whole country be compared, and an annual rate of change calculated.

ERGO is a company specialising in agricultural and environmental resource assessment. During the early 1990s, its staff completed two World Bank assisted projects for the Federal Government which are of particular relevance to this proposal: the Nigerian National Livestock Survey, (RIM, 1992), and a Woody Vegetation and Wood Volume assessment of northern Nigeria (RIM, 1991). The field work for both studies was carried out during 1990, and was based on the division of the survey areas into a lattice of 20 x 20 km grid cells. Estimates of the requisite parameters were made for each cell within the two survey zones (See Diagram opposite).

1990 Surveys: 20 x 20 km Grid Cells



Crosses - Wood Volume Survey (RIM, 1991) Squares - Livestock Survey (RIM, 1992)

The National Livestock Survey, whilst primarily concerned with the provision of population estimates for approximately twenty livestock species, via complementary aerial and ground survey techniques, included direct visual assessments from the air of the extent of the major vegetation and land use categories in each of the 2,280 component grid cells. The Wood Volume survey, through a combination of aerial photography, the interpretation of contemporary satellite imagery and extensive ground truthing, provided estimates of standing wood volumes in each of these cells in the northern third of the country. Despite extensive searches, ERGO is unaware of any data sets, of either land use, vegetation, wood volumes, or livestock in Nigeria which are as up-to-date, objective, or complete.

Comprehensive, quantifiable and accessible sources of earlier land use data are also scarce. One which does, however, meet these criteria is the set of Side Looking Airborne Radar (SLAR) Vegetation and Land Use maps produced for the Nigerian Federal Department of Forestry in 1975, which show the national distribution of more than thirty vegetation types at a scale of 1:250,000.

Because both the 1990 and 1975 vegetation data sets are geographically based it is possible to measure the extent of each vegetation category from the 1975 SLAR maps in a form that is compatible with the 1990 estimates, thereby allowing a calculation of the change in the extent of major land use categories between 1975 and 1990, for the whole country.

Some refinement of this basic comparison may be possible. One component of the 1990 wood volume survey was the revision of the boundaries of the 1975 SLAR vegetation categories, using LANDSAT imagery. Thus, as well as making a direct comparison between the 1990 and 1975 vegetation data, it may be feasible to use the 'updated' SLAR boundaries to evaluate more precisely the correspondence between the various vegetation categories estimated during 1990 and the SLAR vegetation categories. If successful, this would permit a more precise estimation of any land use changes based on contrasts between the 1990 and 1975 data.

In any assessment of temporal trends, it is desirable to have information from more than two periods - data from intermediate points in time may confirm apparent trends, or identify them as curvilinear or cyclic, rather than merely linear. Research currently in its initial stages at the Department of Zoology, Oxford University (Rogers and Williams, in press), suggests close links between the 1990 assessments of vegetation cover and the annual amplitude and seasonality of vegetation indices extracted from 8 km resolution satellite imagery from 1987-1989. By quantifying these links, and then comparing the calibrated 1989 imagery with scenes from the early eighties, it may be possible to estimate the extent of the various vegetation categories during, for example, 1982 or 1983, thus providing a datum point between 1990 and 1975.

The approach outlined above integrates three distinct sources of data which estimate the extent of the major vegetation and land use types over the whole of Nigeria. Preliminary trials indicate that a period of six man-weeks will be sufficient to extract the relevant data from the 1975 SLAR maps, evaluate the required calibration procedures and make the comparisons needed to produce estimates of land use changes for the period between 1975 and 1990 (see attached Table).

It is emphasised that the proposed analyses are new. The basic 1990/1975 comparisons will produce estimates of land use change that are likely to be considerably more reliable than projections based on extrapolation from outdated figures, largely because they will be founded on independent measurements from over two thousand locations within Nigeria. However, until they are tried, it cannot be certain that the suggested refinements using satellite imagery will add to the precision and accuracy of any trend identified.

Nevertheless, the incremental cost of these calibrations and additional analyses is small, and the potential benefits substantial. If successful, these new techniques will allow the estimation of land use changes in areas for which reliable baseline calibration data of the kind available for Nigeria is not obtainable.

Once the rates of vegetation and land use change have been calculated, there remains the problem of interpreting the results in terms of biomass so that the amount of carbon held in the vegetation. This process would require the identification of conversion factors for each vegetation and land use type. It is possible that a search of the archives of the Oxford Forestry Institute, the largest forestry library in Europe, would yield the requisite information. Though not envisaged as part of the present proposal, such a search could be made in due course, if deemed appropriate.

APPENDIX 2: FOURIER ANALYSIS OF NOAA IMAGERY

1. BACKGROUND

In any assessment of temporal trends, it is desirable to have information from more than two data points. Data from intermediate points in time may confirm apparent trends, or identify them as curvilinear or cyclic, rather than merely linear. Research currently in its initial stages at the Department of Zoology, Oxford University (Rogers and Williams, 1994), suggests close links between the 1990 aerial survey assessments of vegetation cover and vegetation indices derived from 1987-1989 Advanced Very High Resolution Radiometer (AVHRR) imagery obtained by the National Oceanographic and Atmospheric Agency (NOAA) series of meteorological satellites.

The AVHRR measures the amount of radiation reflected from the Earth's surface at several different wavelengths. The data used here take the form of Normalised Difference Vegetation Indices (NDVI), which are ratios of the visible and near infra-red reflectances, and have been shown to be positively correlated with the levels of photosynthetic activity of surface vegetation. NDVI data are available for the whole of Africa for each 10 day period from late 1981 to mid 1991, at a spatial resolution of eight kilometres - i.e. for 8 km squares covering the whole continent. Given these data, it is possible to derive a mean NDVI for any specified period for any specified area. Thus NDVI figures for each aerial survey grid square in Nigeria can be calculated.

The results presented in this Appendix first quantify the observed links between the 1987-1989 AVHRR data and the 1990 aerial survey data. This process provides a calibration of the satellite imagery. The second step of the analysis compares the 1987/89 imagery with scenes from the early eighties. Providing the links between the two recent data sets are strong enough, and that there has been no major change in the NDVIs characteristic of each vegetation type between years, it is possible to estimate the extent of the various vegetation categories during that period, thus providing a datum point for land use percentages between 1990 and 1976.

It is emphasised that this analysis is exploratory. The techniques used are still being refined and developed, and are yet to be exhaustively tested. However, given that the initial results are encouraging, it suggests that there is significant potential for further development of the use of AVHRR data in the estimation of land use change in any areas for which the satellite data is, or will become available. The advantage of such techniques is clear - AVHRR satellite data are being acquired on a regular basis for the whole planet. Their use would streamline land use change assessment, and reduce the need for the extensive (and expensive) data collection exercises that are otherwise required for this type of work.

2. ANALYSIS AND INTERPRETATION OF THE NOAA DATA

To date, many of the vegetation assessments using NDVI data have relied on looking at the indices themselves, their means, maxima and minima. A series of NDVI measurements is now available over time, however, and these data allow several types of additional information to be extracted. Extensive work has been done in this area, using statistical reductions of time series, which have generally relied on principal component analysis or maximum likelihood classifications. The results of such studies are often rather difficult to relate to recognisable biological phenomena, such as seasonality and degree of inter- and intra-annual variation in vegetation cover, since the methods assume no auto-correlation between the values of the NDVI for any one place through time

An NDVI can be imagined to provide a continuous record through time of vegetation activity which is the product of cyclical events in weather and climate repeated over time-scales from days to centuries.

Obviously, in many areas, the annual cycle of rainfall is a major determinant of vegetation activity, but biannual and tri-annual cycles, especially in equatorial regions, are also expected to play an important rôle.

The strength and timing of each of these cycles can be revealed by time-series analysis using Fourier techniques. These are commonly employed to look for cyclical phenomena in otherwise noisy data such as long-term meteorological records, but are also useful for revealing the cycle characteristics of data that have obvious periodicities, such as NDVIs. Fourier analysis, applied to monthly NDVI records, provides an estimate of both the amplitude (i.e. the strength) and the phase (i.e. the timing) of annual, bi-annual, tri-annual and more frequent cycles that combine to determine the NDVI signal, and these characteristics of the NDVIs may be used to classify vegetation type using discriminant analysis.

An example of 3 years' of NDVI data from a site near Abuja, Nigeria, is shown in Fig. A 2.1 (the thin line). Fourier analysis breaks down this signal into its annual, bi-annual and tri-annual components and these are shown in Fig. A2.2 (there are also higher frequencies but these tend to be insignificant). It can be seen that the signals differ in their amplitudes and in the months in the year at which they reach their maxima. If the three components shown in Fig. A2.2 are added together, the result is as shown by the thick line in Fig. A2.1, which is a reasonable description of the NDVI signal.

Figure A2.1: Fourier Composite and Observed NDVI, Abuja, Nigeria

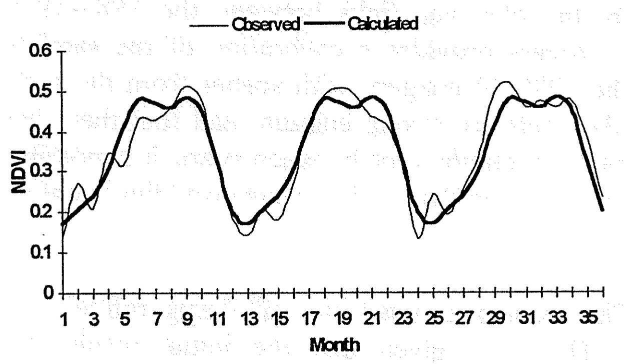
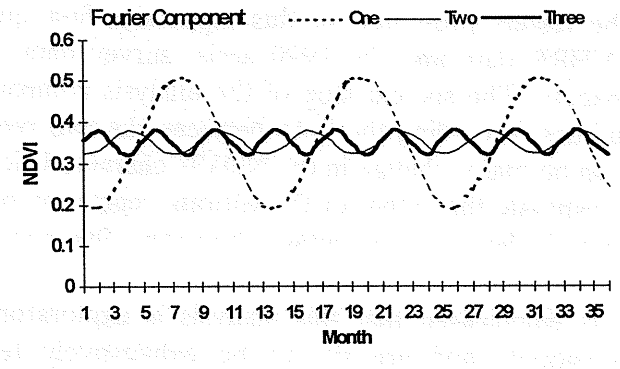


Figure A2.2: Fourier Component NDVIs, Abuja



Fourier analysis has thus achieved a considerable degree of data reduction (the 36 monthly values were reduced to 7 variables, a mean and the amplitude and phase of the first three Fourier components), whilst extracting biologically useful information from the data set. In practice, both the amplitudes and phases of each of the three components appear to be useful if classifying vegetation type (and, in turn, the distribution of pests such as tsetse flies and diseases such as trypanosomiasis).

2.1. Comparison of Recent Data

The first step in evaluating the results of the Fourier analyses is the comparison of its prediction of the extent of the different land use types, using AVHRR data from 1987-1990, with the 1990 aerial survey data extrapolated to 1988 on the basis of calculated rates of change in percentage vegetation cover. This is summarised in Table A2.1 and Figure A2.3, and demonstrates a highly significant match between the two sets of information. This shows that the Fourier analysis can be used with some confidence to extract the extent of the various land use types in general terms. Some of the categories are less accurately predicted, however, - particularly cultivation, which Fourier analysis substantially underestimates. This is most probably because farmland, especially in the south of the country, returns a similar NDVI signature to natural background vegetation, and is thus difficult to differentiate from it.

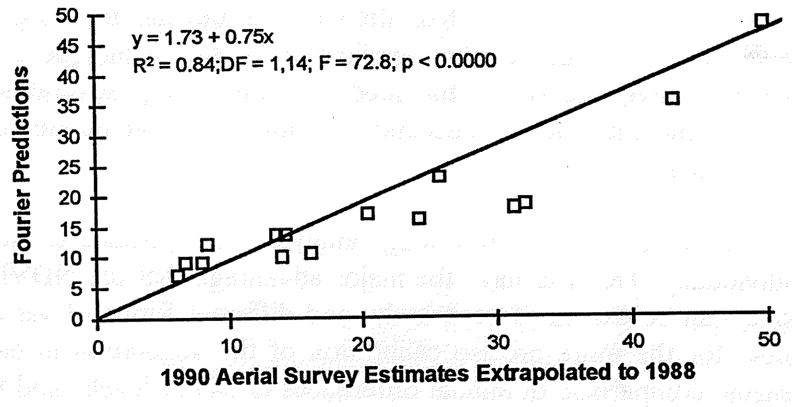
It is envisaged that this stage of the analysis will be refined further - most notably by treating the various vegetation types within the different ecological zones separately. This may well enhance the precision of the calibrations, and allow for the more accurate estimations of land use cover.

Table A2.1: Comparison of Fourier and Aerial Survey Vegetation %, 1988

Vegetation %	Air	Fourier
Grass	6.09	7.29
Scrub	13.47	13.63
Active Cultivation	24.17	16.17
All Cultivation	31.37	17.91
Parkland	16.02	10.68
Open Wood	20.41	17.02
Dense Wood	25.79	23.05
All Wood	43.06	35.42
Forest +Wood	49.79	47.99
Closed Canopy Forest	8.34	12.10
All Forest	6.59	9.16
AirGrass*	7.88	9.17
AirCultivation*	32.18	18.32
AirScrub*	14.07	13.83

* Includes Bare Ground

Figure A2.3: Comparison of Fourier and Aerial Survey Estimation of % Land Use, 1988



The close concordance between the aerial survey data and the Fourier transforms of the AVHRR figures suggest that the satellite derived information may be sufficiently accurate to make a comparison between two separate years. This will only be valid if the relationship between visual and remotely sensed data, and the characteristics of the satellite remain constant from year to year. Neither is likely to be the case. Mean annual rainfall - and so mean NDVI values - vary each year. Also, satellites deviate slightly from their nominal trajectories, and their sensors deteriorate, and despite the calibrations routinely performed to compensate for these changes, small variations in the data extracted are likely. Nevertheless, given the promising results described above, NDVIs separated by several years were examined in order to assess the degree to which these variations affected the process of extrapolation. The results are presented in the following section.

2.2. Comparison of 1987/89 and 1982/83 Satellite Data

Table A2.2 shows the Fourier estimates of vegetation cover for 1982/83 and 1987/89, using the calibration between the aerial survey and most recent AVHRR data. The implied rates of change are at variance with those presented in the main report, as they suggest that cropping has fallen, and that most natural vegetation types, and in particular, woodland, have increased during the eighties. This contradicts available evidence, and demonstrates that the calculated 1987/89 calibration factors cannot be applied directly to the 1982/83 data.

Table A2.2: Comparison of Fourier Vegetation %, 1982/83 and 1987/89

Vegetation %	1982/83	1987/89	Vegetation %	1982/83	1987/89
Grass	6.81	7.29	All Wood	11.91	35.42
Scrub	20.90	13.63	Forest +Wood	30.23	47.99
Active Cultivation	21.45	16.17	Closed Canopy Forest	10.84	12.10
All Cultivation	21.59	17.91	All Forest	8.46	9.16
Parkland	7.79	10.68	AirGrass*	8.07	9.17
Open Wood	3.96	17.02	AirCultivation*	24.18	18.32
Dense Wood	6.13	23.05	AirScrub*	20.67	13.83

* Includes Bare Ground

A likely reason for this result is, as implied at the end of the preceding section, that 1982/83 were drought years. The mean NDVIs recorded for those years was substantially lower than that for the period 1987/89. As a result, the calculation of the extent of vegetation types in 1982/83, which was based on calibrations for years with a substantially higher average NDVI, can be expected to be inaccurate. A correction factor must first be calculated to compensate for inter-annual variation in mean NDVIs, before the 1982/83 extrapolation can be made more accurate.

Preliminary screening of the relevant data shows the relationships between annual mean NDVIs to be complex and non-linear. Their definition is beyond the scope of the present Terms of Reference, which thus precludes further application of this technique to the current task. It is probable that extensive investigation in the medium term, using several sets of inter-annual comparisons, will provide the information necessary to make the technique useful for temporal as well as spatial comparisons.

In addition, as with the first stage analyses, it is planned to treat the data from each ecological zone individually. This will have the major advantage that the NDVI data returned from vegetation in each zone, can be examined separately, and different forms of variation identified This refinement should allow for the more precise calibration of the vegetation in each zone, which would permit a more reliable comparison of annual differences in NDVI levels, and thus facilitate the calculation of a more directly relevant correction for such variations.

APPENDIX 3: DATA TABLES

Table A3.1: Mean Percentages of SLAR Vegetation Categories

SLAR Category	SPSS Name	Mean%	SD	Max. %
COMPLEX, GRASSLAND, shrub	COGRSH	0.00	0.00	0.00
COMPLEX, SHRUBLAND AND THICKET, thorny/non thorny	COGRTH	0.19	3.16	91.00
FARMLAND	FARM	2.17	11.14	99.00
FARMLAND, 30- 60%	FARM3060	10.36	20.32	100.00
FARMLAND, > 60%	FARM60	11.10	24.60	100.00
FARMLAND, derived savannah zone	FARMSAVZ	0.54	5.22	100.00
FARMLAND, forest zone	FARMFORZ	0.01	0.21	8.00
FARMLAND, mosaic - farmland/immature forest	FMMIFO	2.87	13.81	100.00
FARMLAND, mosaic - farmland/immature forest /rubber forest	FMMIRBFO	1.05	7.65	99.00
FARMLAND, mosaic - farmland/oil palm forest/immature forest	FMMFIFO	0.23	2.86	58.00
FARMLAND, mosaic - farmland/oil palm	FMMOIL	0.54	4.93	89.00
FARMLAND, mosaic - farmland/oil palm/immature forest	FMMOIIFO	0.59	6.20	100.00
FARMLAND, mosaic - farmland/rubber forest	FMMRBFO	0.03	0.68	19.00
FARMLAND, mosaic - farmland/swamp forest	FMMSWFO	0.30	4.49	100.00
FARMLAND, mosaic - farmland/wooded shrub grassland + patches of woodland	FMMWSG	10.41	24.05	100.00
FARMLAND, mosaic - farmland/riparian forest	FMMRIPFO	0.05	0.79	25.00
FOREST, immature	FOIM	0.20	1.53	24.00
FOREST, mature disturbed	FOMADIST	0.53	4.10	79.00
FOREST, mature	FOMAT	1.08	8.44	100.00
FOREST, mosaic - mature disturbed /oil palm/farmland	FOMOIDIS	0.01	0.40	16.00
FOREST, mosaic - oil palm /swamp	FOMOISW	0.13	2.45	77.00
FOREST, mosaic - swamp/rubber	FOMSWRB	0.27	4.51	99.00
FOREST, mosaic - swamp/rubber/farmland	FOMSWRBF	0.20	3.79	100.00
FOREST, mosaic -mature disturbed/farmland/oil palm	FOMMDFMO	0.12	2.23	70.00
FOREST, mosaic - mature disturbed/immature	FOMMDIM	0.94	6.64	100.00
FOREST, oil palm	FOOIL	0.81	7.13	97.00
FOREST, raffia palm	FORAF	0.20	2.04	53.00
FOREST, riparian	FORIP	1.07	4.19	60.00
FOREST, rubber	FORUB	0.49	5.19	98.00
FOREST, swamp	FOSW	2.41	12.41	100.00
GRASSLAND, aquatic/farmland	GRAQFM	0.03	0.58	23.00
GRASSLAND, aquatic grassland	GRAQGR	0.11	2.91	98.00
GRASSLAND, aquatic	GRAQ	1.08	6.49	98.97
GRASSLAND, dry	GRDR	0.05	1.38	56.00
GRASSLAND, dry grassland	GRDRGR	0.13	2.40	73.00
GRASSLAND, grassland with scattered trees	GRTR	0.01	0.22	10.00
GRASSLAND, grassland	GRGR	0.10	0.76	17.00
GRASSLAND, montane	GRMON	0.25	3.75	99.00
GRASSLAND, mosaic - aquatic	GRMAQ	0.00	0.05	2.00
GRASSLAND, mosaic - grassland/farmland	GRMGRFM	0.08	0.96	25.00
GRASSLAND. mosaic - upland wooded shrub grassland /riparian forest	GRMUWSRF	0.63	5.85	94.00
GRASSLAND, shrub grassland	GRSHGR	0.28	3.94	81.00
GRASSLAND, shrub	GRSH	2.21	9.64	99.00
GRASSLAND, wooded shrub	GRWDSH	8.73	20.64	100.00
GRASSLAND/SHRUBLAND TRANSITION, dense shrub grassland	GRSHTRSG	1.91	10.56	100.00
MANGROVE	MAN	1.21	8.87	98.00
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, crop plantation	PLCR	0.11	0.95	23.00
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, forestry plantation	PLFO	0.11	0.97	28.00
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, irrigation project	PLIR	0.02	0.50	18.00
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, livestock project	PLLIV	0.00	0.02	1.00
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, mech farm project	PLMECH	0.00	0.05	2.00
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS,rainfed farm project	PLRAIN	0.00	0.05	2.00
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, shelter belt	PLSHEL	0.00	0.08	2.00
SHRUBLAND AND THICKET, non-thorny	SHTNOTH	0.04	1.02	38.00
SHRUBLAND AND THICKET, thorny/non-thorny	SHTTHNTH	2.24	10.90	100.00
SHRUBLAND AND THICKET, thorny	SHTTHOR	0.00	0.13	5.00
WATER	WATER	0.35	1.83	28.00
STANDING WATER, lake	LAKE	0.20	2.53	65.00
WOODLAND, broad-leaved	WDBLVD	4.03	13.96	100.00
WOODLAND, broad-leaved/riparian forest	WDBDRPFO	0.23	3.34	94.19
WOODLAND, mosaic -broad leaved /riparian forest	WDMBDRPF	0.10	2.50	93.00
WOODLAND, woodland/riparian forest	WDWDRPFO	0.02	0.52	19.00
WOODLAND	WOOD	0.17	2.38	54.00
WOODED SHRUB GRASSLAND/WOODLAND TRANSITION	WSGWDTR	26.63	34.61	100.00

Table A3.2: SLAR Conversion Tables

SLAR Vegetation Category	SPSS Name	Air Vegetation Category					
		plant	cult	grass	scrub	wood	forest
COMPLEX, GRASSLAND, shrub	COGRSH	0	0	25	75	0	0
COMPLEX, SHRUBLAND AND THICKET, thorny/non thorny	COGRTH	0	0	0	100	0	0
FARMLAND	FARM	0	80	10	10	0	0
FARMLAND, 30- 60%	FARM3060	0	50	5	25	15	5
FARMLAND, > 60%	FARM60	0	80	10	10	0	0
FARMLAND, derived savannah zone	FARMSAVZ	0	80	10	10	0	0
FARMLAND, forest zone	FARMFORZ	0	80	0	0	12.5	7.5
FARMLAND, mosaic - farmland/immature forest	FMMIFO	0	50	0	0	50	0
FARMLAND, mosaic - farmland/immature forest /rubber forest	FMMIRB FO	33.3	33.3	0	0	33.3	0
FARMLAND, mosaic - farmland/oil palm forest/immature forest	FMMFIFO	0	30	0	0	50	20
FARMLAND, mosaic - farmland/oil palm	FMMOIL	0	50	0	0	25	25
FARMLAND, mosaic - farmland/oil palm/immature forest	FMMOIIFO	0	33.3	0	0	33.3	33.3
FARMLAND, mosaic - farmland/rubber forest	FMMRBFO	50	50	0	0	0	0
FARMLAND, mosaic - farmland/swamp forest	FMMSWFO	0	50	0	0	0	50
FARMLAND, mosaic - farmland/wooded shrub grassland + patches of Woodland	FMMWSG	0	35	5	10	50	0
FARMLAND, mosaic - farmland/riparian forest	FMMRIPFO	0	50	0	0	0	50
FOREST, immature	FOIM	0	0	0	0	100	0
FOREST, mature disturbed	FOMADIST	0	0	0	0	0	100
FOREST, mature	FOMAT	0	0	0	0	0	100
FOREST, mosaic - mature disturbed /oil palm/farmland	FOMOIDIS	0	30	0	0	20	50
FOREST, mosaic - oil palm /swamp	FOMOISW	0	0	0	0	0	100
FOREST, mosaic - swamp/rubber	FOMSWRB	50	0	0	0	0	50
FOREST, mosaic - swamp/rubber/farmland	FOMSWRBF	33.3	33.3	0	0	0	33.3
FOREST, mosaic -mature disturbed/farmland/oilpalm	FOMMDFMO	0	30	0	0	20	50
FOREST, mosaic - mature disturbed/immature	FOMMDIM	0	0	0	0	100	0
FOREST, oil palm	FOOIL	0	0	0	0	0	100
FOREST, rafia palm	FORAF	0	0	0	0	0	100
FOREST, riparian	FORIP	0	0	0	0	0	100
FOREST, rubber	FORUB	100	0	0	0	0	0
FOREST, swamp	FOSW	0	0	0	0	0	100
GRASSLAND, aquatic/farmland	GRAQFM	0	50	50	0	0	0
GRASSLAND, aquatic grassland	GRAQGR	0	0	100	0	0	0
GRASSLAND, aquatic	GRAQ	0	0	100	0	0	0
GRASSLAND, dry	GRDR	0	0	100	0	0	0
GRASSLAND, dry grassland	GRDRGR	0	0	100	0	0	0
GRASSLAND, grassland with scattered trees	GRTR	0	0	0	0	100	0
GRASSLAND, grassland	GRGR	0	0	100	0	0	0
GRASSLAND, montane	GRMON	0	0	100	0	0	0
GRASSLAND, mosaic - aquatic	GRMAQ	0	0	100	0	0	0
GRASSLAND, mosaic - grassland/farmland	GRMGRFM	0	50	50	0	0	0
GRASSLAND. mosaic - upland wooded shrub grassland /riparian forest	GRMUWSRF	0	0	10	30	20	40
GRASSLAND, shrub grassland	GRSHGR	0	0	30	70	0	0
GRASSLAND, shrub	GRSH	0	0	50	50	0	0
GRASSLAND, wooded shrub	GRWDSH	0	0	15	35	50	0
GRASSLAND/SHRUBLAND TRANSITION, dense shrub grassland	GRSHTRSG	0	0	20	70	10	0
MANGROVE	MAN	0	0	0	0	0	0
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, crop plantations	PLCR	0	100	0	0	0	0
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, forestry plantations	PLFO	100	0	0	0	0	0
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, irrigation project	PLIR		100	0	0	0	0
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, livestock project	PLLIV	0	100	0	0	0	0
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, mech farm project	PLMECH	0	100	0	0	0	0
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS,rainfed farm project	PLRAIN	0	100	0	0	0	0
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, shelter belt	PLSHEL	100	0	0	0	0	0
SHRUBLAND AND THICKET, non-thorny	SHTNOTH	0	0	0	100	0	0
SHRUBLAND AND THICKET, thorny/non-thorny	SHTTHNTH	0	0	0	100	0	0
SHRUBLAND AND THICKET, thorny	SHTTHOR	0	0	0	100	0	0
WATER	WATER	0	0	0	0	0	0
STANDING WATER, lake	LAKE	0	0	0	0	0	0
WOODLAND, broad-leaved	WDBLVD	0	0	0	0	100	0
WOODLAND, broad-leaved/riparian forest	WDBDRPFO	0	0	0	0	50	50
WOODLAND, mosaic -broad leaved /riparian forest	WDMBDRPF	0	0	0	0	50	50
WOODLAND, woodland/riparian forest	WDWDRPFO	0	0	0	0	50	50
WOODLAND	WOOD	0	0	0	0	100	0
WOODED SHRUB GRASSLAND/WOODLAND TRANSITION	WSGWDTR	0	0	2.5	5	92.5	0

Table A3.3: Contribution of SLAR Categories to Calculated Land Use Types

SLAR Vegetation Category	SPSS Name	%of plant'n	%of cult'n	%of grass	%of scrub	%of wood	%of forest
COMPLEX, GRASSLAND, shrub	COGRSH	–	–	–	–	–	–
COMPLEX, SHRUBLAND AND THICKET, thorny/non thorny	COGRTH	–	–	–	1.3	–	–
FARMLAND	FARM	–	7.7	2.8	1.5	–	–
FARMLAND, 30- 60%	FARM3060	–	22.8	6.6	17.6	3.5	6.5
FARMLAND, > 60%	FARM60	–	39.2	14.2	7.6	–	–
FARMLAND, forest zone	FARMFORZ	–	+	–	–	+	+
FARMLAND, derived savannah zone	FARMSAVZ	–	1.9	0.7	0.4	–	–
FARMLAND, mosaic - farmland/oil palm forest/immature forest	FMMFIFO	–	0.3	–	–	0.3	0.6
FARMLAND, mosaic - farmland/immature forest	FMMIFO	–	6.3	–	–	3.3	–
FARMLAND, mosaic - farmland/immature forest /rubber forest	FMMIRBFO	30.0	1.5	–	–	0.8	–
FARMLAND, mosaic - farmland/oil palm/immature forest	FMMOIIFO	–	0.9	–	–	0.4	2.5
FARMLAND, mosaic - farmland/oil palm	FMMOIL	–	1.2	–	–	0.3	1.7
FARMLAND, mosaic - farmland/rubber forest	FMMRBFO	1.3	0.1	–	–	–	–
FARMLAND, mosaic - farmland/riparian forest	FMMRIPFO	–	0.1	–	–	–	0.3
FARMLAND, mosaic - farmland/swamp forest	FMMSWFO	–	0.7	–	–	–	1.9
FARMLAND, mosaic - farmland/wooded shrub grassland + patches of Woodland	FMMWSG	–	16.1	6.7	7.1	11.9	–
FOREST, immature	FOIM	–	–	–	–	0.5	–
FOREST, mature disturbed	FOMADIST	–	–	–	–	–	6.6
FOREST, mature	FOMAT	–	–	–	–	–	13.5
FOREST, mosaic -mature disturbed/farmland/oilpalm	FOMMDFMO	–	0.2	–	–	0.1	0.8
FOREST, mosaic - mature disturbed/immature	FOMMDIM	–	–	–	–	2.1	–
FOREST, mosaic - mature disturbed /oil palm/farmland	FOMOIDIS	–	–	–	–	–	0.1
FOREST, mosaic - oil palm /swamp	FOMOISW	–	–	–	–	–	1.6
FOREST, mosaic - swamp/rubber	FOMSWRB	11.6	–	–	–	–	1.7
FOREST, mosaic - swamp/rubber/farmland	FOMSWRBF	5.7	0.3	–	–	–	0.8
FOREST, oil palm	FOOIL	–	–	–	–	–	10.1
FOREST, rafia palm	FORAF	–	–	–	–	–	2.5
FOREST, riparian	FORIP	–	–	–	–	–	13.4
FOREST, rubber	FORUB	42.0	–	–	–	–	–
FOREST, swamp	FOSW	–	–	–	–	–	30.1
GRASSLAND, aquatic	GRAQ	–	–	13.8	–	–	–
GRASSLAND, aquatic/farmland	GRAQFM	–	0.1	0.2	–	–	–
GRASSLAND, aquatic grassland	GRAQGR	–	–	1.4	–	–	–
GRASSLAND, dry	GRDR	–	–	0.6	–	–	–
GRASSLAND, dry grassland	GRDRGR	–	–	1.7	–	–	–
GRASSLAND, grassland	GRGR	–	–	1.3	–	–	–
GRASSLAND, mosaic - aquatic	GRMAQ	–	–	–	–	–	–
GRASSLAND, mosaic - grassland/farmland	GRMGRFM	–	0.2	0.5	–	–	–
GRASSLAND, montane	GRMON	–	–	3.2	–	–	–
GRASSLAND. mosaic - upland wooded shrub grassland /riparian forest	GRMUWSRF	–	–	0.8	1.3	0.3	3.2
GRASSLAND, shrub	GRSH	–	–	14.2	7.5	–	–
GRASSLAND, shrub grassland	GRSHGR	–	–	1.1	1.3	–	–
GRASSLAND/SHRUBLAND TRANSITION, dense shrub grassland	GRSHTRSG	–	–	4.9	9.1	0.4	–
GRASSLAND, grassland with scattered trees	GRTR	–	–	–	–	+	–
GRASSLAND, wooded shrub	GRWDSH	–	–	16.8	20.7	10.0	–
STANDING WATER, lake	LAKE	–	–	–	–	–	–
MANGROVE	MAN	–	–	–	–	–	–
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, crop plantations	PLCR	+	0.5	–	–	–	–
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, forestry plantations	PLFO	9.4	–	–	–	–	–
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, irrigation project	PLIR	–	0.1	–	–	–	–
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, livestock project	PLLIV	–	+	–	–	–	–
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, mech farm project	PLMECH	–	+	–	–	–	–
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS,rainfed farm project	PLRAIN	–	+	–	–	–	–
PLANTATIONS AND SPECIAL AGRICULTURAL PROJECTS, shelter belt	PLSHEL	+	–	–	–	–	–
SHRUBLAND AND THICKET, non-thorny	SHTNOTH	–	–	–	0.3	–	–
SHRUBLAND AND THICKET, thorny/non-thorny	SHTTHNTH	–	–	–	15.2	–	–
SHRUBLAND AND THICKET, thorny	SHTTHOR	–	–	–	+	–	–
WATER	WATER	–	–	–	–	–	–
WOODLAND, broad-leaved/riparian forest	WDBDRPFO	–	–	–	–	0.3	1.4
WOODLAND, broad-leaved	WDBLVD	–	–	–	–	9.2	–
WOODLAND, mosaic -broad leaved /riparian forest	WDMBDRPF	–	–	–	–	0.1	0.6
WOODLAND, woodland/riparian forest	WDWDRPFO	–	–	–	–	–	0.1
WOODLAND	WOOD	–	–	–	–	0.4	–
WOODED SHRUB GRASSLAND/WOODLAND TRANSITION	WSGWDTR	–	–	8.5	9.1	56.1	–

+ indicates a contribution of less than 0.1%