Integration of remote sensing techniques for resource evaluation in pastoral systems research

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Introduction

The leading assumption of this paper is that natural resource surveys and inventories are an essential prerequisite for planned development and should be integral components of the descriptive and diagnostic phases of livestock systems research.

In the past, range resource assessment at ILCA was rarely formally placed in this sequential framework, but awareness that such assessment was needed has been increasingly felt. The trends in ecological and vegetation research at ILCA is a convincing illustration. For instance, in Mali during the earlier years, emphasis was placed on detailed ecological studies on the Niono ranch in order to understand the vegetation dynamics of the upland Sahelian ecosystem. This was combined with extensive vegetation mapping in the Niger Delta and its surroundings according to the exacting procedures of the Zurich-Montpellier school of phyto-sociology. Initially, there was little concern about the application of this research to other disciplines or to the production systems within which the research was done. Such research was considered a laudable pursuit in its own right. In recent years, inter-disciplinary research has become prominent resulting in data flows from ecological research that were more oriented to the needs of range and animal nutrition science, without neglecting the pure research aspects of the work. This more pragmatic and applied approach led to maps of the ILCA study area that not only depicted vegetation types, but also contained complementary information for carrying capacity estimations and assessment of land use suitability for grazing, flooded rice and rainfed cropping.

This trend was not restricted to ILCA alone, but also noticeable in the various national and international agencies engaged in other surveys and inventories. As will be shown in the sections on resource surveys and methodology, emphasis moved from heavy and costly procedures to rapid, cost-effective and consumer-oriented data generation. Although cost escalation reinforced this trend, the knowledge that many of the earlier inventory reports remained shelf-bound and never effectively influenced their designated audiences, was more important.

This paper is designed to provide a short and selective overview of resource surveys and their methodologies that seem most appropriate to pastoral and agro-pastoral regions in Africa. Full acknowledgement must be given to Dent and Young (1980) from whose book several tables and figures are derived and on which substantial parts of the text is based. The most recent applications of remote sensing techniques are briefly summarised and put in the context of rapid appraisal methods and early warning procedures within a livestock systems research approach,

Types of surveys - a historical perspective

Soil survey

Soil survey involves the production of a pedological map, which shows the distribution of soil units defined primarily according to their morphology and their physical, chemical and biological characteristics.

These units are based on the description of soil profiles, their comparison and subsequent grouping into a classification system that is significant for the aims and purpose for which the survey was intended. Stobbs (1970) classified soil surveys in three classes from exploratory to detailed and indicated the appropriate mapping scales (Table 1). Classification of soil types varies with survey objectives but usually follows either the FAO soil map of the world (FAO-UNESCO, 1970-80) or the U.S. Soil Taxonomy (Soil Survey Staff, 1975) and the selection of what system is used depends often on the donor agency that has commissioned the survey.

General purpose soil surveys are most appropriate in sparsely settled areas in developing African countries, where there was and often still is a dearth of basic geographical information on resources. Exploratory and reconnaissance surveys provide a first approximation of such data. In densely settled areas small-scale surveys serve no direct useful purpose and instead detailed surveys are needed (Table 1). General purpose soil maps may serve as a basis for further stages of interpretation, namely land evaluation (see below), which apart from soil units includes other relevant physical, economic and sometimes social factors.

During the 1960's a large number of soil surveys were carried out in Africa. Although they were meant as a basis for a land resource inventory, they have been criticised in that their only purpose was to make a soil map, as a desirable end in itself. A more tenable criticism is the cost and time involved in describing, mapping and reporting. Dent and Young (1980) calculated that for a survey at a scale of 250,000, 100 man-days/1,000 km² were needed or about US$ 15/km² at 1980 prices, of which the actual interpretation of aerial photos (scale 1:40,000) would take 7 to 10 man-days. This is somewhat lower than the 8 man-months/1,000 km² needed for resource mapping in the Sudan (Wilson, 1979). If these costs are applied to the reconnaissance survey of the Amboseli-Kibwezi sheet in Kenya, this project of 12,600² km would have cost US$ 200,000.

Land systems survey

Although soil surveys have been used to produce derived information on land resources, capability and suitability, more direct approaches to natural resource inventory were sought, that would be more rapid and less costly. In anglophone Africa the most common approach is the use of the land system concept as the basic mapping unit for subdividing and classifying land. A *land system* is defined as an area with a recurring pattern of topography, soils and vegetation and with a relatively uniform climate. This area is subdivided into *land facets* which are the smallest areas that can be recognized and delineated on aerial photographs and are usually linked by geomorphological process. A land system can be alternatively defined as an area with a recurring pattern of genetically linked land facets.

Table 1. Types of soil survey

Type	Map units	Scale	Purpose
Exploratory	Associations of phases of great soil groups	1:1,000,000 and smaller (schematic	1. To locate areas of substantial soil difference

		maps)	(inventory) 2. Locate more detailed work 3. Test legend
Reconnaissance	Associations of phases of soil series or higher categories (great soil groups or families)	1:62,500 to 1:500,00	1. To survey areas suited only to extensive use 2. Pre-detailed survey to locate and define such work
Detailed low intensity	Phases of associations	1:30,000 & smaller	For forestry and grazing development areas

Source : Stobbs (1970).

As part of the integrated approach, derived information is reported on vegetation, range and water resources, on actual and potential land use, the latter being based on land suitability ratings for each land system and its constituent facets.

Numerous integrated surveys have been carried out by the Land Resources Division in Africa, in particular in Nigeria, Zambia and Malawi (LRD, 1966-79). In the agropastoral zone in northeast Nigeria, emphasis was put on assessing range resources, actual and potential seasonal stocking rates and associated limitations to use such as flooding, inaccessibility and tsetse challenge (de Leeuw et al, 1972; de Leeuw, 1976). From these inventories came recommendations on seasonal de-stocking requirements if a more balanced utilisation of pastoral land was desired (Tables 2 and 3). Although these recommendations were rarely actively implemented, they helped to increase the awareness of the problems in ministries and planning authorities.

In the subhumid zone in Nigeria land systems and soil mapping was followed by a detailed land evaluation based on the suitability for eight individual crops. Suitability was assessed from climatic limitations, soil physical and chemical characteristics and erosion hazards and this led to a map of crop options at a scale of 1:250,000 (Hill et al, 1978)

The main advantages of the land systems approach is speed and relative cheapness, the integration of different environmental factors and a clear communication of results (although some reports run to over 1,000 pages). Disadvantages are a high degree of generalisation, variable and somewhat ill-defined mapping units and the static nature of the information presented. Greater emphasis should be given to the dynamic aspects of environment such as soil moisture regimes, successive stages in the vegetation (cropping/fallows, effects of fire on woody/herbaceous species balance) and the interactive effects between range resources and livestock use.

Natural resource surveys and land suitability evaluation

As has already been shown above for the central Nigeria survey (Hill et al, 1978), a basic natural resource survey can lead to the production of maps and other data on which land evaluation is based.

The information needed for a range resource inventory concerns amounts and seasonal distribution of dry matter production, digestible protein, etc., but to define mapping units and to delineate their boundaries calls for some combination of vegetation physiognomy and species frequency according to established principles of vegetation mapping.

Table 2. The estimated actual and potential wet-season cattle population in northeast Nigeria (in thousands)

Zone	Estimated	Potential	Difference (%)

Tsetse-free	1,987	1,214	+ 65
Tsetse	584	2,352.	- 75
TOTALS	2,571	3,569	

Source: de Leeuw (1976).

Table 3. Potential year-round population (1000 AUs)

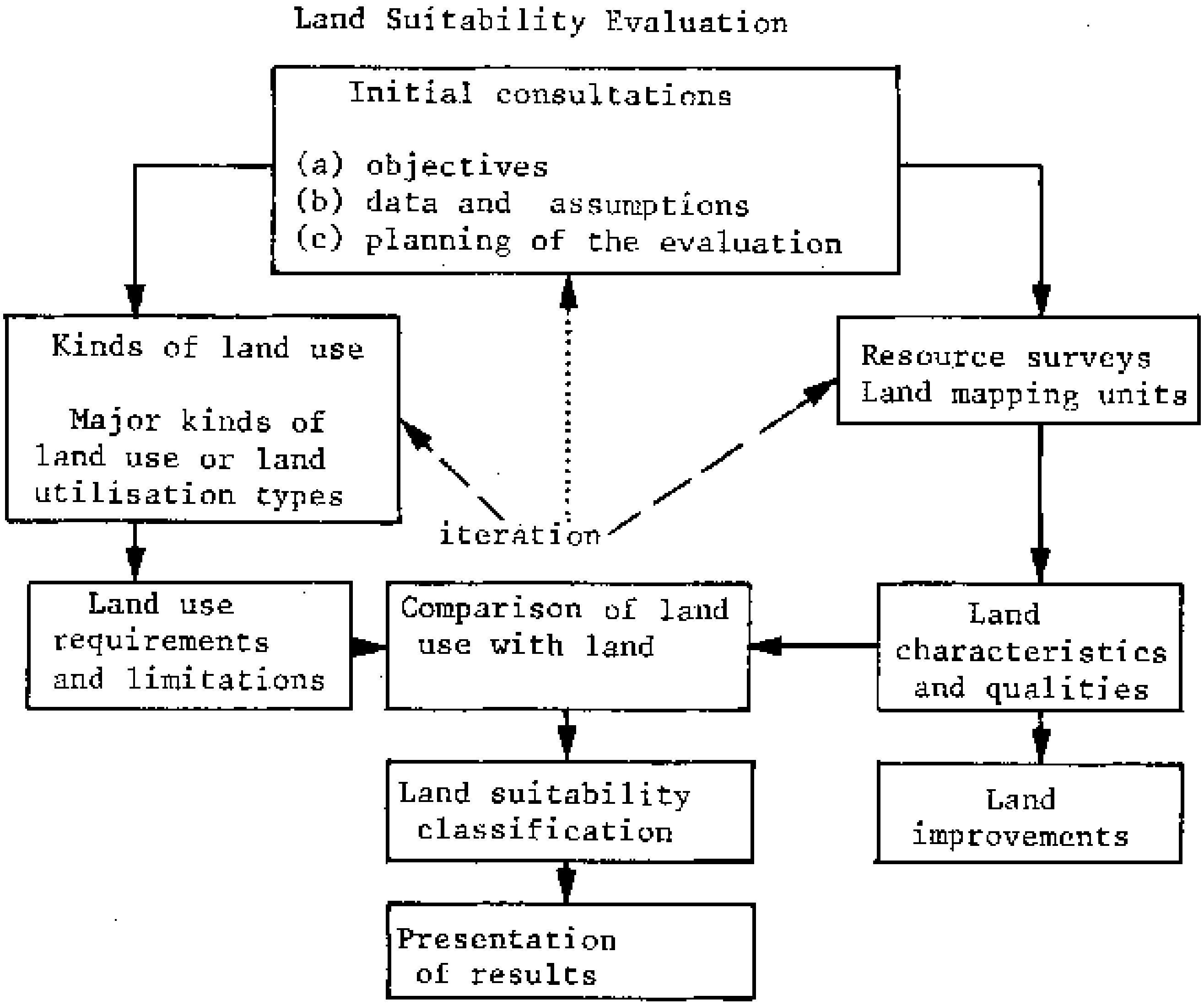
	Tsetse-free zone			**Tsetse zone**	
	wet season	**dry season**		**wet season**	**dry season**
savanna	1,000	-		1,576	972
fallows	213	148		229	115
cereal residues	-	363		-	180
alluvial/flooded land	-	840		-	400
Sub-totals	1,213	1,351		1,805	1,667
Grand total			3,028		

Source: de Leeuw (1976).

The fundamental descriptive features for livestock production systems are the types and numbers of livestock, the livestock intensity and the degree of nomadism. The livestock intensity is the number of livestock units per square kilometre of grazing land. Where present, livestock systems may be classified as total nomadism, semi-nomadism or transhumance (for definition, see Ruthenburg, 1980). These descriptive headings can also be used for the livestock component of mixed or predominantly arable farming. The activity flow-chart of a land suitability evaluation is given in Figure 1.

Source: Dent and Young (1980), p. 146

Fig 1. Schematic representation of activities in land evaluation.



The resource survey has the function of dividing the study area into a number of relatively homogenous units and of providing the information necessary to evaluate each of these units for the kinds of land use under consideration, Thus, resource surveys should not be treated as a separate activity, but as an integral part of the evaluation. For example, in a semi-arid region that is dependent on pastoralism, a survey effort would be directed towards range and water resource surveys and the determination of livestock carrying capacity. Seen in this light, the numerous surveys and mapping carried out in francophone West Africa by IEMVT could be termed pastoral resource surveys. Dent and Young (1980) enumerate the land qualities related to livestock production as follows (Table 4).

Table 4. Land qualities related to livestock production

Nutritive value of natural pastures	
Nutritive value of improved pastures	
Resistance of degradation of vegetation	
Resistance of soil erosion under grazing conditions	
Toxicity of grazing land	
Availability of drinking water for livestock	
Climatic hardships affecting livestock	
Endemic pests and diseases	

Access within the production unit	
Size of potential management units	
Location: -	(a) existing access
	(b) potential access

Source : Dent and Young (1980),pp. 166–168.

Remote sensing methodology

Remote sensing methods have been classified according to the altitude at which imagery is taken, and include satellites, and photographs and visual observations from low-flying aircraft. Satellite imagery and conventional aerial photographs usually provide total cover, whereas low-altitude aerial surveys are usually based on sampling strips. The characteristics of-these methods are summarised in Tables 5 and 6.

Table 5. Some characteristics of the different methods used in remote sensing

Vehicle	Scale of general use	Usual cover	Sensors	Primary Use
satellite	1:1,000,000-1,250,000	total	various basically scanning radiometers	mapping
high-level aircraft	1:20,000-1:100,000	total	cameras	mapping + overall quantifications of use + use of patterns
low-level aircraft	1:300-1:20,000	sampling usually quadrats	cameras	quantifications of use + use of patterns photogrammetric
low-level aircraft	not applicable non-photogrammetric	sampling usually strips	human observers and oblique small-format cameras	quantification of use + use of patterns photogrammetric
landrover, light air-craft or foot	not applicable non-photogrammetric	sampling usually quadrats, frequently linked with low-level photogrammetry	human observers using a range of resource survey equipment	'ground truth'

Source : Watson and Tippet (1981), Fig, 1.

Satellite imagery

The main source of imagery has come from the LANDSAT series, which produces monochromic or colour-enhanced images of 34,000 km^2 with a resolution of 80 m (LANDSAT-3) at a frequency of every 18 days. Thus, images at different seasons and successive years are readily available and relatively cheap.

LANDSAT is increasingly used for rapid small-scale reconnaissance surveys when mapping is envisaged at a scale from 1:1,000,000 to 250,000. Usually monochrome prints are used for landscape or land systems mapping, while false colours are more appropriate for vegetation and land use.

Interpretation of one LANDSAT image costs about US$ 20/1,000 km^2 (1980) and it is possible to map large areas in no more than a few months. Mitchel and 'Howard (1978) reported that a land systems map of Jordan (c. 100,000 km^2) was mapped on a scale of 1:1 million in 1.5 months of interpretation, one month of field work and two weeks for report preparation and printing.

In addition to LANDSAT, satellites (or aircraft) have been equipped with infrared detectors that record the far-infrared radiation of the earth's surface and can distinguish vegetation and soil types by their thermal emission characteristics. Recently Tucker (1983) used the thermal channel of the NOAA satellite to detect reflectivity differences and found that variations in dry standing biomass could be derived from remote-sensed temperature differences (Table 6).

Aerial photographs

Since the 1950s aerial photo interpretation has become an important tool for soil and other surveys, in particular for reconnaissance studies in Australia and developing countries. Black-and-white photos are most commonly used but other types of film have been tried for specific purposes: near infrared for tree differentiation in forest evaluation and false-colour photography in vegetation and land-use surveys and large-scale disease detection of crops and forests. Colour photos have been tried for mapping desert landscapes and urban fringe zones and also for sampling land use and vegetation patterns from low-flying aircraft (Watson and Tippet 1981; K. Milligan, personal communication)

Side-looking radar (SLAR)

Although SLAR has very low resolutions (Table 6), it is used for mapping regions which are rarely cloud-free to permit other methods of remote sensing. SLAR was the basis for a reconnaissance resource inventory of the Amazon basin and for a country-wide land use and vegetation map of Nigeria. The quality of this map is being tested through comparison with low-altitude vegetation sampling as well as with existing land-use maps based on aerial photo interpretation (Hill et al, 197=8; Milligan and de Leeuw, in press).

Spectral radiance

Linear or ratio combinations of two wavelength regions, red and near infrared (see Table 6), measured at ground level (1-1.3 m) at low altitude from aircraft (60-200 m) or from satellites have been used to estimate green standing biomass (Tucker, 1980). For instance in the Serengeti (McNaughton, 1979) and in the Amboseli ecosystem in East Africa (Western and Grimsdell, 1979) satisfactory correspondence was reported between clipped ground biomass and 'green machine' measurements on the ground and from low-flying aircraft at least for open grassland with a low woody cover. Estimating biomass in vegetation types high in woody cover is less promising, although Herlocker and Dolan (1980) in north-east Kenya found a good correlation between clipped green biomass of dwarf shrubs and hand-held radiometer readings, Similarly, promising results were obtained in the Sahelian zone in Senegal from radiometer readings of the NOAA-7 satellite during the 1981 rainy season. From these readings (calibrated with ground clippings) a map was made of cumulative biomass production for a 30,000 km² region in classes of 200 kg/ha in the range from 0-1,600 kg DM/ha (Tucker, 1983; Gaston and Boerwinkel, 1982).

Table 6. Some characteristics of remote-sensing systems

Remote sensing system	Wavelength	Resolution	Special facilities	Applications in soil or related surveys
normal air photography	0,4-0.7 m m	very high	-	numerous
near-infrared monochrome photography	0.7-0.9 m m (plus visible, 0.4-0.7 m m)	high	chlorophyll reflects, strongly, water absorbs	detection of drainage-impedance surface water; differentiation of tree species
true-colour photography	0.3-0.7 m m	high	ground surface	urban fringe surveys, display
false-colour photography	0.5-0.9 m m	high	emphasises variations in	vegetation and land use mapping, soil surveys in

			vegetation	intertidal zone
thermal infrared	8-14 m m	low	records heat emitted by the ground surface	none
side-looking airborne radar (SLAR)	0.8-3.0 cm	very low	penetrates cloud	possibly reconnaissance in cloud-covered areas
satellite MSS	0.5-1-1-m m	high relative to small-scale image, low relative to ground	uniform coverage of large area	coverage of very large areas, initial overview in other surveys

Source : Dent and Young (1980), Table 3.4, p. 50.

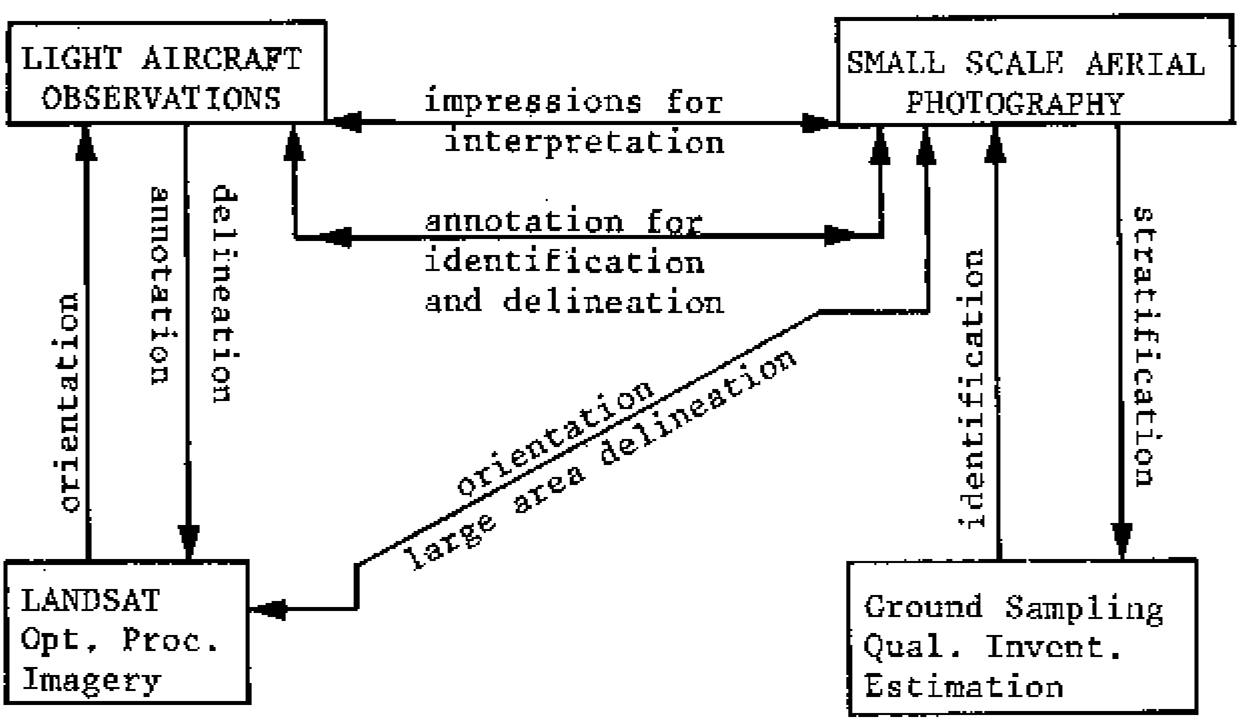
Although Tucker (1980) concluded that 'for large area surveys, the spectral method has been shown to work well and allows for synoptic coverage of large areas from aircraft and/or satellite platforms', several problems in the calibration techniques have to be resolved (solar zenith angle, sunlight vis-à-vis overcast conditions etc.) before a more general adoption of this methodology can be-recommended.

Low-altitude aerial survey

Aerial observations have become an integral part of reconnaissance and inventory surveys. For a detailed discussion, reference is made to Milligan and de Leeuw (1983) who have reviewed the aerial survey methodology within the framework of ILCA's livestock system research programmes in Mali, Niger and Nigeria.

Source : Thalen (1981), Fig. 4.

Figure 2. Possible combinations of complementary reconnaissance range land survey techniques.



The integration of remote sensing techniques and ground truth

Introduction

In most resource surveys at the reconnaissance level, information is gathered from space, air and ground and it is clear that information quality improves from space to ground as do costs. Consequently, a balance needs to be struck between extensive and intensive methods which is geared to the objectives of the survey undertaken.

Thalen (1981) reviewed the different method combinations for the evaluation and resource mapping of arid rangelands with the focus 'on assessing *what* grows *where* and when and how *good* is it. He showed that the most cost-effective approach for arid land vegetation surveys was the use of low-altitude aerial surveys in combination with LANDSAT imagery or detailed topographical maps. However, to produce a rangeland map of the Kalahari desert in Botswana (240,000 km² at a scale of 1:500,000) LANDSAT imagery at different scales was used for orientation and initial delineation of rangeland types together with complementary conventional aerial photography and aircraft observations for more detailed type identification and description as well as for stratification and subsequent ground truth sampling (Fig. 2).

A similar approach was used to describe, assess and map the natural resources of Mali south of the 18° parallel. A broad land systems map was produced from LANDSAT-2 false-colour composites enlarged to a scale of 1:200,000. With the major land systems so identified, representative sample transects were selected from false-colour images and subsequently photographed with hand-held cameras from light aircraft simultaneously at scales of 1:2,000 and 1:8,000. The resulting slides were analysed for tree and grass cover, land use and soil surface characteristics and correlated with false-colour pixel distributions on the LANDSAT prints so as to relate the latter to the real world. Transect photo data were then used for the location of ground samples for data collection on soils, vegetation and cropping. However, it is unfortunate that an appraisal of this approach has to await the publication of the maps and reports.

An integrated appraisal approach

As shown by Milligan and de Leeuw (1983) the use of aerial surveys within the different ILCA programmes has been less integrated than was desirable. Data collection from aircraft was often done as an independent exercise and data integration was carried out afterwards by interested researchers (e.g. de Leeuw and Milligan, 1981)

Having gained experience of aerial surveys in the context of livestock systems research (Milligan et al, 1982; Milligan, 1982), a better planned and more integrated approach seems worth testing. Some work has already started in the Maasai system project where aerial surveys are part of an interdisciplinary study and direct comparisons between a large volume of ground truth data and aerial survey observations can be made (e.g. Peacock et al, 1982).

The proposed approach differs from earlier work in that it is planned to execute a rapid appraisal of a target area (50,000 to 100,000 km² in size) which should deliver a comprehensive description of the resource base and the people that use it together with a constraint diagnosis of the production system in the area.

As set out in Fig. 3, the appraisal is executed in time sequence with the following steps :

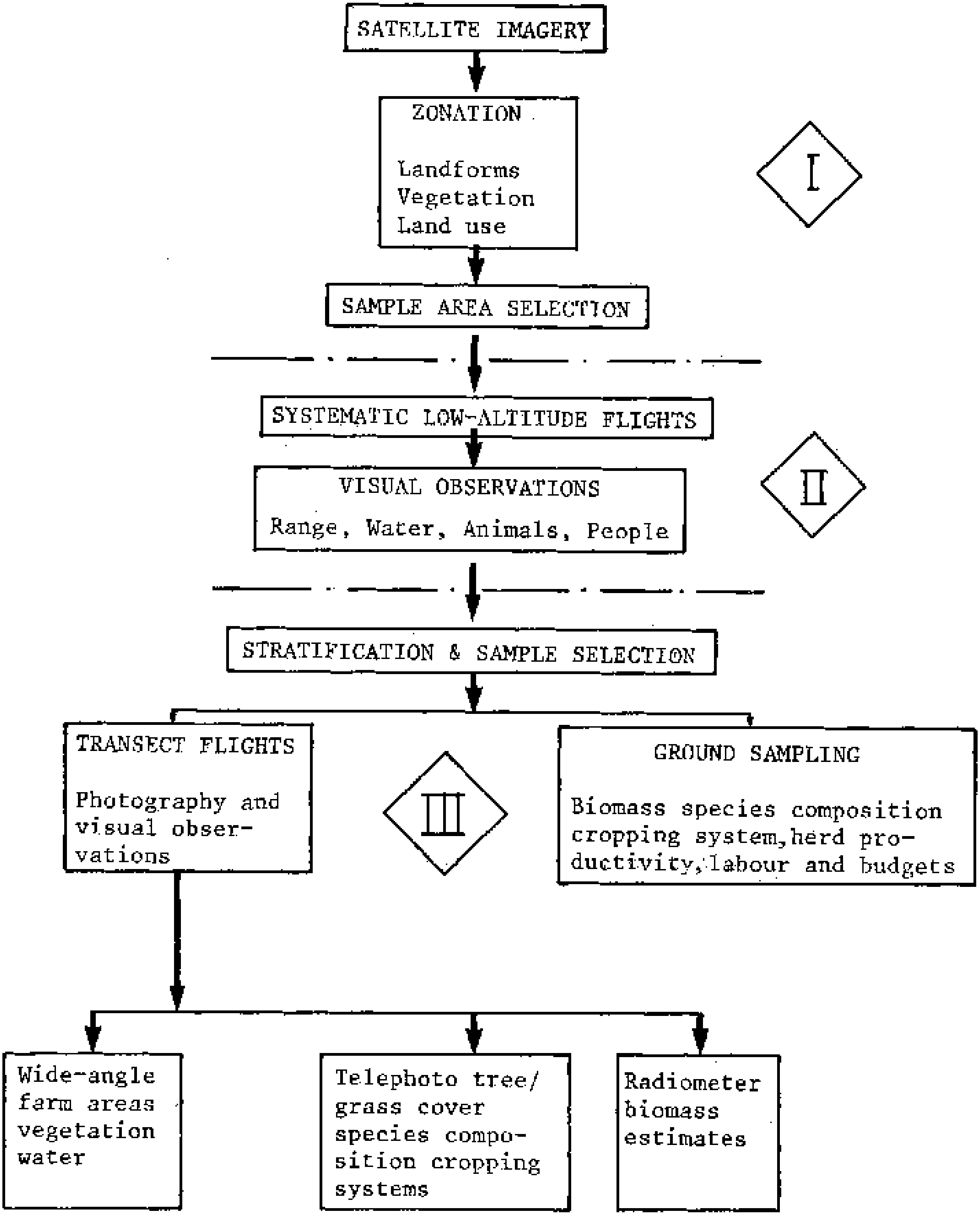
1. From satellite imagery and other information, landscape (landform or land system) units and vegetation zones are delineated and areas of particular interest defined.

2. Systematic and/or stratified low-altitude aerial surveys are carried out over the whole zone at the same or different intensities according to strata. After an initial data analysis and mapping of range, water livestock and human resource

distributions, the target area is subdivided in homogeneous 'land units', which provide the base for further aerial survey and ground observations.

3. Range resources are further assessed by multi-scale low-level aerial photography along transects and if possible, biomass estimates are made from radiometer readings followed by ground sampling of biomass for quality and quantity and species composition. At the same time ground teams select representative households for rapid appraisal of human and herd demography, labour budgets and income and expenditure. If large seasonal differences in resource distribution are expected, a second aerial survey is planned to look at all system attributes that are subject to large seasonal variations.

Fig 3. A rapid appraisal approach for pastoral systems research



Early warning procedures

Forecasting of environmental conditions, in particular of range and water resources relative to existing livestock and human requirements, would be a prerequisite for the better long-term management of fragile ecosystems that are subject to varying climatic events.

It is postulated that timely prediction is most urgent in regions with a short single rainy season and with range resources that largely consist of annual grasses. The need is much lower in regions with bimodal rainfall patterns. While in the Sahel two successive rainy seasons with poor rainfall will have a disastrous impact on long-term livestock productivity due to its two-year continuous time span, a similar event in East Africa (e.g. the Maasailand) is of much shorter duration (10-12 months).

The same is true for recovery rates following droughts. While it took nearly ten years for Sahelian cattle herds to reach their pre-drought levels, livestock populations in Kajiado (southeast Kenya) recovered in half that time. More important than population recovery has been the long-term effect of the Sahelian drought on livestock ownership patterns. Since the drought, ownership has shifted markedly from herders to outsiders (traders and civil servants). This trend is a concomitant result of the unfavourable price ratios between stock and grain during drought since many producers not only lost stock through death but had to sell at low prices to buy high-priced grain and became indebted to traders, moneylenders and others. Such a 'drought syndrome' can be reduced if pastoralists can be persuaded to react timely to the deteriorating situation by early selling of stock and early purchase of grain.

Prediction in mono-modal rainfall regions can be based on available resources at the end of the growing season. As disappearance rates of standing biomass are fairly well known and if the size of the livestock population dependent upon the resources is known from aerial surveys, the balance between supply and requirements can be calculated for the dry season. If the region covered is sufficiently large (the NOAA satellite can cover up to 600,000 km^2 in one composite image), cropping areas south of the pastoral zone can be included from which potential crop yield estimations can be derived.

Once the alert for pending drought is raised, adapted management strategies can be put into operation (supplementary feeding, mobilisation of additional water resources in under-utilised areas etc.) combined with accelerating the flow of stock through marketing channels and providing credit for early grain purchases.

The integrated approach could thus be extended to include an 'early warning' component. To be effective it is essential that biomass estimations through remote- sensing are reliable for large regions, and it thus seems worthwhile to accord a high priority to developing this methodology.

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Intégration des techniques de télédétection pour l'évaluation des ressources dans la recherche sur les systèmes pastoraux

Résumé

Cet exposé s'articule autour de l'hypothèse selon laquelle les enquêtes et les recensements sur les ressources naturelles constituent un préalable fondamental au développement planifié et devraient constituer une composante intégrale des phases de description et de diagnostic de la recherche sur les systèmes d'élevage. Le document est conçu pour donner un aperçu bref et sélectif sur les enquêtes sur les ressources et les méthodologies qui semblent les plus appropriées aux régions pastorales et agro-pastorales de l'Afrique.

Les types d'enquêtes précédemment utilisés ont notamment porté sur la pédologie, les systèmes fonciers, les ressources naturelles et les caractères des sols. Une enquête pédologique implique l'établissement d'une carte pédologique qui indique la distribution des unités pédologiques définies en premier lieu en fonction de leur morphologie et de leurs caractéristiques physiques, chimiques et biologiques. Dans l'Afrique anglophone, l'approche la plus commune se fonde sur l'utilisation du concept de l'unité territoriale considérée comme l'unité cartographique de base pour la subdivision et la classification des terres.

Les méthodes de télédétection ont été classées en fonction de l'altitude à laquelle les photos sont prises; elles incluent l'utilisation d'images transmises par des satellites, de photos et d'observations visuelles à partir d'un appareil volant à basse altitude. Les images recueillies par satellite et les photographies aériennes de type classique fournissent en général une couverture globale alors que les enquêtes à basse altitude sont généralement basées sur des bandes d'échantillonnage. La source essentielle des images recueillies par satellite provient des séries Landsat qui produisent des images monochromatiques ou en couleur de 34 000 km avec une résolution de 80 m, prises à des intervalles de 18 jours. Le Landsat permet ainsi de disposer d'images peu coûteuses aux différentes saisons et sur des années successives.

Depuis les années 50, la photo-interprétation aérienne est devenue un outil important pour les enquêtes pédologiques et autres. Les photos en noir et blanc sont les plus communément utilisées mais d'autres types de pellicules ont été essayes à des fins particulières, y compris l'utilisation de photographies de proche infrarouge et de fausse couleur. Parmi les autres techniques utilisées, on note celles du radar à vision latérale, de la radiance spectrale et des enquêtes à basse altitude. Dans la plupart des enquêtes sur les ressources, la qualité de l'information s'améliore et les coûts diminuent quand on passe de l'espace au sol. Il convient d'établir un équilibre entre les méthodes extensives et intensives en vue d'atteindre les objectifs de l'enquête entreprise. Il est proposé une approche intégrée en matière d'évaluation qui diffère de l'approche utilisée dans les travaux antérieurs en ce sens qu'elle est conçue pour permettre ´l'évaluation rapide d'une zone-cible qui doit donner lieu à une description exhaustive des ressources de base et des populations qui les utilisent ainsi qu'un diagnostic relatif aux contraintes du système de production de la zone. L'évaluation est effectuée en séries chronologiques avec les étapes suivantes:

1. Délimitation des unités de paysage et des zones de végétation et définition des zones d'intérêt particulier sur la base d'images transmises par satellite et d'autres données.

2. Enquêtes à basse altitude systématiques et/ou stratifiées sur l'ensemble de la zone à la même intensité ou à des intensités différentes selon les strates. Après une analyse préliminaire des données, et le levé de la distribution des parcours, de l'eau, du bétail et des ressources humaines, la zone-cible est subdivisée en

unités territoriales homogènes qui fournissent la base d'enquêtes aériennes et d'observations au sol plus approfondies.

3. L'évaluation des ressources des parcours se poursuit par les photographies à basse altitude à échelles multiples le long de transects et, si possible, des estimations de la biomasse sont effectuées sur la base de mesures radiométriques suivies par le prélèvement au sol d'un échantillonnage de la biomasse en vue d'en déterminer la qualité, la quantité et la composition par espèce. En même temps, des équipes au sol sélectionnent des ménages représentatifs pour une évaluation rapide de la démographie humaine et animale, des budgets, des revenus et des dépenses.

L'approche intégrée peut être élargie pour inclure une composante "système de prévision avancée". Pour être efficace, il est essentiel que les estimations de la biomasse par la télédétection soient fiables pour de vastes régions et il semble par conséquent indiqué d'accorder un rang élevé de priorité à la mise au point de cette méthodologie.
