International Workshop on Sustainable Use of Rangelands and Desertification Control

Rapid Resource Assessment and Environmental Monitoring: Are Aerial Surveys Still Useful?

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ABSTRACT

A range of techniques are available for rangeland resource assessment and environmental monitoring: from the use of satellite imagery, aerial photography and aerial observation, to ground truth studies; from total coverage, to random, stratified or systematic survey sample survey. Each technique has its own advantages and drawbacks in terms of resolution; cost; personnel and logistic support required; and most importantly, the parameters that can be assessed reliably and cost effectively.

This paper examines the role of Integrated Air and Ground Survey, as initiated in the early eighties and developed to date, and attempts to identify the 'niche' for which it is best suited.

Examples are taken from more than 50 surveys carried out by ERGO personnel in Sub Saharan Africa, between 1984 and 1994, to demonstrate the range, adaptability and suitability of the methods available. Their future usefulness, in the context of ever more 'high tech' resource assessment techniques, is considered.

A variety of actual and potential applications of the data collected by this methodology are described, including: the estimation and mapping of human and livestock populations and of land cover; establishing the role of livestock in relation to their agro-economic environment; the definition of livestock and agricultural systems; assessing land degradation; and validation by 'ground truthing' of remotely sensed vegetation data.

1. INTRODUCTION

Sustainable use of rangelands requires access to reliable baseline information. These data are provided by rangeland resource assessment and monitoring of a variety of types of information including: the distribution, productivity and composition of natural vegetation and agricultural land; rainfall and temperature regimes; edaphic and hydrological data, rangeland utilisation by wild and domesticated animals; land tenure and ownership; and socio-economic information and marketing.

Rangelands are not, however, static entities, but usually are subject to major seasonal variations, as well as longer term cycles of drought and recovery. Given the inexorable rise in the human populations that exploit the rangelands, there is often a general medium to long term trend towards over-grazing and degradation. It is therefore not enough to furnish baseline data alone and a temporal perspective is essential if planning for sustainable rangeland exploitation is to be feasible.

A properly planned rangeland resource assessment and environmental monitoring programme must include both an initial study to establish prevalent resource levels and, if possible, establish broad historical trends; and a longer term monitoring exercise to maintain the currency of the information and identify on-going trends. The techniques used for each of these two phases may differ, provided the various methods produce compatible and comparable information.

Techniques available range from the use of satellite imagery, aerial photography, videography and aerial observation to ground based studies; from total coverage to random, stratified or systematic sample survey. Each technique has its own advantages and drawbacks in terms of resolution; cost; personnel and logistic support required; and most importantly, the parameters that can be assessed reliably and cost effectively.

This paper considers the role of low level aerial survey techniques, as initiated in the early eighties and developed to date, and attempts to identify the 'niche' for which it is best suited.

2. AERIAL SURVEY

2.1 High Level Survey

High level surveys are usually flown at heights of some 5,000 to 10,000 feet above ground level (agl) and are primarily suited for cartography (i.e. the production of maps), using high resolution photography, both digital and conventional, or airborne radar and radiometry sensors. Such techniques are frequently used for vegetation mapping, geological and hydrological assessment, or by dint of stereo photography, for the production of topographic maps. This technique has, until relatively recently, been the basis of most national map series.

Because of the comparatively high unit cost - in the region of tens to hundreds of dollars per square kilometre - high level aerial surveys are increasingly used for military purposes or for surveys areas measured in hectares rather than square kilometres, and are less widely commissioned for large areas. Despite the clarity consequent upon their potentially high resolution - in the order of one meter - high level aerial survey techniques cannot readily be adapted for the assessment of animal populations.

2.2 Low Level Survey

Low level aerial surveys are normally flown between 400 and 2,000 feet agl, and are most often designed to collect numerical information about target animal populations and distributions over large, often remote areas, in a short period. The air crew usually consists of a co-ordinator/navigator, pilot, and two observers or photographers. The survey technique is usually based on a systematic reconnaissance flight (SRF) sampling pattern, which provides uniform coverage of an entire region and enables a geographically co-ordinated gridded database to be established. As a result, unit costs are substantially lower than for high level coverage - around two to five dollars per square kilometre - and are less susceptible to interference from atmospheric dust or clouds.

Key features of this technique are its repeatability, and that it does not rely on any previous knowledge of the area concerned. Repeat surveys at different times of the year allow seasonal changes in distribution and abundance to be determined.

2.2.1 Sampling Strategies

SRF surveys are able to obtain a wide range of information, through visual observation, or by photographic or videographic means (see below). The essence of the technique rests on systematic flights over a whole survey zone, but using sampling rather than total coverage of the area concerned. A systematic sample from a patchy population ensures that all parts are represented in the correct proportions, whereas a random sample may fall in areas of high or low density more often than the proportion of such areas in the population would suggest.

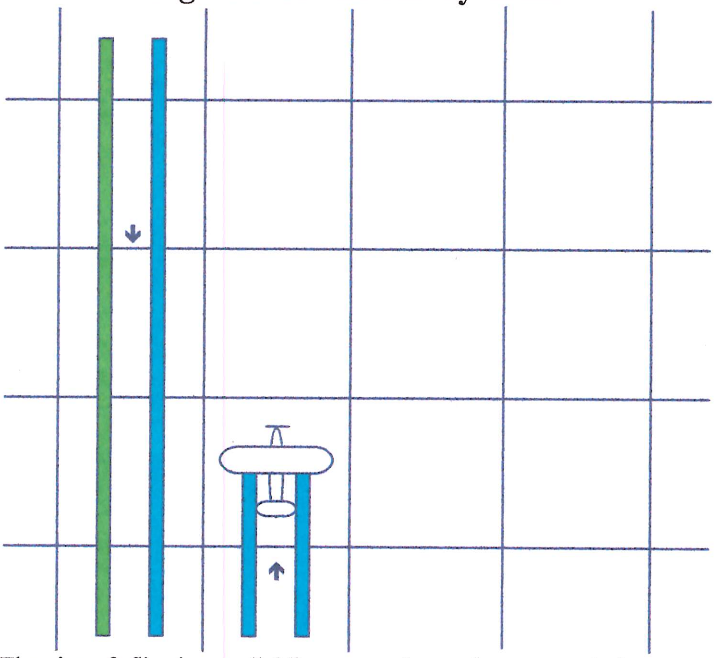
Further, a systematic sample provides more or less constant accuracy throughout the sampling frame, unless there are regular and periodic spatial patterns in the population's distribution. This is extremely unlikely to be the case for any natural system.

As far as stratification is concerned, that is the sampling of different sectors of a survey site at different intensities, there are arguments both for and against. The points in favour of stratification are essentially that areas with low populations can be sampled at low intensity, whilst those with high numbers can be covered more intensively, and thus with greater precision.

This however presupposes some advance knowledge of the distribution of a population within the survey site. It is also complicated by the very real possibility that different target populations have different distribution patterns. The choice of a particular stratified strategy might for example increase the precision of, say, cattle population estimates, but would have the reverse effect as far camels were concerned. Similarly, stratification in favour of cultivated land could adversely effect the reliability of estimates of woodland or forest. Thus, if the provision of overall distribution maps and population estimates for a range of parameters is required, then all the advantages lie with unstratified sampling.

In view of these arguments, the default technique generally adopted follows standard procedures of Systematic Reconnaissance Flights (SRF), described by Norton-Griffiths (1978) and Clark (1986), in which a series of parallel flight lines are flown over the given region at an equal distance apart. Each flight line is divided into sectors of equal length to form a sampling grid, often based on the Universal Transverse Mercator (UTM) projection.

Figure 1: Aerial Survey Grids



The aircraft flies in parallel lines over the study area, and observers record from fixed sample bands to each side. The flight lines are divided into equal sectors, to create a grid cell lattice, by which each record is located

The aircraft is usually flown along the centre line of each grid, and observations made from, or photographs taken of a fixed sample band (Figure 1). The size of each cell depends on the desired sample intensity for a given survey. The grid cell sizes commonly vary from 1 by 1 kilometres, to 20 by 20 kilometres, which result in sample percentages of between 2% and 50% according to flying height and strip width.

The major consequence of choosing a systematic sampling pattern is that the calculation of the error term is somewhat complex as it has to be calculated from what is, statistically speaking, a single estimate of the target population for the whole survey area. The population estimates and associated standard errors (SEs) of aerial survey data may be calculated using either the Jolly Ratio Method (which uses the flight line as the sample unit) or the Marriott 4-cell Method, for which the grid cell or 'sub-unit' is the sample unit. The relative advantages of each are discussed at length in Marriott and Wint (1985), and depend on the spatial integrity of the survey area, as well as the distribution pattern of the population within it.

Both methods will tend to give similar standard errors if the target animals are evenly spread throughout a survey area, or if they are rare and found in isolated large groups. The Jolly SE estimates will tend to be lower if the targets are quite abundant, and aggregated in large herds regularly spaced throughout the area. The Marriott SE estimates will tend to be the lower if there is any spatial trend in numbers from one end of a flight line to the other, or if there are substantial areas of high density, surrounded by less well stocked regions.

It should be emphasised that both methods are statistically conservative, and give rise to SEs well above the inherent errors of the sampling strategies used. There is thus a case for using whichever method provides the lower calculated SE. It is also stressed that, although the calculated standard errors may differ, depending on the method adopted and the underlying statistical assumptions, the size of the estimated population is <u>not</u> affected.

The formulae for the total population, the variance and the Jolly standard error are:

Population Total: $Y = Z \, . \, R$

Population Variance: $\text{Var}(Y) = \frac{N(N-n)}{n} . (s^2_y - 2.R.s_{yz} + R.s^2_z)$

where:
- Y = total population estimate.
- N = potential number of sample units in the survey region.
- n = actual number of sample units surveyed.
- Z = area of the survey region.
- z = area of any one sample unit.
- y = number of animals counted in that unit.
- R = ratio of the animals counted to the area searched ($\Sigma y / \Sigma z$).

and:

s^2_y = variance of animals counted between sample units.
s^2_z = variance of sampled area between sample units.
s_{yz} = covariance between counts and areas of each unit.

Note that, for the Jolly estimate, flight lines can be defined in either the horizontal or vertical orientation, and given the conservatism of the method, it is acceptable to use the direction which gives the lowest SE.

The relevant formula for the Marriott standard error is:

$$\mathrm{Var}(Y) = \Sigma \, \frac{(4y(i,j)-y(i-1,j)-y(i+1,j)-y(i,j-1)-y(i,j+1))^2}{20n^*}$$

where:

Y = total population estimate.
i,j = coordinates of a grid point.
y = number of items recorded for a given grid.
n = number of grid points with 4 surrounding neighbours.

The standard error is the square root of the variance of the estimate, based on the difference between sample value (y) at point (i,j) and the average of its four neighbours, provided they all fall within the overall survey sample.

2.2.2 Photography and Videography

Low level aerial photography (LLAP) can be carried out using either video or small format (35mm) still cameras. As videography is the subject of a separate workshop paper, only the latter will be considered here.

LLAP surveys have been used largely for estimating crops or natural vegetation cover, with vertically mounted cameras, usually equipped with wide angle lenses to maximise the sample size. Telephoto lenses can also be fitted to permit the ancillary identification of individual crops. The cameras have data backs to imprint time and frame identifiers on each photograph, and with intervalometers which control the exposure frequency. Typically, such surveys would be flown at 2000 feet agl, giving frame dimensions of 900m by 600m on the ground, so that a continuous strip coverage can be produced from exposures as intervals of 20-30 seconds (or approximately 1.5 hours per bulk film).

A survey of substantial size can require several thousand photographs from which the requisite data must be extracted, which precludes the use of digital photography unless very substantial data storage and processing power is available. Thus photo-interpretation is most effectively done manually, and is carried out by point sampling of the projected colour images at a scale of 1:1,000. Each slide is projected onto a matt white screen with a 6 by 4 array of 24 cross hair sample points, being the number closest to 20 (the minimum number of replicates required) that fit in a regular, and thus unbiased, lattice within the shape of the photograph.

Because the ground coverage of each frame is dependent upon the flying height, which can vary by 100 feet or more, this technique is not suited to absolute measures of vegetation cover, but rather to estimating percentage cover. Interpreters thus classify each sample point into one of several mutually exclusive and easily distinguishable land cover categories, such as: tree canopy; shrub cover; farmland; and other (e.g. bare ground, water, or grassland). The occurrence of a number of additional features - such as severe erosion, major towns, roads and large rivers - anywhere within a frame may also recorded.

2.2.3 Visual Observation

Attempts have been made in recent years to use satellite imagery and conventional aerial photography to estimate animal populations. However, the availability of satellite imagery and the resolution of both imagery and photography are generally such that they are not appropriate for the assessment of livestock or wildlife populations. High resolution aircraft-mounted video has also been tried in a number of areas, with limited success, as the equipment need to stabilise the video platform is expensive, prone to malfunction, and produces tapes which require a substantial amount of time to analyse. As a result, animal populations are best assessed using visual observation.

2.2.3.1 Methodology

Only the animals within a fixed strip of ground on either side of the aircraft, delineated by viewing frames, are recorded. Each observer is also required, wherever possible, to take photographs of all herds in excess of ten falling within the ground sampling strip. These photographs can be used in two ways: either by using them as the primary source of counts, or as a means to calculate observer counting error which can then be applied to all observer counts. The first of these is less reliable in areas with significant vegetation cover as animals may be obscured from the lens, and a calibration exercise must be carried out to provide correction factors for different cover levels and types.

Observers, by contrast, have a more flexible field of view as they can look forward and backward along the strip, and are therefore able to see (and count) the animals sheltering under trees and bushes. Comparison of subsequent accurate photocounts with the estimates recorded by observers during the survey allow an individual counting bias to be determined for each parameter recorded. These are used to correct those estimates for which clear photographs are unavailable. Calculated observer biases are usually less than 5%, and commonly between 1% and 2%.

Though the technique was developed for the estimation of animal populations, it can be effectively used to count human habitations, or indeed any target that is visible from the air (see Table 1). Rural habitation may be divided into village and pastoral dwellings. In many cases distinctive sub-types may also be distinguished; for example, Fulani rugas and Twareg tents in West Africa, Beja tents in Sudan and Tiv huts in Nigeria. Major urban centres and large towns are not easily estimated visually, and are better assessed photographically.

Table 1: Information Typically Collected From The Air

WITHIN THE SAMPLE BAND		
Numbers of	*Animals*	Cattle, sheep and goats, horses and donkeys, camels, wild animals.
	Habitation and Settlements	Villages, rooftops of selected architectural types, Compounds, tents of selected architectural types,
	Other	Corrals, tar roads, all weather roads, tracks Rivers and open water, wells
WITHIN EACH GRID		Presence of open water, % cultivation, % grassland, % burned ground, gully and sheet erosion score(0-5) % open canopy woodland, % savannah woodland, grass cover, indicator plant species (e.g. *Calotropis* spp) Flying altitude, direction and time.

These parameters are not an exhaustive list, but are indicative of those commonly collected during SRF surveys.

Whilst visual observation is primarily used for estimating animals and human habitation, it may also be used to collect estimates of land cover, though within each survey grid rather than within the observation strips. Typical cover types assessed are: land within the cultivation cycle (active cropping plus fallow), bare ground, grassland, scrub, open woodland, dense woodland, and forest.

As these are assessed visually by the front seat observer, the estimates are obviously not as precise as those provided by photogrammetric methods. They are, however, sufficiently accurate to provide useful information (see below), and, equally importantly, involve little if any incremental cost.

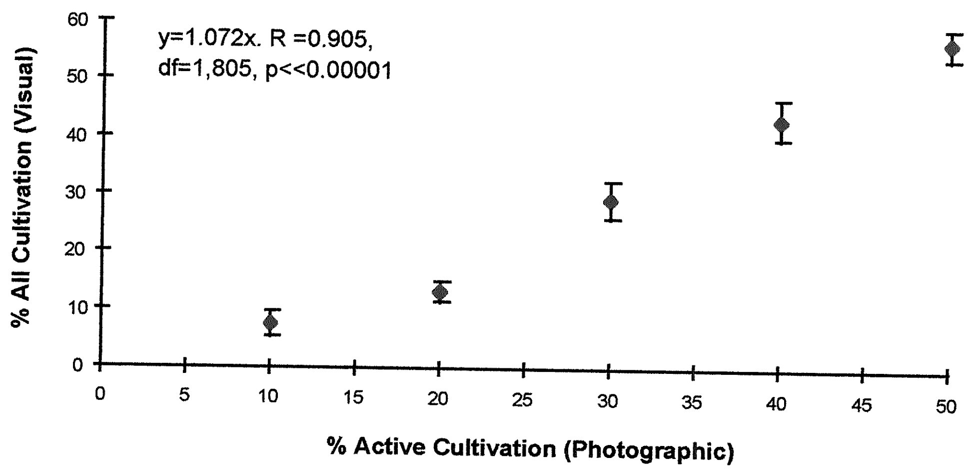
2.2.4 Data Accuracy

This is shown by repeated estimates of permanent habitation levels which should change little from year to year. For example, in the Bahr el Ghazal region of Tchad, the 1991 and 1993 estimates for permanent numbers were 79,700 and 82,800 respectively; and for Niger State, Nigeria permanent habitation estimates for 1989 and 1990 are 17.5 and 17.8 per square kilometre respectively.

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. 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 MSS satellite imagery. 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

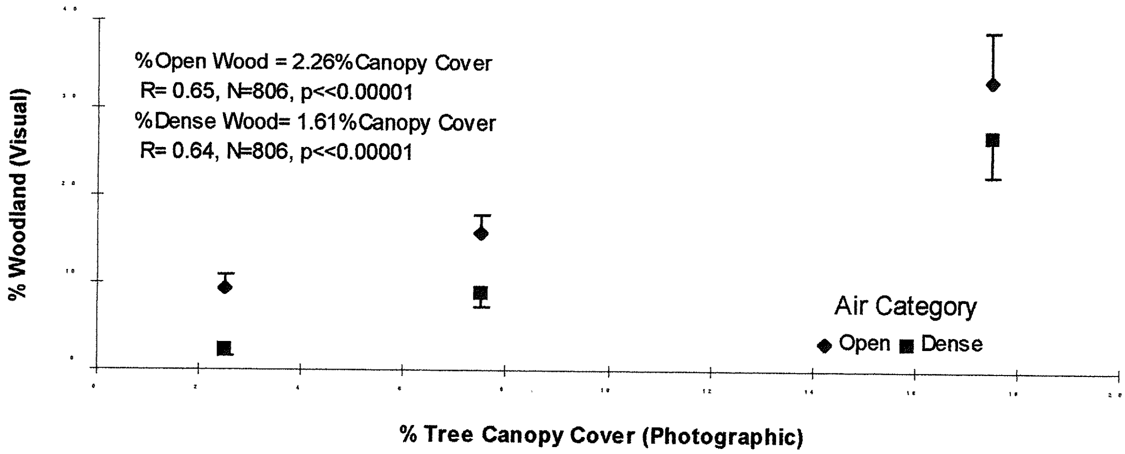


Mean %:- Visual = 32.5, SE = 1.14. Photographic = 32.05, SE = 0.47. T= - 0.72, ns

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



2.3 Integrated Surveys

Low level aerial surveys alone, both photographic and visual, have significant limitations. Photographic techniques can provide percentage vegetation cover, but little crop or forest production data. Visual counts of animals are limited to the larger species, and do not distinguish between sheep and goats. They are also, for example, unable to assess the numbers of animals under cover in villages.

These limitations can be overcome through integrating aerial survey techniques with ground survey methods designed to collect information which cannot be obtained from aerial reconnaissance, such as the proportion of sheep and goats in small ruminant herds, or to provide data which can be combined with aerial counts to give estimates of parameters which would otherwise be impractical. An example is the number of poultry kept in rural villages: air counts give the number of habitations in a sample grid; ground counts provide the number of birds per habitation. Combining the two figures gives village poultry population estimates and distributions. This integrated air/ground approach provides an objective basis for resource assessment and a better understanding of local production systems. Table 2 illustrates parameters that may be collected by the ground element of an integrated livestock survey.

Integrated surveys can also be used to differentiate between the large ruminants associated with human settlement, and those more pastorally managed animals that are found away from villages. This distinction is made by ensuring that the aerial survey observers either record animals seen within village boundaries separately from those elsewhere, or by excluding such livestock from the aerial counts altogether. If the latter course is adopted, then the estimates of total livestock numbers are calculated by adding the numbers derived from aerial counts to those derived from the ground survey and aerial habitation records. If it is assumed that the aerial counts represent pastorally managed animals, then the two sets of figures can be used to give an indication of the populations of animals managed by transhumant/nomadic pastoralists (the 'Pastoral' element) and those managed by mixed farmers, or settled agropastoralists ('Village' animals).

Table 2: Illustrative Ground Survey Parameters: Integrated Livestock Survey

Numbers per Habitation		**Presence of absence of:**	
Camels	Dogs	Pack oxen	Ploughing with:
Cattle	Cats	Horse mills	Camels
Zebu	Rabbits	Water drawing	Oxen
Muturu	Giant rats	Browse cutting	Bulls
Others	Tortoises	Night grazing	Carting
Goats	Fish-wells	Theft	
Sheep	Snail Farms	Dairying species:	Keeping of female:
Horses	Fish ponds	Camels	Camels
Donkeys	Bee hives	Cattle	Cattle
Pigs		Sheep	Goats
Chickens		Goats	Donkeys
Turkeys		Fattening stock:	Dairy products:
Pigeons		Cattle	Fresh milk
Guinea-fowl		Sheep	Butter
Ducks		Goats	Purchase of:
Guinea pigs			Supplementary feeds
			Mineral blocks

Ground survey can also be integrated with aerial survey techniques to produce estimates of vegetation standing crop. A fuel wood survey of northern Nigeria, covering some 322,000 square kilometres, relied on the integrated use of low level aerial photography, ground validation, and satellite imagery. Over 5,000 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 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.

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

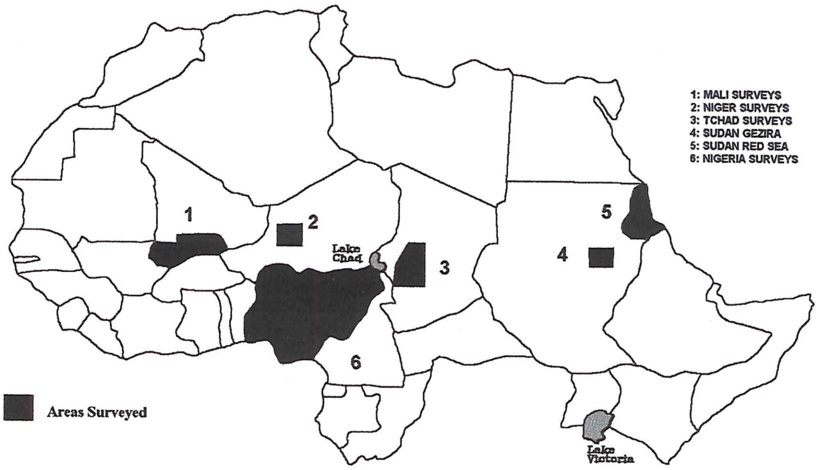
The results demonstrate the value of the integrated use of satellite imagery, sample photography and selective ground truthing in providing rapid, reliable and cost effective assessments of vegetation cover, wood volume and land use for large areas. The method clearly has relevance and applications in many other regions.

2.4 Data Utilisation

Resource assessment is primarily used to establish baseline data or to provide the information required for development planning and targeting. The information can be utilised in a range of additional ways. Because data derived from aerial or integrated surveys are standardised and geo-referenced, they can readily be amassed into archives and examined for internal correlations and relationships as well as analysed in relation to other types of geographical information. The following sections provides five examples.

2.4.1 Livestock and their Environment

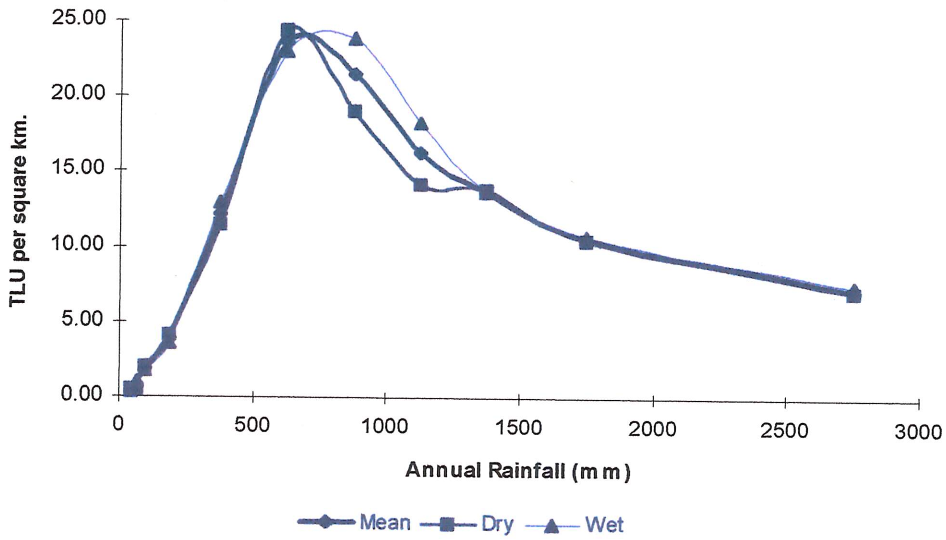
Figure 4: Sub-Saharan Survey Areas



An analysis of over 50 livestock surveys in Sub-Saharan Africa between 1984 and 1993, covering over 2 million square kilometres (See Figure 4), much of it twice or more, examined the seasonal distribution levels of livestock in the regions surveyed (Figure 4). The driest areas (with less than 250 mm precipitation per year) had the lowest livestock biomass - an average of 1.28 Tropical Livestock Units (TLU) (320 kg) per square kilometre. However, a doubling of rainfall to 500 mm was associated with a fourteen fold increase in livestock levels to 18.29 TLU (approximately 4,600 kg) per square kilometre. Peak values were reached at around 825 mm rainfall per annum, after which biomass density declined with increasing rainfall. These biomass values are comparable with those reported by Coe *et al.* (1976), Bell (1982 & 1985) and Fritz and Duncan (1993), but their observations were confined to the arid and semi-arid zones, with less than 1,000 mm per annum.

Only minor differences were revealed in the seasonal distribution of biomass in relation to rainfall (Figure 5). At the macro level this implies that a high proportion of animals were resident, or at least remain within the same rainfall zone throughout the year, and that long distance seasonal movements were relatively uncommon; (unless, of course, livestock movements in one direction are offset by equal and opposite movements in the other, which seems somewhat unlikely).

Figure 5: Seasonal Change in Livestock Biomass Distribution



On closer inspection, seasonal differences were largely confined to the 750-1250 mm rainfall band, corresponding to the interface between Semi-Arid and Sub-Humid Zones, where wet season biomass densities were 25-30 % higher in the wet season than in the dry season. In contrast, Arid and Humid Zones showed only very modest changes in seasonal biomass densities. These observations reflect a seasonal flux of livestock into the southern Semi-Arid and northern Sub-Humid Zones during the wet season, which is perhaps somewhat surprising, but may indicate of the return of transhumant herds from dry season pastures.

Table 3: Livestock Biomass Density by Agro-climatic Zone

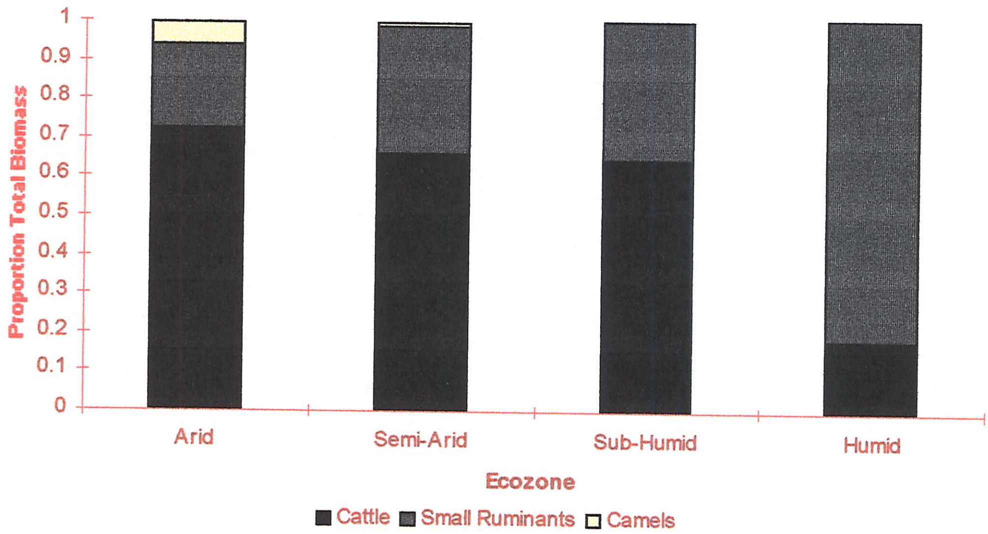
Agro-Climatic Zone	Total (ERGO 1994)			Jahnke (1982)
	Dry	Wet	Mean	1979
Arid	4.2	4.6	4.4	3.5
Semi-Arid	21.7	23.5	22.6	14.4
Sub-Humid	14.0	15.6	14.8	6.3
Humid	8.9	9.2	9.0	9.1
Total	7.6	8.3	7.9	5.59

Densities are in TLU per square kilometre.

Table 3 compares livestock biomass densities for each of the major agro-climatic zones obtained from contemporary field surveys, with Jahnke's more subjective assessments, derived from the FAO's Production Yearbook figures for 1979; Higgins *et al.*, (1978); and OAU/STRC/IBAR, (1976). Major differences are apparent, with Jahnke's figures some 30% lower, overall, and substantial under-representation of livestock biomass in both Semi-Arid and Sub-Humid Zones.

The variable composition of livestock biomass in each of the four agro-climatic zones is shown in Figure 6, as the relative proportions of camels, cattle and small ruminants. Camels are largely confined to the arid zone, although some extend into the Semi-Arid Zone. Cattle account for around two-thirds of livestock biomass in the Arid, Semi-Arid and Sub-Humid Zones, although the proportion declines with increasing humidity, as the contribution of small ruminants increases. Their relative proportions are reversed in the Humid Zone, where small ruminants account for some 80% of livestock biomass.

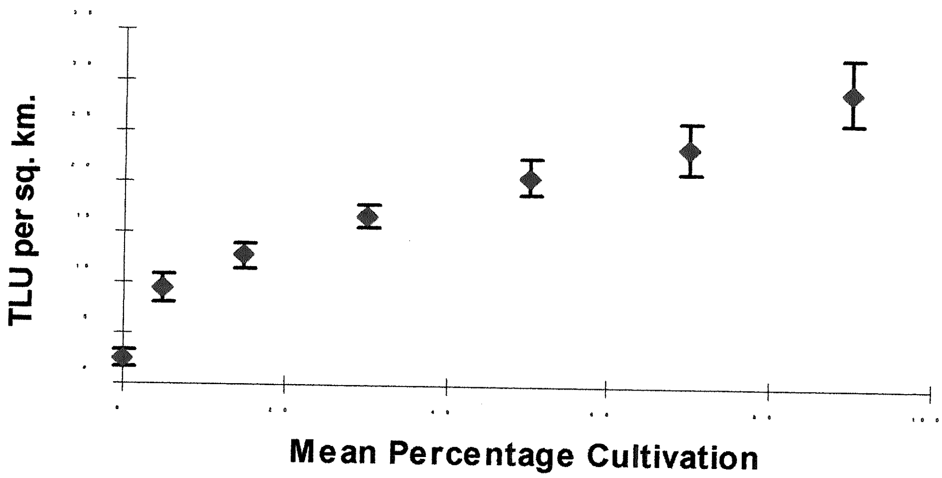
Figure 6: Livestock Composition by Agro-Climatic Zone



A large number of statistically significant correlations between livestock (cattle, camels, small ruminants) and environmental parameters (rainfall, grass cover, grassland, open woodland, dense woodland, forest, cultivation and rural settlement) can be generated. Only some of the more significant and interesting relationships are considered, relating to livestock biomass as a whole, rather than individual species.

The three most significant bivariate correlates of livestock biomass distribution were: **percentage cultivation, or land use intensity** (accounting for 54% variance); **density of rural settlement** (51% of variance) and **mean annual rainfall** (37% of variance).

Figure 7: Livestock Biomass: % Cultivation



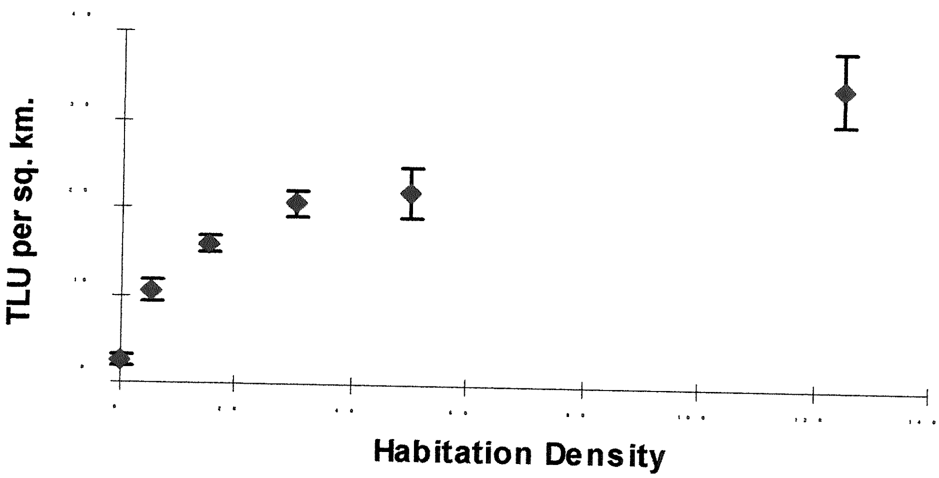
Log10 (y)=0.3014 + 0.5561 Log10(x).R^2=0.535; N=3663; p << 0.0001

The strongest association found was between livestock biomass and percentage of land under cultivation (Figure 7). Not only is there a more or less even incremental rise in biomass density across the complete spectrum of cultivation levels, but the degree of variation, as shown by the vertical bars (indicating two standard errors), is surprisingly low.

Statistical levels of significance are astronomical for this level of association, with probabilities of chance occurrence much less than 1 in 1,000,000). There is, therefore, little room for doubt that livestock tend to congregate where land is cultivated.

Not surprisingly, there is also a strong positive correlation between livestock biomass levels and the density of rural settlement, as recorded by aerial survey, in terms of number of rooftops per square kilometre (Figure 8), although the linkage is marginally weaker than for cultivation. The relationship is slightly less robust than for cultivation, with greater variation in more densely settled areas.

Figure 8: Livestock Biomass: Habitation Density



Log10 (y)=0.3582 + 0.5897 Log10(x).R^2=0.507; N=3663; $p << 0.0001$

The most significant result of these analysis is thus to show that livestock numbers are much more closely associated with the consequences of human activity - either percentage cultivation or habitation density - than they are with the extent or distribution of natural grazing. This pattern also holds true for the subset of livestock that are more pastorally managed - those that have traditionally been thought to concentrate in areas where natural grazing is widespread.

Further, the similarity between the trends established for all livestock and the pastorally managed element suggest that there is little reason to view the latter as a special case, affected by factors specific to the pastoralist management system. This conflicts with many traditional views which hold that pastoralists minimise the risk to their animals by following the best of the natural grazing. Rather it suggests that cultivation, or the vegetation associated with it, has, over much of the Sahel at least, become the most predictable source of livestock fodder, obviating the need to travel long distances in search of less certain natural resources.

If this is indeed the case, and if, as seems inevitable, human activity continues to expand in the future, then the trend away from dependence upon extensive rangelands is likely to continue. It therefore seems essential that future development planning address the interface between livestock and cropping as a higher priority than has been the case to date (Bourn and Wint, 1994).

2.4.2 Livestock, Human Activity and Land Degradation

Ecologists, economists and others have long debated the linkage between the size of human populations and the degradation of their environment. Population densities *per se,* or population growth, have not, however, been correlated with soil erosion, water impurity, deforestation and other major ecological changes (Tiffen *et al*, 1994; Mortimore 1989; Clarke and Rhind, 1992).

The data set examined in the preceding section includes measures of percentage erosion only for Nigeria during 1990 and demonstrates a striking association between erosion and three predictor variables. Stepwise multiple regression (Equation 1) reveals that the extent of bare ground in a survey grid is the primary predictor of erosion levels. The next strongest predictor is the percentage of active cultivation (excluding fallow), followed by livestock biomass per km^2.

Equation 1

Lg10 (% Erosion) = -1.03 + 0.265Lg10 (% Bare Ground) + 0.198 Lg10 (% Active Cultivation) + 0.216 Lg10 (Livestock Biomass per km^2) R^2 = 0.206; DF = 3, 1916; $p << 0.0001$

The statistical significance of the relationship is overwhelming - R^2 is 0.54 with in excess of 1,900 data points, as compared to a threshold value of 0.02 at the 1% level of significance. The level of erosion is thus most severe in areas with little natural vegetation - presumably those more arid and agriculturally marginal regions - and its incidence within these regions is highest where there are both extensive cultivation and high livestock numbers.

2.4.3 Land Use Change

The assessment of land use change requires that compatible sets of information are available from two periods sufficiently far apart that differences between them are greater than the errors inherent in their estimation. Various classifications of Nigerian vegetation have been published since the 1950s, but most are rather broad, and unsuited to the present task. An exception is the set of maps 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, based on Side Looking Airborne Radiometry (SLAR). A dataset which is compatible in spatial terms, comparable in the parameters assessed, and also covers the whole country is that available from the Nigerian National Livestock Resources survey of 1990 (Resource Inventory and Management Ltd, 1992), conducted on behalf of the Federal Department of Livestock and Pest Control Services, for which land use cover was estimated during the course of a low level aerial survey.

The aerial survey data are based on visual estimates of five major land use categories within each of 2280 survey grids covering the whole country. A comparison with photographic assessments and between repeated visual surveys confirms their reliability.

In order to match aerial survey estimates with the SLAR data, two steps were needed: recording the amount of each SLAR vegetation category within each 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, subdividing each into 100 cells, and recording the predominant vegetation category within each cell, and calculating the percentage of each cell covered by each vegetation category. Matching the SLAR and aerial survey data was achieved by a combination of regression and distribution analyses. The degree of 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 compounded annual rate of 6.9%. Projections, using these estimated rates of change, suggest 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.

2.4.4 Agricultural System Definition, Display and Identification

Geo-referenced data of the sort produced by integrated air and ground survey is well suited to internal examination of relationships of the sort described in the previous section. It is also amenable to interrogation using conditional statements to locate, for example, all data points with animal densities falling between prescribed thresholds, in densely populated areas. These sorts of queries can be used both to define and map agricultural systems, and indeed to validate the defining criteria. The possibility thus arises of defining the Production Systems so often used by agricultural development planners so that they have a basis in actual data, and have a real geographical identity, rather than being founded on hypothesis and assumption.

Figure 9 depicts such a process, whereby small ruminant density is first plotted against human habitation density and rainfall, to give a three dimensional surface which is a visualisation of the interrelationships between the three parameters derived from survey data from a substantial part of the Sahel. This can be used to identify criteria that describe coherent small ruminant Systems, in this case illustrated as two discrete peaks or Regions of the surface plot.

The locations of with corresponding values for the defining criteria (rainfall and habitation density) can then be identified within a particular geographical area, in this case Nigeria, and these can then be mapped to assess their geographical coherence and realism.

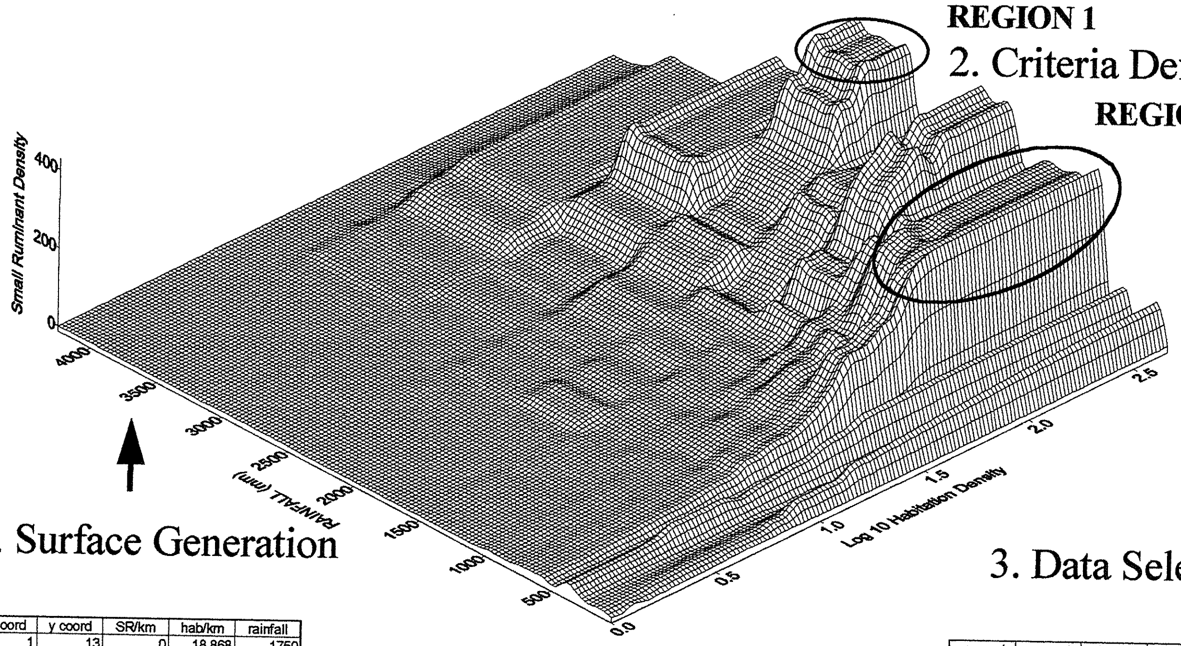
Figure 9: Agricultural System Definition

Small Ruminant Density: Habitation and Rainfall

REGION 1

2. Criteria Definition

REGION 2



1. Surface Generation

3. Data Selection

x coord	y coord	SR/km	hab/km	rainfall
1	13	0	18.868	1750
1	14	0	57.738	1750
1	15	862.231	129.415	1325
1	16	82.991	79.313	1125
1	17	884.461	22.69	1125

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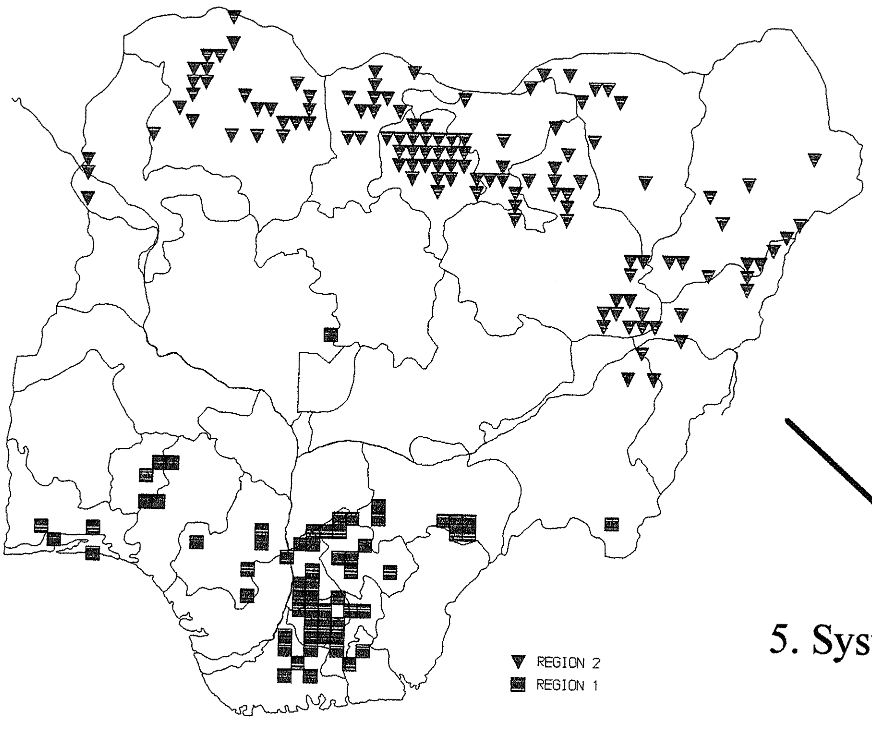
4. Map Production



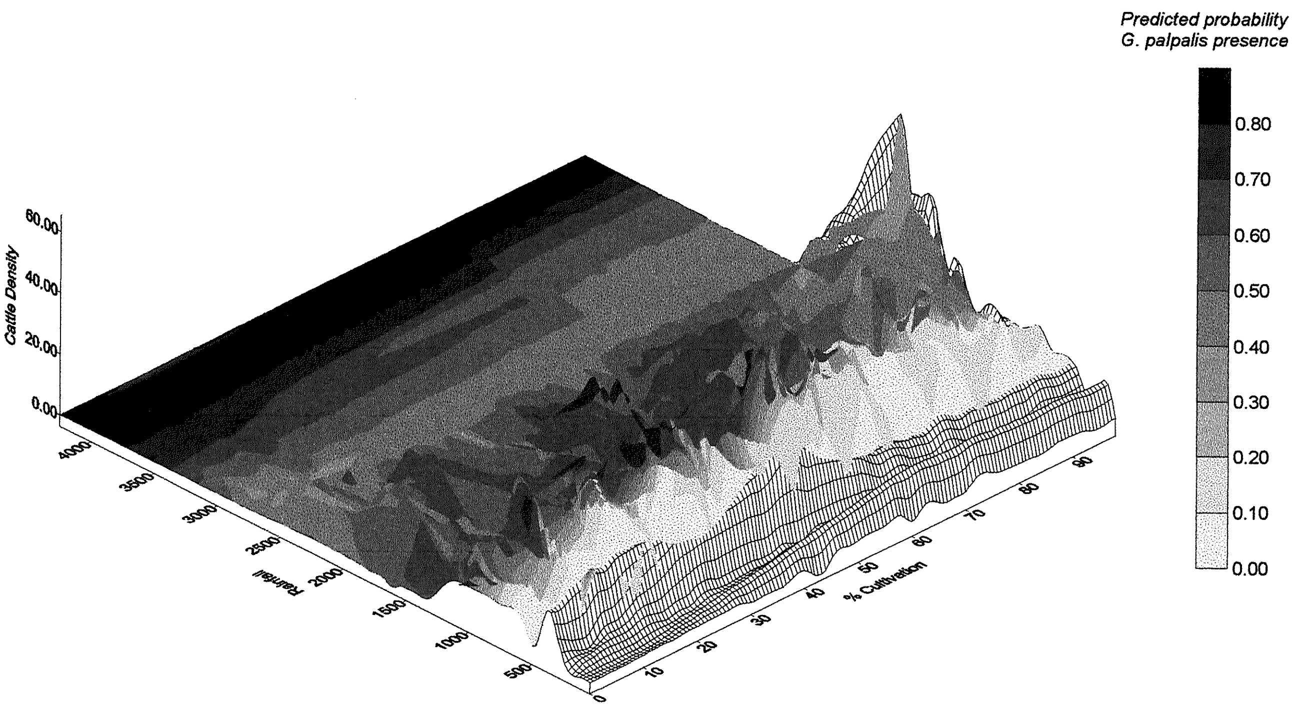
5. System Targeting

A second example might be the development of tsetse control strategies in selected African countries. This process needs to take account of such issues as where to prioritise areas for control, and which type of control (targets, community participation, or aerial spraying) is most appropriate. In this example, human and cultivation data are derived from the aerial survey data set whilst up-to-date tsetse survey data for Togo has been used to model the distribution of the tsetse *G. palpalis* using environmental data from remote sensing satellites (Rogers *et al*, 1994). The satellite data can be used to derive predictions of the probability of occurrence of this species of tsetse throughout Nigeria and these predictions are shown as the coloured overlay on the 3-dimensional surface in Figure 10 below relating cultivation, rainfall and cattle density in Nigeria.

On this surface it is interesting to note the relative restriction of cattle to areas with less than c. 2000mm rainfall annually, and their concentration, within these regions, in areas of higher rather than lower levels of cultivation. A number of other features are noteworthy. The band with more than an 80% probability of tsetse occurrence contains negligible cattle numbers; and the peaks of cattle density occur largely in those parts of the surface where tsetse are predicted to be relatively unlikely to occur.

Figure 10: Tsetse Risk Surface

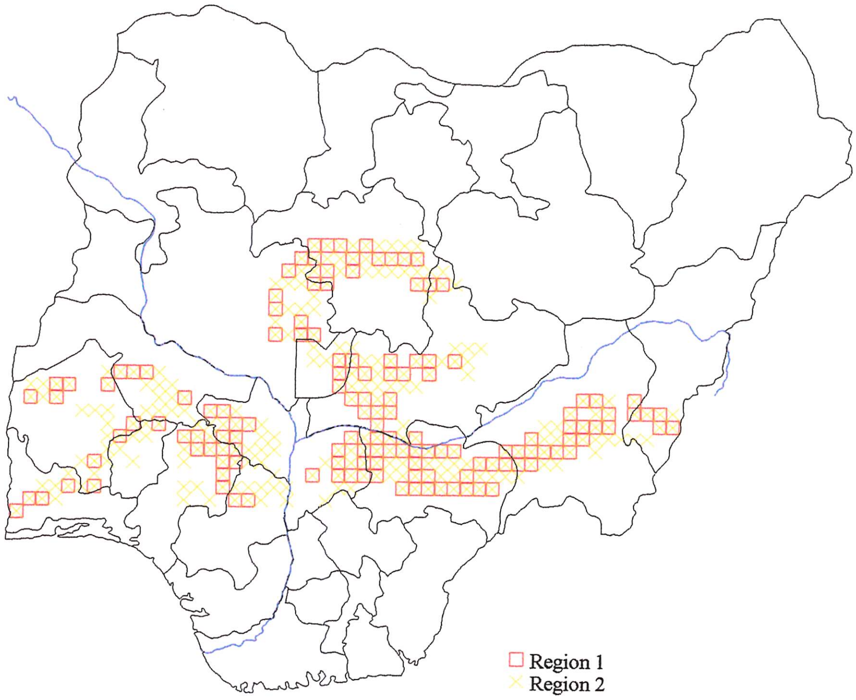
Cattle Density: Rainfall and Percentage Cultivation
Fills represent tsetse presence



Reading from this surface, the major regions where tsetse control appears to be required are those with high cattle densities and with a high probability (more than 70%) of tsetse presence. The 3-D surface shows that these areas are limited to regions with between 1250 and 1400 mm rainfall and with between 10 and 35% cultivation or areas with 1500 to 1600 mm rainfall and with 35 to 45% cultivation.

Such areas are shown as 'Region 1' on the map of Nigeria (right). If the tsetse probability threshold is lowered to 60% then most of the 1250-1600 mm rainfall band with less than 65% cultivation is included in the area to be targeted for tsetse control. These areas are shown as 'Region 2' on the map.

By incorporating data from other parts of Africa which may support different agricultural management practices the relevance of the predictions produced could be applied to a substantially wider geographical area.



2.4.5 Satellite Image Training

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 progress at the Department of Zoology, Oxford University (Rogers *et al*, 1996), 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 Oceanic and Atmospheric Administration (NOAA) series of meteorological satellites.

The results summarised here quantify the observed links between Fourier processed AVHRR data for 1987-1989, and the 1990 aerial survey data extrapolated to 1988 on the basis of known rates of change in percentage vegetation cover. Details of the Fourier processing, and its use in the interpretation of seasonal changes in vegetation cover are presented in another workshop paper and will not be elaborated upon here.

Table 4 and Figure 9, demonstrate a highly significant match between the two sets of information. This shows 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.

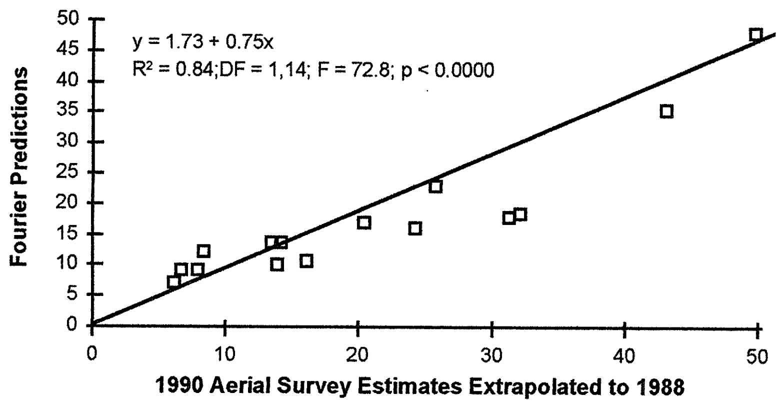
It is envisaged that this stage of the analysis will be refined further - most notably by treating the various vegetation types within the different ecological zones separately. This may well enhance the precision of the calibrations, and allow for the more accurate estimations of land use cover.

Table 4: 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 11: Comparison of Fourier and Aerial Survey Estimation of % Land Use, 1988



3. DISCUSSION AND CONCLUSIONS

The preceding discussion has demonstrated that low level aerial survey is a practicable technique for estimating a wide range of livestock, land cover and habitation parameters. Though some of the worked examples presented are not primarily related to rangeland areas, the techniques are directly transferable to rangeland monitoring - either through photography, or through visual observation.

In isolation, however, the methodology has limitations, in that it is unable to produce estimates of, for example, animal numbers in villages, nor can it provide production or productivity data. The technique is, like many other monitoring methods, most effective if it is combined with others - particularly satellite imagery and ground survey, whereupon it becomes a powerful weapon in the arsenal of resource assessment, because of its adaptability, repeatability, and the ease with which the data derived from it are integrated with other sources of geographical information. Add to these advantages, its comparatively low cost, its reliance upon relatively few specialist skills or equipment, and its rapidity, then low level aerial survey is an attractive option.

The question is whether the relatively simple technology that aerial survey represents will be superseded by more advanced technology, most especially by the use of remotely sensed satellite imagery and digital photography. Both these highly sophistocated applications undoubtedly have the potential to provide accurate assessments of vegetation, assuming that the remotely sensed data are sufficiently well calibrated, and that enough processing power and data storage is available to interpret the information. However, to date, neither is commonplace, and substantial research efforts will be required to make them so. Further, if these techniques are to be available to developing countries, extensive technology transfer and training will be required.

Whilst all things are, of course, possible, it seems unlikely that either satellite imagery or digital photography will be able to replace aerial and integrated air and ground survey in estimating animal populations, because the resolution required to detect even the larger species makes their use over large areas unrealistic, and the fixed lens/sensor viewing angle of the means that many animals are obscured by vegetation.

It appears, therefore, that there will be a place for aerial survey in agricultural resource assessment for some time to come. If so, it seems only sensible to continue to use it to obtain land cover data, given that the incremental cost of doing so is negligible, and the results obtained are not only adequate for most, if not all, monitoring purposes, but also represent a potential source of the much needed calibration for satellite remote sensing technologies.

If this is to be the case, then low level aerial survey has an important role to play, in conjunction with other resource assessment methods - not only to ascertain the population levels and, perhaps more importantly, the distribution patterns of animals in relation to resources, such as rangeland grazing, cultivation, or human habitation, but also in the validation of other remote sensing methods. A recent IFAD environmental assessment study in Jordan has identified just such an instance (ERGO, 1995), whereby the majority of the data required would be collected through satellite imagery, together with the requisite ground truthing, whilst the aerial survey component would provide the livestock related information needed to assess rangeland utilisation.

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