THE GLOBAL ENVIRONMENT MONITORING SYSTEM

GEMS PAC
INFORMATION SERIES
NO. 1

NAIROBI
APRIL 1980

Selected works on Ecological Monitoring of Arid Areas

[UNI]TED NATIONS ENVIRONMENT PROGRAMME

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Corrigenda

The figures accompanying Document 5 have been transposed and some figure numbers omitted.

Figure 1 is on page 21
Figure 2 is on page 22
Figure 3 is on page 19
Figure 4 is on page 23

The figure on page 20 may be ignored.

PREFACE

The Global Environment Monitoring System (GEMS) Programme Activity Centre of the United Nations Environment Programme (UNEP) is responsible for coordinating United Nations endeavours in environmental monitoring, particularly of pollution, climate and renewable natural resources.

The system of ecological monitoring being applied by the GEMS arid land renewable resource monitoring network collects time-series information on the life-support capacities of large areas of land. The three-tiered approach, using data collected from the ground, from light aircraft and from satellites, is the result of more than a decade of research and practical application throughout the world's rangelands, Africa in particular.

The approach is today attracting widespread attention and soon nearly five percent of the world's arid or semi-arid lands will have been covered using GEMS methodology.

Increased demand for information literature has led the GEMS/PAC to compile under one cover a set of basic background literature on ecological monitoring. The list is not exhaustive, and additional references will be found cited with each paper. The papers are:

Document 1 GEMS/PAC (1979). An introduction to ecological monitoring. Information paper prepared for Meeting of UNDP Resident Representatives, Dakar, June 1979.

Document 2 GEMS/PAC (1979). Ecological monitoring for desertification. Background paper prepared for the Expert Meeting on Methodology for Desertification Assessment and Mapping, Geneva, May 1979.

Document 3 Croze, H. and Gwynne, M.D. (1978). Rangeland monitoring: function, form and results. Discussion paper prepared for the West African Rangeland Coordination Meeting, Regional Centre for Remote Sensing, Ouagadougou, November 1978.

Document 4 Croze, H., Norton-Griffiths, M. and Gwynne, M.D. (1978). Ecological monitoring in East Africa. New Scientist, Vol. 77 (1088), 2 Feb. 1978: 283-285.

Document 5 Gwynne, M.D. and Croze, H. (1975). The concept and practice of ecological monitoring over large areas of land: the Systematic Reconnaissance Flight (SRF). Paper presented at the Ibadan/Garoua International Symposium on Wildlife Management in Savanna Woodland, Ibadan, September 1975.

Document 6 Gwynne, M.D. and Croze, H. (1975). East African habitat monitoring practice: a review of methods and application. In the Proceedings of the International Livestock Centre for Africa (ILCA) Seminar on Evaluation and mapping of Tropical African Rangeland, Bamako, March 1975: 95-142.

DOCUMENT 1

AN INTRODUCTION TO ECOLOGICAL MONITORING

1. Overview

Ecological monitoring, as applied by the Global Environment Monitoring System, is a methodology which:

- increases the cost-effectiveness of agricultural and natural resource data collection,

- allows efficient detection of environmental degradation, such as desertification,

- gives both managers and landuse planners complete and up-to-date information on their country's life-support capacities.

This paper gives a brief description of ecological monitoring - what it is, how it works, what results it produces and what it costs.

GEMS/PAC
UNEP

Nairobi
May 1979

2. <u>What is Ecological Monitoring?</u>

Ecological monitoring is a strategy for collecting information on the life-support capacities of large areas of land. It is a combination of techniques which have been developed and tested, largely in semi-arid regions of East Africa, over the past decade. The techniques are relatively straight forward and inexpensive. What is innovative, is the way in which they are combined to produce a multi-disciplinary approach to the problems of optimum utilisation of natural resources.

In a nutshell, data on people, animals, plants and the earth itself (soils, landform) are collected simultaneously from <u>three levels</u>:

- from the <u>ground</u>, by mobile teams and some fixed stations;

- from the <u>air</u>, by human observers flying low over the ground in light aircraft on Systematic Reconnaissance Flights (SRF);

- from <u>space</u>, by the colour-sensitive scanners in orbiting satellites such as LANDSAT.

Aerial photographs may also be used, where they are available and where budgets allow, for additional interpretation and mapping.

The data are collected according to a Systematic sampling strategy, both in space and in time. All of the information is related to a regular grid pattern which is drawn over the area of interest. This spatial system allows easy mapping of distributions as well as analysis of the correlation between, say, the movements of pastoralists and the greenness of the grass. Moreover, data are collected at regular periods over time, so that changes in productivity and utilisation may be measured, studied and understood.

The ecological monitoring strategy is designed to improve its own cost-effectiveness. Ground techniques provide very detailed information, but are expensive to operate over large areas of land. Aerial and space techniques, respectively, supply less detailed information, but are far cheaper and quicker to apply. As an ecological monitoring programme progresses, the information collected from the three levels - ground, air and space - are compared and correlated, so that the more extensive and inexpensive methods may ultimately replace the more costly.

3. <u>What is an Ecological Monitoring Unit?</u>

An Ecological Monitoring Unit (EMU) is an operational body comprised of project manager, technical experts and field staff whose job it is to run the ecological monitoring programme.

Typical expert disciplines are ecology, soil science, agriculture, botany, remote sensing and data analysis. Depending on budgetary constraints, the expert team can be reduced, if absolutely necessary, to two people: for example, a project manager who is a pilot and ecologist, and a botanist who can deal with remote sensing and data analysis. They will be very busy people, however.

The EMU can be parastatal or set within a relevant ministry. The Kenya Rangeland Ecological Monitoring Unit, for example, is inter-ministerial, coordinated by a Steering Committee of experts and planners from the Ministries of Agriculture, Wildlife and Tourism, and Finance and Planning. It is housed in its own premises and staffed by people from both Agriculture and Wildlife.

4. <u>What information can Ecological Monitoring provide</u>?

Ecological monitoring provides quickly and inexpensively a wide range of information relevant to productivity over large areas of agricultural or natural resource land. The information is of two sorts: state and process.

Information of the state of the land, tells what the situation is like now, at a certain point in time. There are many types of questions which can be answered with inventory data from one single monitoring operation. A few examples are:

- how many cattle are in the area?
- what proportion of the land is covered by different crop types?
- what is the current landuse pattern?
- what is the woodland cover?
- what is the state of the wildlife resource?
- what is the distribution of soils suited to irrigation?

Similarly, data analysis from a single ecological monitoring programme in an area can tell about <u>process</u>, that is, what is happening in the area and what is likely to happen. For example:

- is desertification increasing? If so, why?
- how will a proposed dam effect agricultural activity downstream?
- are woodlands receding? If so, why?
- what are/will be the sociological, economic and ecological effects of an irrigation scheme?
- what are the best locations for water schemes?
- what has been the effect of a drought on livestock numbers and species mix?

.../4

Clearly such information is of use both to managers, who must make day-to-day decisions on how to run a particular part of the production system, as well as to planners, who have to account for the optimum use of large areas of land over long periods of time.

The continually up-dated information from monitoring has the additional advantage that it provides a check and measure of the effectiveness of management itself: the same methodology which provides information on which to make decisions for action, is also able to monitor the effects of the actions.

5. What is required for ecological monitoring?

The people and institutional framework required for ecological monitoring have already been mentioned under the comments on the structure of the EMU. Since the techniques vary from low to medium technology ecological monitoring requires neither very sophisticated equipment, nor a great deal of money.

The more advanced types of analysis of satellite data are exceptions; they are excellent if available, but not vital to an ecological monitoring programme.

Equipment

In order of expense of purchase and maintenance costs, the basic equipment required for ecological monitoring (with minimum capital costs in parentheses) is:

- A 4/6-seater, highwing light aircraft ($50,000)
- 2 4x4 vehicles ($20,000)
- Desk top or mini-computer ($5,000)
- 2 35-mm cameras ($1,500)
- Field equipment: camping gear, rain gauges, neutron probes, soil augers, etc.
- Office equipment: stereoscope, mapping equipment, etc.

Money

The cost of a monitoring programme is obviously a function of detail of information required. The aerial component of the programme, the Systematic Reconnaissance Flight (SRF), gives the most information for cost. An SRF can cost between $40 and $200 per 1000 km^2 of area surveyed, depending on the intensity of sampling. These estimates exclude fuel, but include pilot, observers and data analysis. Most EMUs use an intensity which averages about $105/1000 km^2.

The Kenya Rangeland Ecological Monitoring Unit, which has 10 senior expatriate and counterpart staff, some 20 support staff, 2 aircrafts and five 4x4 vehicles, covers the entire 500,000 km^2 of Kenya's rangelands for an annual running cost of $1,400 per 1000 km^2, in total about 0.5% of what Kenya earns from tourism.

6. Further information

More detailed information on ecological monitoring of natural resources may be found in the following publications:

Croze, H., Norton-Griffiths, M. and Gwynne, M.D. (1978). Ecological monitoring in East Africa. New Scientist 77 (1088): 283-285.

GEMS (1977). Model Project Proposal Document for a Rangeland Monitoring Project, UNEP, Nairobi.

Gwynne, M.D. and Croze, H. (1975a). East African habitat monitoring practice: a review of methods and application. Proceedings of the International Livestock Centre for Africa Seminar on the Evaluation and Mapping of Tropical Rangelands, Bamako, Mali, 1975.

Gwynne, M.D. and Croze, H. (1975b). The concept and practice of ecological monitoring over large areas of land: the Systematic Reconnaissance Flight (SRF). Proceedings of the Ibadan/Garoua International Symposium on Wildlife Management in Savanna Woodland, Ibadan, Nigeria, 23-25 September 1975.

Gwynne, M.D., Sella, F. and Wallen, C.C. (1978). The global environmental monitoring system: principles and progress. Pro. UNEP/WMO Int. Symp. on Global Integrated Monitoring of Environmental Pollution, Riga, USSR, 12-15 December 1978.

Western, D. and Croze, H. (1977). Monitoring rangeland resources in Kenya. International Environmental Monitoring, a Bellagio Conference, 1977. Rockefeller Foundation Report, pp. 64-71.

They are available on request from:

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The Global Environment Monitoring System
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Background paper

on

ECOLOGICAL MONITORING FOR DESERTIFICATION

prepared for the

Expert Meeting on Methodology for

Desertification Assessment and Mapping

Geneva, 14-18 May 1979

by the

Global Environment Monitoring System

Programme Activity Centre

UNEP

Nairobi

May 1979

1. INTRODUCTION

These notes are intended to be read in close conjunction with another work, Rangeland Monitoring: Function, Form and Results (Croze and Gwynne 1978), which is appended, and which should be read first.

The notes address the following subjects:

(a) Desertification monitoring as a special case of ecological monitoring.

(b) The nature of desertification assessment.

(c) Specific inputs at various stages of the monitoring process.

It is intended that together the documents will give governments a clear view of the nature and potentialities of ecological monitoring with special reference to desertification. It is planned that a fully workable field manual for ecological monitoring will be produced by GEMS within the next year.

2. DESERTIFICATION AS A SPECIAL CASE OF "DEPRODUCTION"

In arid and semi-arid rangelands, several processes of "deproduction" occur. Deproduction is a downward trend in ecosystem production. Within each year, primary production falls off as the seasons change from wet to dry. The ecological integrity of the system is kept intact by the flywheel effects of secondary producers - people and livestock stay alive, fortunately, long after the grass has whithered. Only sensitive indicators, like milk production or body condition, track closely the annual ebb and flow of protein.

Over several years, production may drop with a decrease in rainfall. Here again, a measure of ecological inertia is maintained by the secondary producers. Only after prolonged dryness does the biomass of the secondary producers drop, either through death or migration. Such longer term production often appears as though it will reach a point of no return in which there is zero nutrient turnover. When the process seems particularly well advanced, it is called "desertification", whether the cause is drought or poor land use practices.

Since ecological monitoring methodology (e.g. Gwynne and Croze 1975a and 1975b) is geared to measure all stages of deproduction, it can therefore monitor the process of desertification. The combination and correlation of data collected from three levels (ground, light aircraft, satellite), allows for a progressively more detailed picture of ecological processes occurring over very large areas.

A small-scale yet detailed picture, systematically compiled from ecological monitoring, enables one to pin-point actual and potential areas of desertification, assess their nature and estimate their extent.

3. ASSESSMENT OF DESERTIFICATION FROM ECOLOGICAL MONITORING

3.1 Critical data

A wide range of data types pertinent to the process of desertification has now been identified and catalogued (e.g. Barry and Ford 1977, Reining 1978, Gwynne and Croze 1975a). All of these data types are obtainable and quantifyable through one or more levels of ecological monitoring.

The problem is this: we are not yet in a position to know the relative importance of the controlling factors of all forms of desertification. It is, therefore, not possible at this stage to say precisely which factors are the most important to monitor, although we have some pretty strong hunches. It is clear that a major function of ecological monitoring is to collect a bank of extensive time-series data in order to understand the dynamics of production systems. A major function of the analysis of monitoring data is to give insights into the causation of production trends, such as that of desertification.

It must be emphasized that the relative dirth of knowledge need not retard action. Indeed, both management and land use decisions have been made after the very first data collection foray in an ecological monitoring programme (Croze and Gwynne 1978).

3.2 Components of desertification assessment

The correct analysis of monitoring data should yield a set of results which form the components of an assessment of desertification. These components could, at least in part, also form the basis for map legends for display. A list of the components would include:

(a) Process. What type of desertification is occurring.

(b) Rate. How fast it is occurring.

(c) Extent. How widely it is occurring.

(d) Effect on productivity. How the process is effecting both primary and secondary productivity in the short and long term.

(e) Hazard. What is the risk in the area of the occurence of desertification.

Data collected from the now-standard ecological monitoring methodology are able to provide the analytical basis for desertification assessment.

3.3 Who uses the information?

Once monitoring has been set up, data analysed and management plans implemented, it is the task of an ecological monitoring unit to carry on work and measure the effects resulting from theimplementation of the plans themselves. The agency responsible for initiating the work must insure that there exists the institutional establishment which will respond to, and take action on, the monitoring information. In nearly every government such establishments exist; it is vital to identify them and bring them fully into the picture as early as possible in the programme.

4. TIME AND RESOURCE NETWORK OF MONITORING ACTIVITIES

The flow chart of monitoring activities in Fig. 1 shows the necessary steps for implementing a programme of resource and hence desertification monitoring from the initial stage of government interest through data collection and analysis to report preparation.

It has been modified slightly from that originally prepared for use in a model project document for a Pilot Project to Monitor Arid Ecosystems (GEMS 1978) and subsequently used in Croze and Gwynne (1978).

Table 1 is a compendium to be used with the flow chart. It estimates order of magnitude costs and input requirements for each stage of the monitoring process. It is assumed for this purpose that an initial project will run for three years, will be comprised of three senior experts, and will cover an area of some 100,000 km^2. During the period, a programme of resource monitoring will be conducted from the three levels: ground, air and space. There will be a total of five systematic **reconnaissance** flights.

The cost allocations are realistic, but obviously very approximate. The operational details are not given here; many are referred to in Gwynne and Croze (1975), most are published in various technical papers, and a complete Ecological Monitoring Handbook is in the process of being produced by GEMS.

REFERENCES

Berry, L. and R.B. Ford (1977). Recommendations for a system to monitor critical indicators in areas prone to desertification. PID, Clark University, Wocester, Massachusetts. 121 pp.

Croze, H. and M.D. Gwynne (1978). Rangeland Monitoring: function, form and results. Discussion paper prepared for West Africa Rangeland Monitoring Coordination Meeting, Regional Centre for Remote Sensing, Ouagadougou, Upper Volta, November 1978. 8pp.

Gwynne, M.D. and H. Croze (1975a). East African habitat monitoring practice: a review of methods and application. Proceedings of the International Livestock Centre for Africa Seminar on the Evaluation and Mapping of Tropical Rangelands, Bamako, Mali, 1975.

Gwynne, M.D. and H.Croze (1975b). The concept and practice of ecological monitoring over large areas of land: the Systematic Reconnaissance Flight (SRF). Proceedings of the Ibadan/Garoua International Symposium on Wildlife Management in Savanna Woodland, Ibadan, Nigeria, 23-25 September 1975.

Reining, P. (1978). Handbook on Desertification Indicators. AAAS, Washington D.C. 141 pp.

Fig. 1

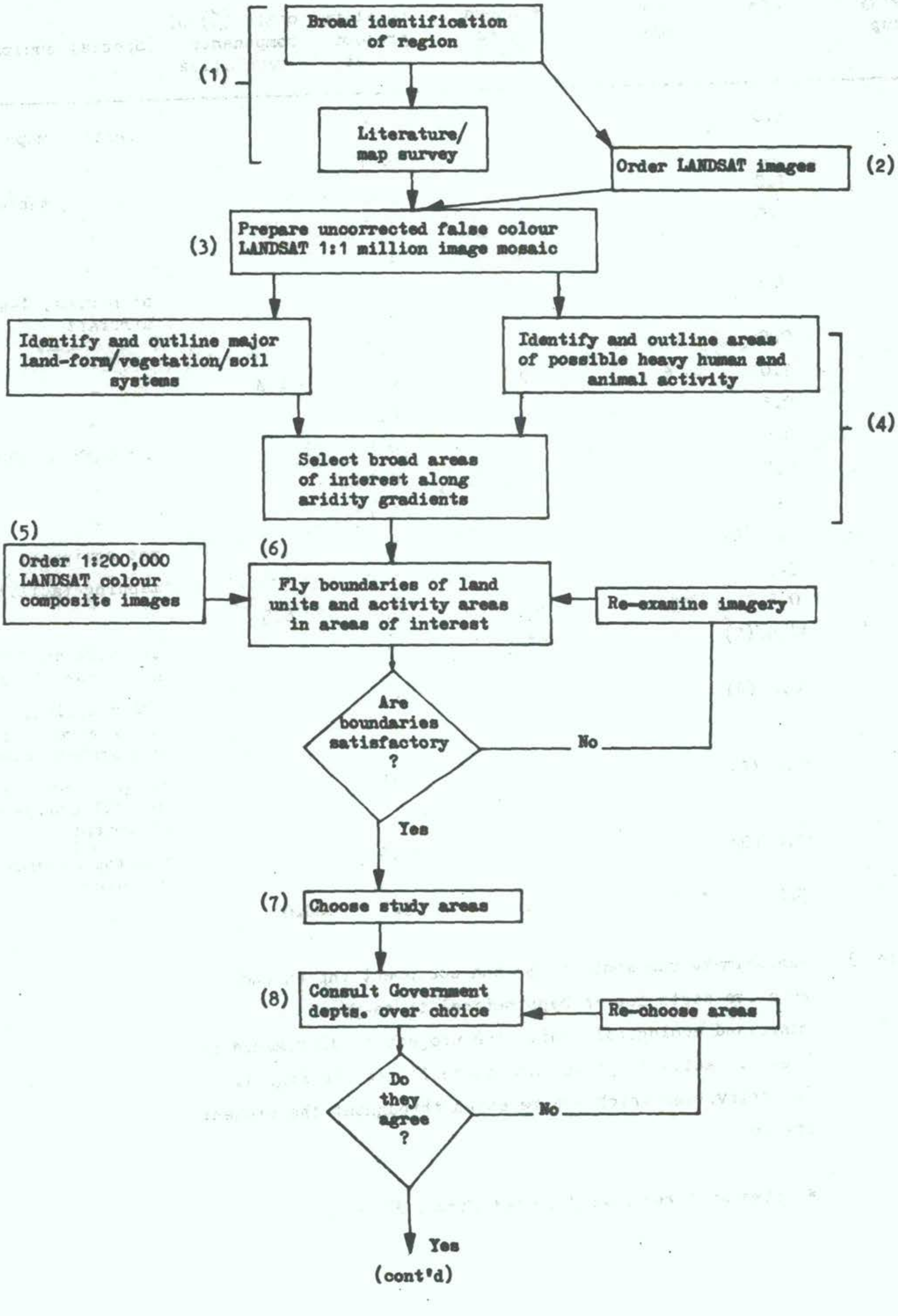
Flowchart showing sequence of activities in an ecological monitoring unit. The numbers in parentheses identify activity groups to cross refer to Table 1. (SRF = Systematic Reconnaissance Flight; GW = Ground work)

Activity group	m/m	cum. m/m	elapsed time (mo.)	relative project cost	costs (%) of components cumulative	Special equipment
1	2.0			0.7		library, maps
2	-			0.1		-
3	1.0			0.3		drafting table, etc
4	1.0			0.3		-
5	-			0.1		-
6	0.5			0.4		high-wing, 4-seat aircraft
7	0.5			0.2		-
8	1.0	6	2	0.3	2.4	-
9	0.5			0.3		-
10	0.5			0.5		aircraft as for (6)
11	0.5			0.2		-
12	-			0.1		-
13	3.0 (R)			1.2		met equipment
14	3.5			1.7		mapping facilities
15	0.5	15	5	0.1	6.5	-
16a	14.5 (R)		8*	26.7		aircraft as for (6) small format camera
16b	30.0 (R)			40.0		4x4 vehicles, camping gear, neutron probes, etc, et
16c	10.0 (R)			10.0		image viewing or digital analysis equipment
17	30.0 (R)			13.5		desktop or mini computer
18	9.0	108	36	3.3	100.0	-

Table 3 Approximate man-month (m/m) and equipment inputs and relative costs for an hypothetical three-year rangeland ecological monitoring project as diagrammed in Fig. 1. Activity groups are those flagged in Fig. 1. (R) activities which are repeated throughout the project period

* time of first useful output from SRF data.

Figure 3: Flow chart of project work procedure



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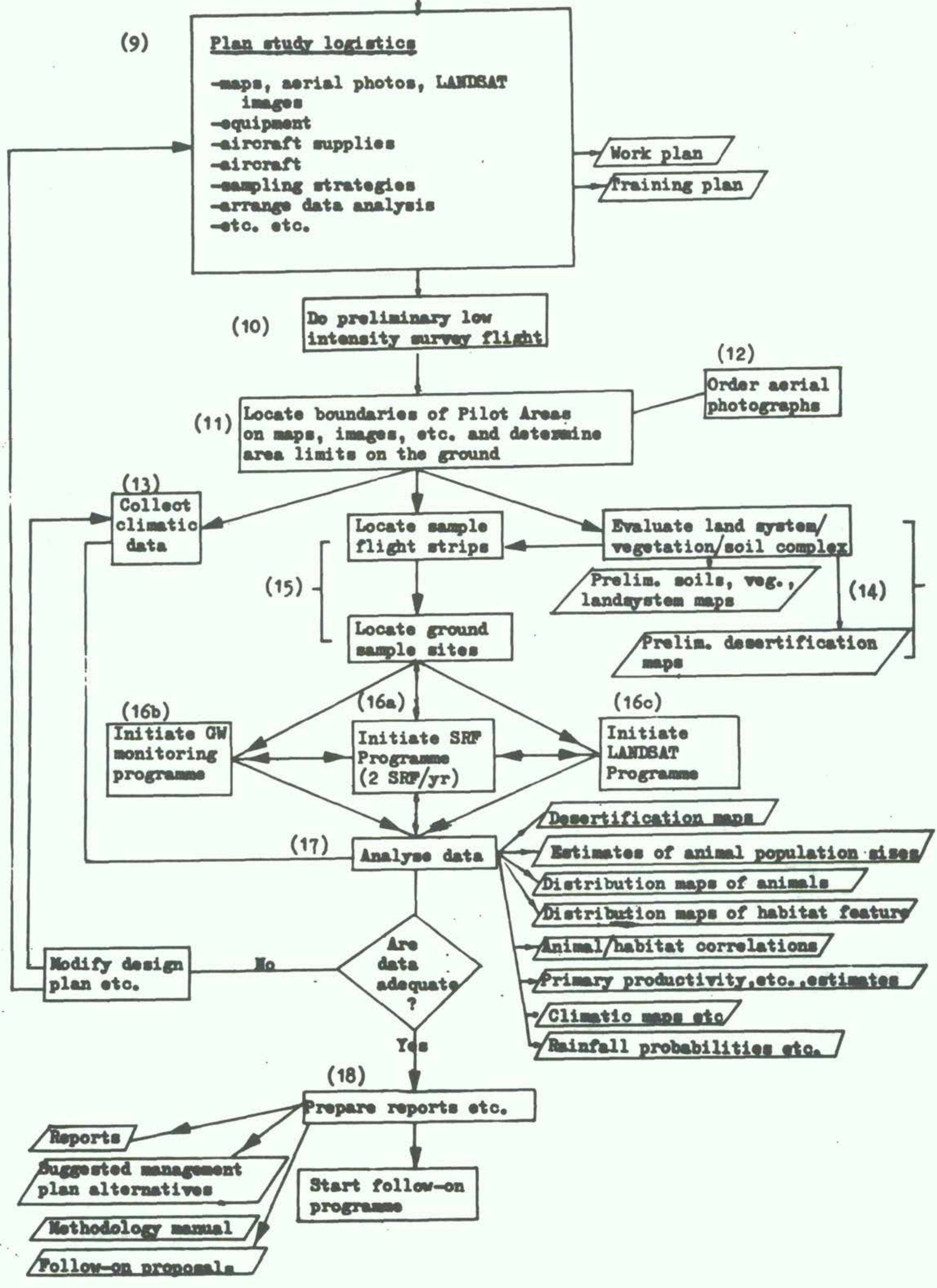

RANGELAND MONITORING: FUNCTION, FORM AND RESULTS

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DISCUSSION PAPER PREPARED FOR THE WEST AFRICA RANGELAND MONITORING COORDINATION MEETING, HELD AT THE REGIONAL CENTRE FOR REMOTE SENSING, OUAGADOUGOU, UPPER VOLTA, 20-24 NOVEMBER 1978

RANGELAND MONITORING: FUNCTIONS, FORM AND RESULTS

Introduction: The Functions of Rangeland Monitoring Data

Semi-arid rangelands throughout the world share a number of common properties. They are characterised by extensive grasslands, which have: high rates of nutrient turnover, large variations in annual production, ad hoc strategies of utilisation by nomadic pastoralist populations, and environmental controlling factors, notably soil and rainfall, the latter being highly discontinuous in space and time. Traditionally these areas have been left to the typically independent pastoral people largely because of administrative remoteness and the relatively 'low potential' for intensive agricultural or husbandry enterprises. Increased attention is now being focused on rangelands. The reasons are complex: the spread of agriculturalists and the attendant government interest and infrastructure; the need to bring outlying border regions under central control; a global protein deficit; and, more recently, a series of dry years which have resulted in considerable loss of human and domestic stock life.

The main objective of governments responsible for such rangelands is to manage production systems there in order to optimise the welfare of the people in the long term. This objective is underlain by the implicit assumption that land use planning for such areas will facilitate their management. These 'levels' of objective are inextricable from each other: one plans in order to manage for the good of the citizenry.

A system must be understood in order to be managed properly. The understanding is derived from data collected and analysed in ways which elucidate the dynamics of the ecological, economic and sociological processes which characterise the areas in question. As the term implies, monitoring is the systematic collection of information in time.

Although activities associated with land use planning and day-to-day management have the same ultimate objective, as indicated above, operationally, they deal with different time-scales. Planning activities investigate the various options for land use in an area, i.e. what is currently going on, and what is possible over a long term. Management is concerned with relatively short-term campaign strategies to deal with changes in production (primary and secondary) for a given set of environmental circumstances in order to maximise secondary production. At this stage we begin to look critically at the methods necessary to do the job. The classification of rangelands or the measurement of grassland trends are important as means rather than end-products of management. Primary productivity (grass, shrubs and trees) is the principal natural resource with which rangeland monitoring is concerned. But, it is only of interest because it is food for livestock which in turn support people.

In order to reduce costs, operational agencies must seek a set of methodologies which, with a minimum of modification, are useful to both planners and managers. It is believed that recently-developed ecological monitoring strategies are able to serve both masters.

Monitoring Methodology: Combinations and correlations

The "monitoring methodology" is not a rigid strategy, but is rather the often *ad hoc* combination of intensive and extensive techniques to provide useful data for planning and management of large tracts of rangelands. Through correlations between intensive and extensive data bases (ground to air to satellite), useful and cost-effective statements can be made about actual and potential production. It is recognised however, that in the process of correlation some precision will be sacrificed. The manager must carefully design his sampling to minimize the loss of information on the one hand but yet not become too detailed on the other. (The Manager who knows everything about 1000 km^2 will not be of much use to the Planner who must deal with 100 000 km^2, unless he (the Manager) has some basis for extrapolating his results).

Thus a primary management consideration in ecological monitoring is to balance effectively the low cost of extensive data collection techniques with the need for high-quality information from intensive data collection techniques. To take extremes: a LANDSAT image produces, in the first instance, low-information data at a cost of approximately $0.01 per square kilometer. On the other hand, a vegetation survey carried out by a ground team produces detailed data at a cost of the order of $100.00 per square kilometer. Clearly the information quality of the extensive approach must be improved to be of much use, while the cost of the intensive approach must be lowered to be practical. The former can be done very quickly; the latter can be hardly done at all.

The ecological monitoring methodology advocates the simultaneous application of data-collection from three levels: the ground, by teams sampling in time and the air, in Systematic Reconnaissance Flights (SRF) from light aircraft and space, from LANDSAT visual or digital data, (Gwynne and Croze 1975a; Croze et al 1978).

It has been argued (e.g., Gwynne and Croze 1975b) that the most cost-effective 'first look' at a rangeland area on which to base subsequent data-collection strategies is the SRF. If the SRF is repeated in time, the quality of the data, such as population estimates of animals or patterns of seasonal change in primary production, becomes more precise. The precision is enhanced if the SRF programme is run concurrently with collection of information on the ecological state on the ground. Time series ground data also improve in quality as patterns of production change are related to controlling factors (rainfall and soil type) and modifying factors (animal use, fire, influence of man).

If the third tier of data acquisition, satellite imagery, is added to the scheme, it becomes possible to relate both mico-events in production recorded on the ground, as well as meso-events in animal distribution from SRF to the macro-scale produced by a set of LANDSAT spectral reflectance signatures over hundres of square kilometers (e.g. Gwynne 1977).

The combinations of methods allows correlations between them, which eventually should result in the phasing out of the more expensive intensive techniques. Management and planning decisions may then be made as a matter of course, using the cheapest data collection technique, backed up and checked at a manageable frequency with quality control air and ground samples. Fig. 1 illustrates the application and progression of methodologies schematically.

Up to the present, however, no area has yet arrived at this happy state in which a time-series of satellite-generated data provides policy makers with the necessary information on which to plan and manage. We are still at the stage of tentatively combining the methodologies and extracting the correlations.

The reason for this retarded state of the art lies largely in an inherent conservatism among ground or aerial-orientated researchers to expand beyond their predisposed data-collection platform. Another, more practical reason, is the lack of easily accessible, easily usable data analysis facilities. The advent of the interactive, user-orientated mini computer is largely overcoming this practical constraint.

In the meantime, therefore, while this correlative data base is being built up, planning and management agencies are receiving usable information from the monitoring system. This occurs largely because of the flexibility of the monitoring strategy. With a basic understanding of the nature of the problems, useful information may be obtained from any particular one or nearly any combination of the three tiers of data collection. Brief tabloids of results obtainable from SRF and from visual analysis of LANDSAT data are given in Tables 1 and 2 respectively.

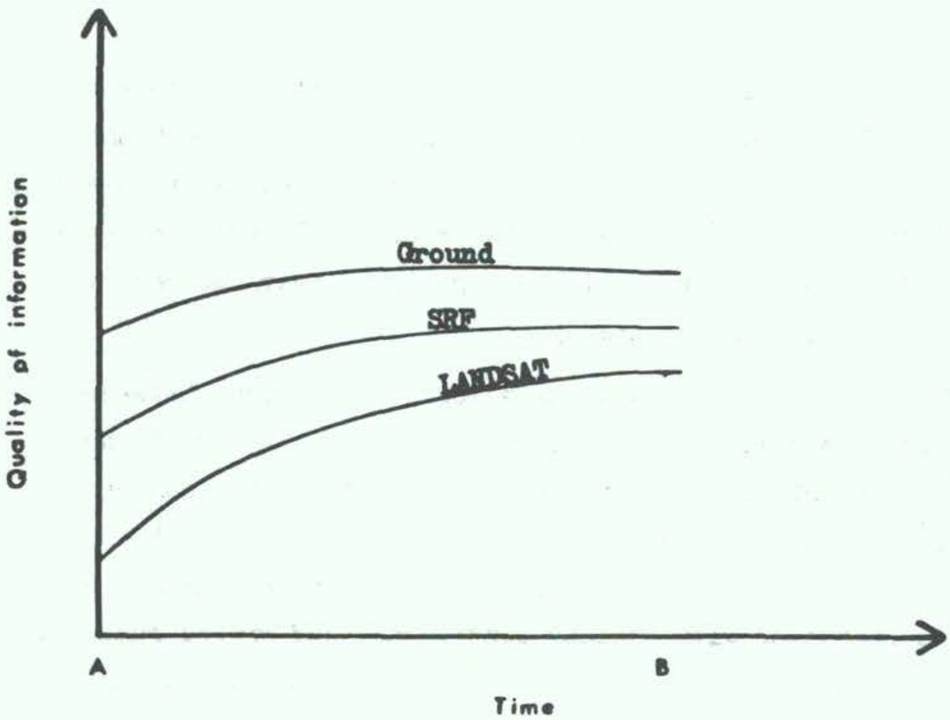


Figure 1. Information Quality from three levels of Ecological Monitoring

A. At the onset of the monitoring programme, ground work produces high quality information but is too expensive and too detailed to supply management data for very large areas. The quality of remotely obtained data from Systematic Reconnaissance Flights (SRF) or from satellite imagery is relatively low, but extremely useful for first approximations.

A-B. Simultaneous data collection and synthesis from three levels allows correlations between the results of extensive and intensive methods. If the correlations are satisfactory, then the extensive way begins to replace the intensive.

B. At this point, the quality of the information from the extensive methods is such that the more intensive (and expensive) methods are phased out and repeated only as occasional checks. High-quality information may then be obtained at relatively low cost for very large areas.

Cost of Monitoring: Value for Money

Although the SRF rests somewhere between ground work and satellite imagery analysis in terms of information quality, particularly at the outset of the investigations, its cost effectiveness is considerably higher. This is a difficult point to quanlify directly. Certainly an examination of Table 3 indicates that the flying and data acquisition part of an SRF programme is relatively inexpensive. For example, at a 10 kilometer intensity, it would cost $13,000 to cover an area of 100,000 km^2, roughly three times the size of the Sahelian zone in Upper Volta. For this outlay, one would get data on the attributes listed in Table 4, taken from Gwynne and Croze (1975a). Comparable information collected from the ground, or from aerial photography with ground checks would take many man hours of collection while, obviously, only the crudest of relationships could be derived from the first set of uncorrelated LANDSAT images.

As the monitoring programme progresses and the correlations between the various levels of data acquisition increase, the relative cost relationships between the three levels of data acquisition change. Fig. 2 is an attempt to express these changes. It can be seen that the costs per unit of information from SRF are consistantly lower. Those of ground work are high and improve only slightly with time. The initial high cost and subsequent dramatic improvement of the cost rate for LANDSAT information occurs because after relatively expensive initial ground correlation a remarkable level of detail is eventually possible for very large areas of land. It never quite reaches the effectiveness of SRF, largely because it is unable to cope with the difficulty of accounting for the whims and biomasses of secondary production(i.e. domestic livestock and wildlife).

Information Flow: Development of a Work Plan

Results are what managers and planners require, and it is appropriate to consider the organisation of the flow of information to attain the results. Fig. 3, adapted from a Rangeland Monitoring

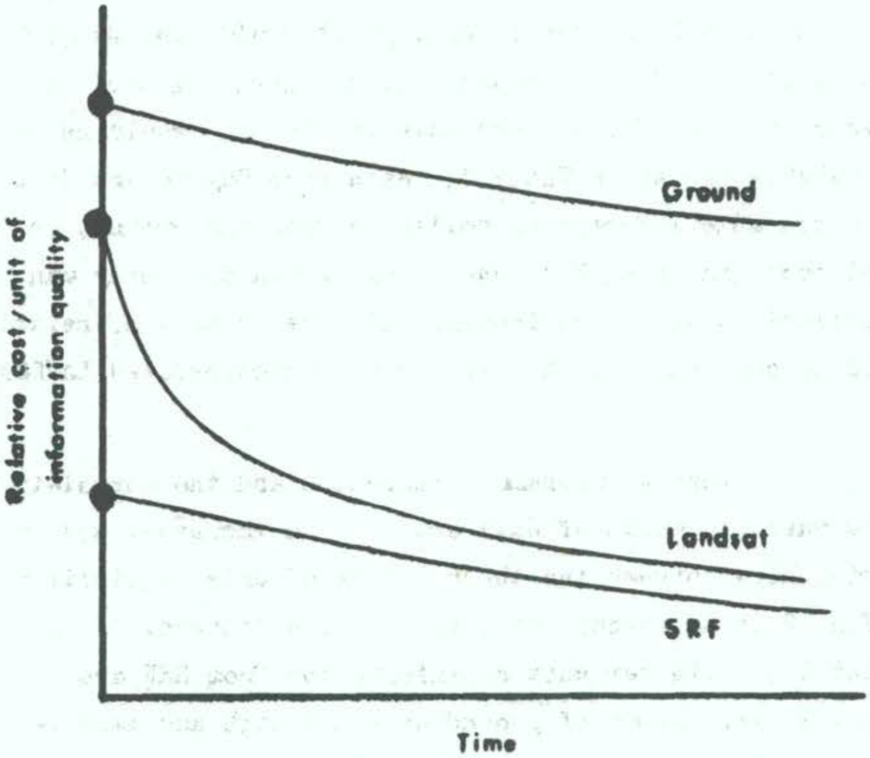
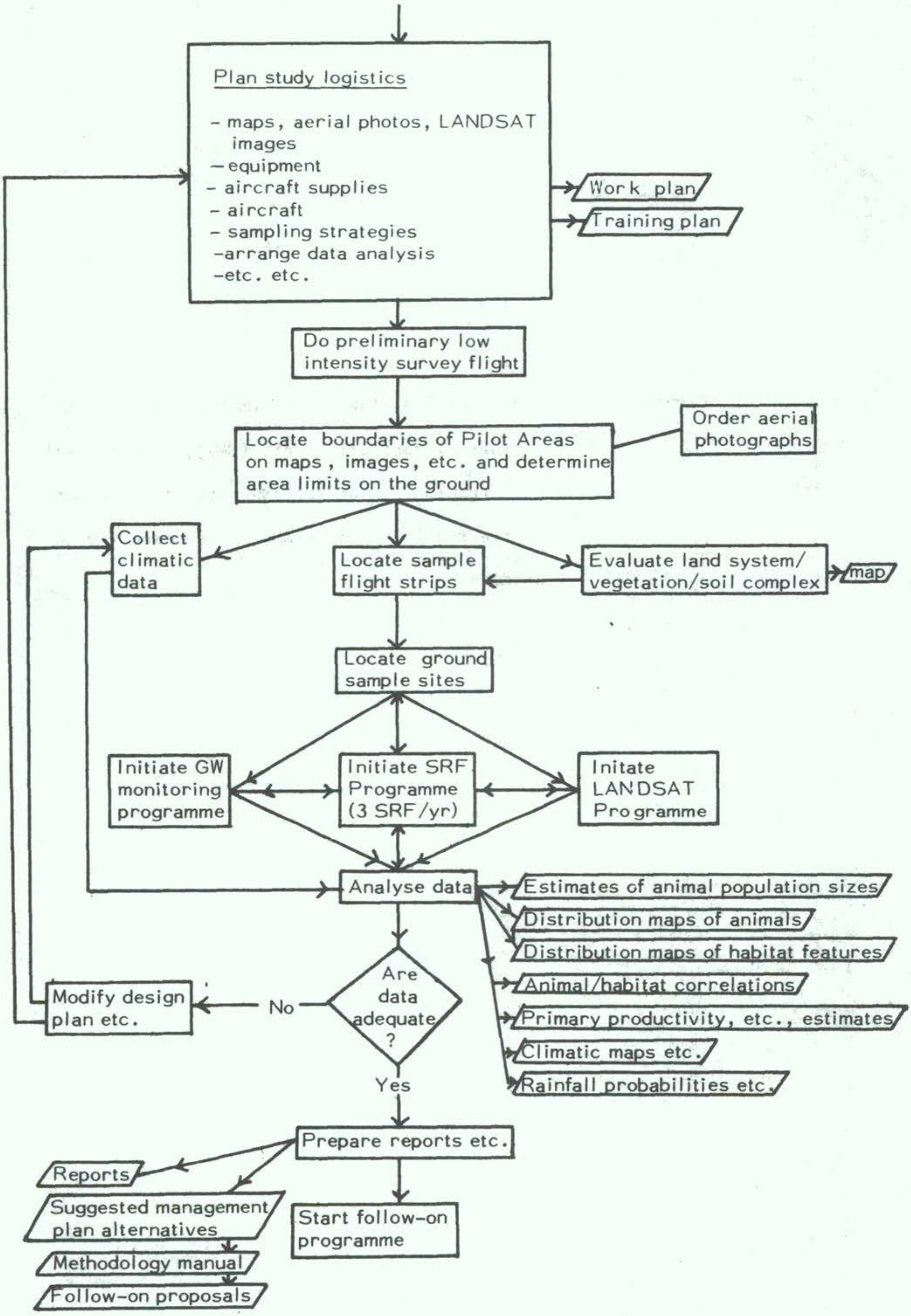


Fig. 2. Shows diagramatically the relative changes in cost per unit of information collected from the ground, from LANDSAT imagery and from SRF.

Figure 3: Indicates the flow of information through an Ecological Monitoring Unit (EMU), together with the organization of the EMU work plan and some of the results that an EMU can be expected to produce


Plan study logistics
- maps, aerial photos, LANDSAT images
- equipment
- aircraft supplies
- aircraft
- sampling strategies
-arrange data analysis
-etc. etc.
Work plan
Training plan
Do preliminary low intensity survey flight
Locate boundaries of Pilot Areas on maps, images, etc. and determine area limits on the ground
Order aerial photographs
Collect climatic data
Locate sample flight strips
Evaluate land system/ vegetation/soil complex
map
Locate ground sample sites
Initiate GW monitoring programme
Initiate SRF Programme (3 SRF/yr)
Initate LANDSAT Programme
Analyse data
Estimates of animal population sizes
Distribution maps of animals
Distribution maps of habitat features
Animal/habitat correlations
Primary productivity, etc., estimates
Climatic maps etc.
Rainfall probabilities etc.
Modify design plan etc.
No
Are data adequate ?
Yes
Prepare reports etc.
Reports
Suggested management plan alternatives
Methodology manual
Follow-on proposals
Start follow-on programme

Project Document (GEMS 1977) shows a typical work plan strategy designed to organise data collection and dissemination of analysed information to managers and planners. The steps are logical and simple: one plans the approach, executes the initial stratification from a low intensity survey flight, fixes preliminary operational boundaries over the study area, initiates data collection from the three levels (ground, air and space), analyses the data, produces preliminary results, reviews the depths and scope of the information obtained, (revises data collection, if necessary), prepares reports for operational units (management and planning), and initiates follow up programmes.

Given careful organisation in the initial planning phase and a degree of bureaucratic autonomy (to minimise time-consuming delays, such as interministerial squabbles over territorial rights), there is no reason why the review state ('Are the data adequate') cannot be attained within eighteen months from the inception of the monitoring project. This suggests that managers and planners can have relevant reports in hand less than two years after the starting date. Moreover, due to the flexibility of the strategy, the full programme can be short-circuited in cases of urgent need for rapid policy decisions, and bear fruit after the first half year (cf. the Rukwa, Tanzania, case study).

Case Studies: Monitoring for Planners

Southern Tanzania: A single SRF coverage of 30,000 km^2 in the Rukwa region of Tanzania determined the current distribution of infrastructure, domestic livestock and wildlife (Ecosystems 1978a) which allowed a preliminary land use plan for the area (Rodgers 1978) to be prepared in less than a half a year from the time of data acquisition.

Kenya: As part of the International Bank for Reconstruction and Development (IBRD) Tourism loan to the Government of Kenya

(IBRD 1975) SRF data are being used to identify the ranges of 'very large herbivore' (elephant, rhinoceros, buffalo, hippopotamus and giraffe) populations vis à vis current land use patterns in order to produce a set of land use options which make the best use of this particular sector of the wildlife community.

Saudi Arabia: Water development for livestock production in the Arabian shield south is using SRF data on aerial photographs to outline the seasonal ranges of livestock as an aid to effective deployment of a water scheme network (Ecosystems 1978).

Kenya: SRF monitoring data has identified concentration and dispersal areas for wildlife and domestic livestock allowing planners to decide where to allocate effort in developing the two types of enterprise (FAO 1978).

Kenya: A combination of ground and SRF Monitoring data (Western and Croze 1977), identified areas of differential utilization of primary production and seasonal dispersal of livestock and wildlife. The data were used in the delineation of land use zones and in the deployment of watering points to increase available forrage to pastoralists herds.

Case Studies: Monitoring for Managers

All in Kenya: Analysis of SRF monitoring data has produced figures which identify potentially dangerous rates of decline in those wildlife species which are important as attractors of foreign exchange from tourist revenue. Grevy's zebra and elephants have declined by 60% since 1972 (Western 1978; Dirschl and Wetmore, 1978; and Hillman 1977).

Based on distribution data from SRF, compensation for potential domestic stock grazing foregone to wildlife has been calculated for three key wildlife/pastral areas (Ecosystems 1978c).

Using inexpensive visual analysis of LANDSAT false colour images and average herbivore occupancy data from SRF, it has been found that LANDSAT spectral reflectance catagories are better predictors of animal (domestic livestock and wildlife) occupancy than conventional rainfall and evapo-transpiration indices (Gwynne 1977).

Studies of community dynamics of wild herbivores from SRF distribution and numbers data related to ground production data has provided base-lines for assessing effects of various park management strategies (Western 1973, Cobb 1976).

Comprehensive Resource Assessment Programme

The flow of information, beginning at the determination of the existing state of knowledge of an area through the acquisition of further data and its evaluation to management and planning, is shown in Fig. 4. Information moves from the particulate in the initial stages to the general in the latter part, and is structured by the evaluation process into forms suitable for short term operation by managers and for long term land-use allocation by the planners. It must be emphasized that throughout data are drawn from a number of disciplines - agriculture, ecology, sociology and economics - and that management and planning cannot take place without information from all of them.

The diagram also makes clear the close relationship between monitoring, research and evaluation and indicates the need for a single body to be responsible for the collection, processing and dissemination of information for this activity cluster. At the national level this can best be done through a national government ecological monitoring unit such as that established in Kenya (Kenya Rangeland Ecological Monitoring Unit).

Figure 4: Indicates the relationship between inventory, monitoring and management. See text for a full discussion.

Figure 4

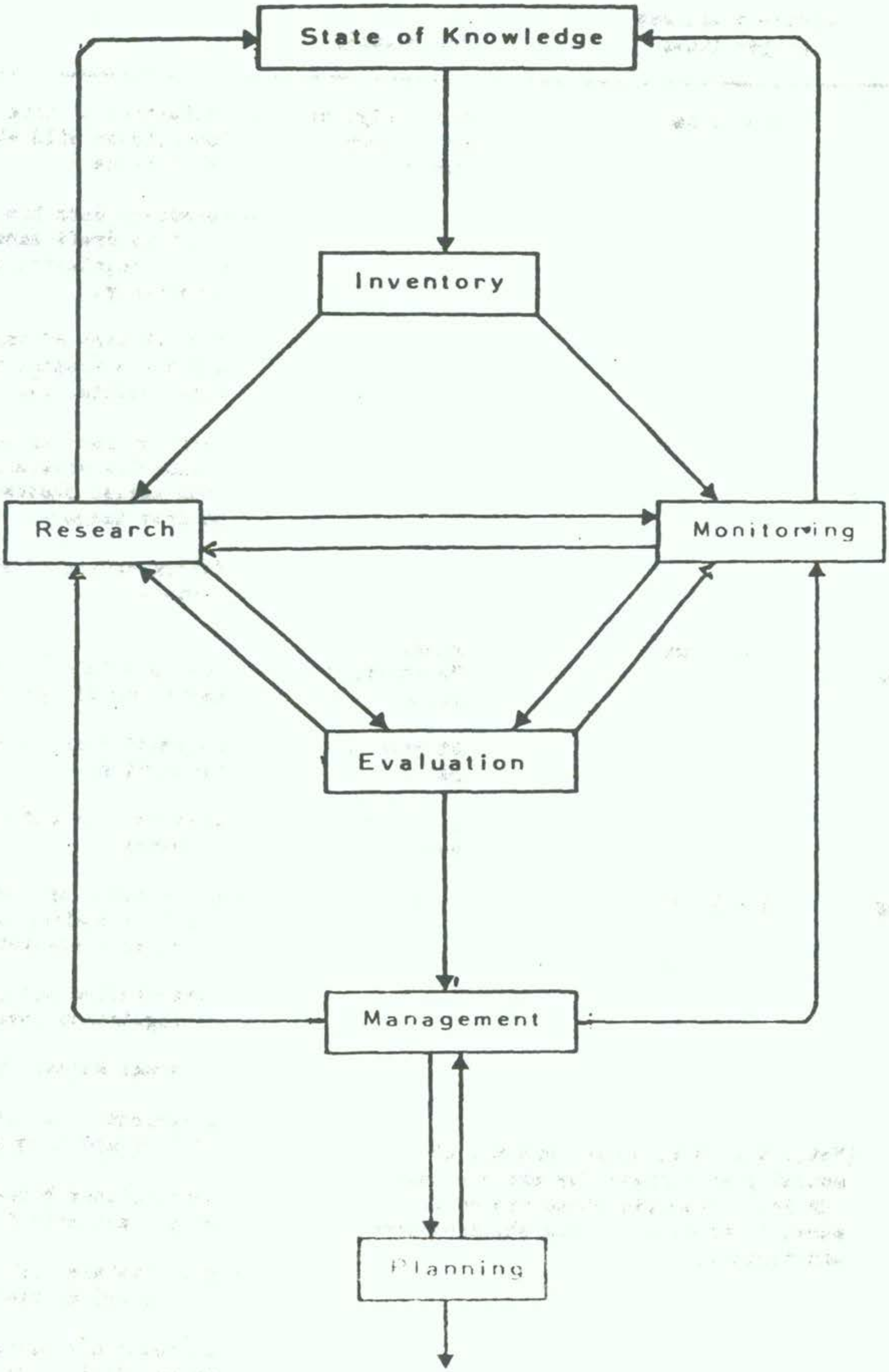

State of Knowledge
Inventory
Research
Monitoring
Evaluation
Management
Planning

Table 1

Some results from Systematic Reconnaissance Flights

Type of Flight	Intensity: Distance between flight lines	Intensity: Periodicity	Type of result
Inventory	5 - 10 km	Once only, or once every few years	- estimation of size of domestic or wild animal populations. - permanent data base from which to draft maps of soils, vegetation or topography. - distribution of infra-structure (roads, villages, water points...). - verification of eco-zone boundaries determined from aerial photos or Landsat imagery. - determination of stock routes.
Specific objective	20 - 50 km	Annual. Beginning of rains.	- advanced information on beginning of 'green wave'
		At peak of rains.	- Estimation of annual production
		End of dry season.	- Distribution and type of of burns.
Monitoring	5 - 30 km	Seasonal.	- estimations of animal population sizes of increasing precision. - distribution and phenology of vegetation cover. - seasonal animal distribution - distribution of biomass of 1ary and 2ary production - correlations between biotic and abiotic factory - establishment of boundaries of ecological mgmt. units - correlations between animal distribution and spectral signatures from Landsat imagery

(Note: the above operations are not mutually exclusive: for example, and SRF for a specific objective could serve to produce results obtained from monitoring.)

Table 2

Some results which are obtainable from visual Landsat data

Type of image	Results
1:1,000,000 mosaic of colour composites	- preliminary definition of ecological zones
1:1,000,000 colour composite transparancies (in a seasonal series).	- identification of ephemorally green areas, - identification of zones with a high procution potential - estimation of occupancy by pastoral peoples domestic stock and wildlife (given correlations with a data base of distributions from SRFs). - Soil humidity (give correlations with a data base from ground studies).
1:500,000 and 1:250,000 colour composites, paper positives or transparencies	- preliminary topography, soils or vegetation maps.

Table 3

Systematic Reconnaissance Flights

Approximate costs according to intensity of coverage

Intensity (distance between flight lines)	Optimum area	Maximum Daily Coverage	Proportion Coverage		Cost ($ per 1000 km^2)
			Animal	Habitat	
5 km	500 - 10,000 km^2	5,000 km^2	10%	40%	250
10 km	1,000 - 500,000 km^2	10,000 km^2	5%	20%	130
20 km	greater than 10,000 km^2	20,000 km^2	2%	10%	70
50 km	greater than 100,000 km^2	50,000 km^2	1%	5%	40

Note: the above figures give order of magnitude estimates only and will be modified by as much as 25%, depending on local conditions. They include the cost of pilot, crew and data analysis.

Table 4

Habitat attributes which may be monitored by an Ecological Monitoring Unit at the three levels of data acquisition (ground, air space). See text for discussion.

"Permanent attributes":

- topography
- soils
- drainage
- water holes
- static animal features such as termite mounds

"Semi-permanent attributes"

- plant physiognomy (cover, vegetation type, etc.)
- plant community composition
- zoogenic features (wallows, salt licks, etc.)
- distribution of non-migratory large mammal species
- human settlement (villages, roads, farms, ranches)

"Ephemeral or seasonal attributes"

- rainfall
- insolation
- soil moisture
- evapotranspiration
- plant phenology (greenness)
- plant productivity (biomass, part composition, chemical composition, energy content, etc.)
- distribution of migratory large mammal species
- large mammal productivity (biomass, reproductive state , condition, food offtake, etc.)
- large mammal population structure
- fire
- surface water

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Ecological monitoring in East Africa

Only by systematic monitoring of animal populations and vegetation cover over a long period of time will it be possible to understand the complex dynamics of the ecosystem. Such a monitoring system has now been developed

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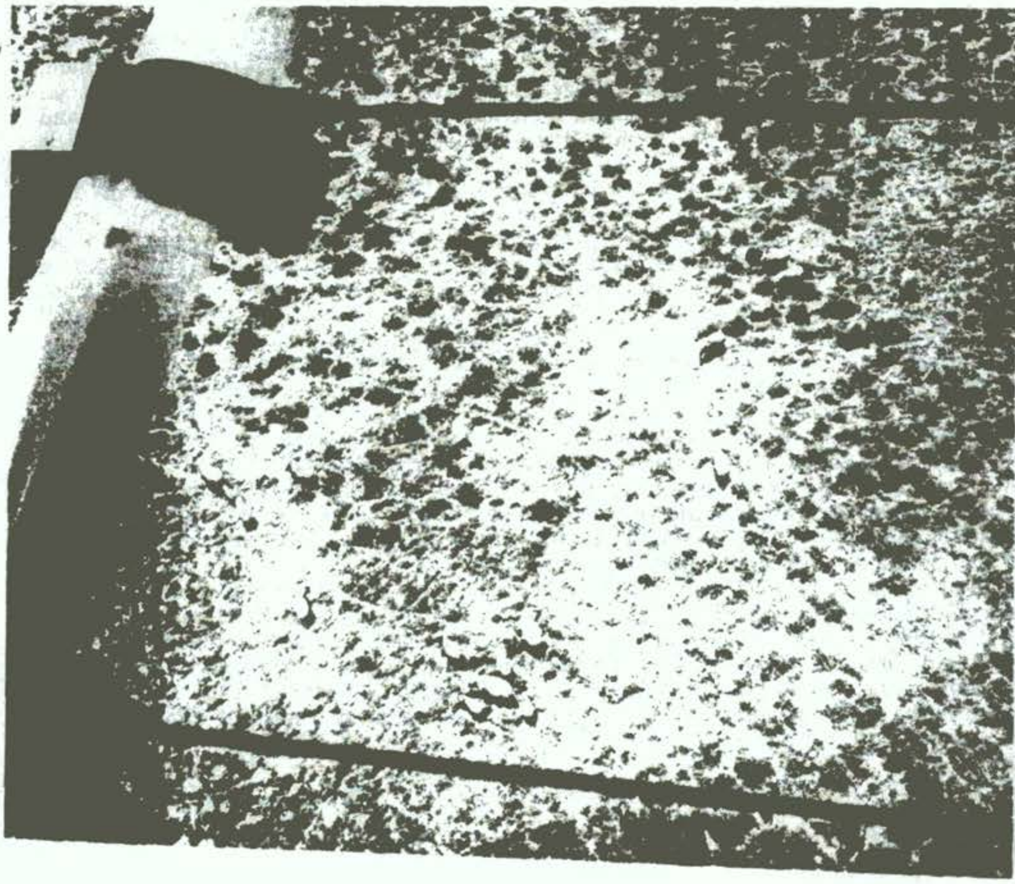
Two decades of field studies in East Africa have now been brought together—an ecological monitoring strategy that has been tested and applied throughout the region. The results are providing information about the life-support capacities of rangeland areas on a scale and at a resolution never before achieved. It has not been easy to outgrow the image of "Kenya Cowboy": light aircraft are still flown rather close to the ground and four-wheel driven trucks still smash through the bush. These days, however, we are not just locating the game, but attempting to unravel the dynamics of semi-arid ecosystems.

East African ecologists have moved from studying just single species towards studies of whole ecosystems or groups of ecosystems far larger than political boundaries. Yet the ecological monitoring strategy has evolved largely in response to what might be called political pressures. At the outset, national park managers found that striking changes were occurring in their domains: populations of elephants or wildebeeste began increasing, woodlands were being replaced by grasslands, and droughts became more frequent. These kinds of problems, rather than an inherent interest in lion behaviour or herbivore community dynamics, motivated parks authorities, game departments, and ministries of natural resources to request or to permit ecological research in their parks and reserves. They were told that the results could help them manage wildlife areas in such a way as to maintain the productivity of a resource on which, for example, Kenya's highly profitable tourist industry is founded.

KREMU survey almost complete

The large size of East African parks forced ecologists to take to the air, originally in attempts at total counts of certain wildlife species, and later for random transect samples of the same beasts. In 1969, the scientists of the Serengeti Research Institute in northern Tanzania began systematic monthly aerial coverage of the 30 000 sq km Serengeti ecosystem. Since then some 100 000 sq km has been covered in Tanzania and 260 000 sq km in Kenya. The recently formed Kenya Rangeland Ecological Monitoring Unit (KREMU, a joint venture between the government of Kenya and Canadian International Development Agency) will soon have surveyed the so-called low-potential semi-arid pastoral areas of Kenya, some 500 000 sq km. When the survey is completed, a standard ecological monitoring methodology will have been applied over an area of East Africa twice that of the United Kingdom.

The value of monitoring took some time to be appreciated, largely because ecologists, more concerned with results than effects, made a crucial mistake. They were primarily interested in the academic nature of the results, assuming that management authorities knew how to apply the data. Too often policy-makers were handed a geology



Left: An observer's view of elephant from 300 feet high. The observer counts the animals he sees between the marker rods fixed to the wing struts
Below: A monitoring plane in action over Amboseli National Park

or vegetation map, or the numbers of livestock in a certain area, or a publication on the population dynamics of a popular species, by an ecologist who then believed his responsibility had ended.

The lack of synthesis and, more important, translation has left its mark. Even to-day, most governmental and international agencies do not recognise that an understanding of the elements, dynamics and limits of primary productivity provides the key to managing both wild and human-dominated ecosystems. Nevertheless, with the demand for land-use plans and the necessity to increase returns from marginal lands, the need for large-scale monitoring is increasing. What began as fairly modest parks inventories has grown into comprehensive programmes embracing large areas of rangelands on which sizeable human populations depend.

Insights into variability

Monitoring creates the long-term data bases that are essential for predictive models. Studies on single species are able to call on extensive population and habitat data for insight into the causes of population change. Such studies give population models which can be used for exploring management options. Subsequent monitoring checks the validity of the model predictions as well as the effectiveness of the management based on them.

Continual monitoring also gives insights into the inherent variability within ecosystems. Climatic analyses, for example, can differentiate within a park ecosystem between areas of high and low rainfall variability. The areas of high variability would be expected to be less stable, and contribute to dramatic fluctuation of plant and animal population. Similarly, climatic analyses can indicate whether there are long term trends, or cyclical events, affecting an ecosystem.

Extensive monitoring of a broad range of environmental parameters indicates the capacity of an ecosystem to respond to, and absorb impacts such as heavy grazing, settlement, fire and drought. The large areas covered by monitoring allows "hot-spots" of change or instability to be assessed against the overall patterns. These events such as soil erosion, overgrazing and deforestation, are often striking, visible and emotive. Too often, unfortunately, management responses have been disproportionately influenced by the local hot-spot which has later turned out to be the exception rather than the norm.

Extensive monitoring, especially when integrated with intensive research programmes, can help to resolve problems of conflicting land-uses—for example, in areas bordering parks and reserves and in extensive rangeland areas where development is planned. The recent changes to the Amboseli National Park, Kenya, involving the development of alternative grazing and watering areas for the local Maasai pastoralists, were all designed on the basis of long-term monitoring data.

Finally, monitoring provides important feedback between environmental management and its effects. On the one hand, quality control of the management process is achieved by matching the observed effects against the predicted results. This is particularly important when a decision is made against active management. On the other hand monitoring allows management to be flexible in the face of unexpected changes or only slowly emerging trends. It so happens that such changes appear to be the rule rather than the exception in semi-arid ecosystems.

The concept of monitoring and the potential uses are universal to all ecosystems. The methodology developed in East Africa is tailored to the particular conditions of size of area, terrain, and vegetation cover there. It involves three observation platforms—the ground, low-level overflights, and space. The pivotal technique is the systematic reconnaissance flight (SRF), because it is the most efficient first step for an overall assessment of an unsurveyed area.

The design of the SRF begins with a grid system, usually with 10 x 10 or 5 x 5 km squares, which is laid over a map of the study area. Flightlines, 10 or 5 km apart, pass through the centre of each grid square, and data are recorded with reference to the grid numbering system. The pilot maintains a constant height, for example 300 feet above ground level, navigates, calls out the grid square number to the crew—and avoids vultures! A front right-hand observer collects habitat data, such as estimates of cover and greeness of grass and shrubs, the 8000 angstrom and 6700 angstrom readings from a digital photospectrometre which can be correlated to green biomass, the presence and availability of surface water, the proportion of the grid square covered by a burn, and the presence and degree of erosion. Two trained observers in the back count or photograph the animals they see between transect marker rods fixed to the wing-struts. Livestock are also recorded as well as the number of human habitations and whether they are occupied or not. The technique is simple, but demanding: after two and a half hours the attention of even the best observer flags and a rest is necessary to maintain searching efficiency.

The basic results of the SRF spatial and temporal distributions of animal and plant attributes are produced quickly using data handling computer programmes. One SRF, costing between US $50 to 100 per 1000 sq km, produces a quick look at the state of the resources. Major geological features, soils and vegetation form can also be mapped. Time, interest and finance permitting, the flights are repeated to correspond with the dominant meteorological events. The green flushes produced by the sporadic short-rains are mapped. The seasonal distribution of browsing and grazing species are described with respect to vegetation type. The numbers of the animals observed or the relative biomasses of domestic stock and wildlife are estimated. The distribution matrices over, say, two years of SRFs, divided by the number of flights, produces average occupancy over the study area. Using multivariate techniques, the animal events can be correlated with the habitat changes. At this point controlling factors in the system begin to come clear and managers can be advised on those which might effectively be manipulated.

Views fom the air and from the ground

In a comprehensive ecological monitoring programme, aerial observations must be supplemented by studies on the ground. Essentially these studies seek to explain and to confirm the observations from the air. The KREMU is planning a series of ground plots which will be set out, as it were, under the SRF grid. The plots will be used as point sample descriptions of what is seen from the air in terms of topography, drainage, soil and vegetation type. After base-line descriptions, they will be focal points where rainfall, evaporation, soil moisture, rates of erosion, plant phenology and productivity will be monitored at a seasonal frequency. Recent problems which have been studied on the ground within a monitoring framework include: effects of intense herbivore grazing on productivity and grass community structure; herbage characteristics which affect selectivity and digestibility; performance of wild ungulates under ranch-type management; facilitative use of pasture by communities of herbivores; the relationship between the colour of cattle, thermoregulation and water turnover; and the relative importance of biotic and abiotic factors affecting soil erosion.

At the other end of the scale, satellite imagery is producing tantalising results. Soil maps have been produced from imagery, the detail and accuracy of which rivals that of more traditional techniques. Phenological changes in vegetation are striking in a time-series of images, and correlates are not too far away that will allow seasonal estimates of forage biomass over thousands of sq km of rangeland. Such techniques have been used, of course, in high-potential areas, but it is in the vast low-potential regions where a technique for quickly pin-pointing and reporting flashes of production could augment the already very efficient strategies of the nomadic pastoralists.

The emphasis of ecological monitoring is beginning to shift from wildlife to human resources for two reasons. One is the undeniable shrinkage of wildlife populations, due to competition with man for resources, and poaching for profit (as opposed to traditional hunting for food). There are potential governors, however, which could dampen the rate of attrition. The success of the spread of agriculturalists into marginal areas is a function of available capital, enough, for example, to offset the lack of adequate rainfall through irrigation. The spread, therefore, proceeds slowly indeed in the semi-arid rangelands of developing countries. Furthermore, if efforts such as the recent United Nations Development Programme/FAO Kenya Wildlife Management Project can advise how wildlife might yield a sustainable income to the newly title-deeded pastoral landowners, then a sort of home-guard may eventually take a stand against poachers.

The other reason why monitoring attention has switched to human-dominated ecosystems is the apparent increase of human suffering. This is usually attributed to the unbridled increase of the pastoralists and their stock populations. Unfortunately the monitoring base-line data does not exist from far enough back in order to assess if the increases are real, or the results of improved censusing methods, and if the range is "overgrazed" and causing stork mortality as a symptom of some undefined "imbalance". Evidence is accumulating, for example, which suggests that the pastoralists' rate of increase may be lower than other social groups, and that drought—with the attendant failure in primary production—is orders of magnitude more important in contributing to mortality than stocking rate.

Recent work in Kenya suggests that very high stocking rates may actually increase production of forage through growth inducement, whilst barely increasing erosion rates over those associated with medium stocking rates. It is unlikely that massive destocking would much improve climatic conditions; it is certain that the economic and social costs would be enormous to both the pastoralists and their governments. So-called "overstocking" is in fact a deliberate strategem among some pastoralists to compensate for the inevitable and (in the current economic ontest) unavoidable drought-induced mortality.

We are learning from monitoring: learning, for example, that we still know less about the dynamics of tropical ecosystems than we do of temperate ones. Often this admission leads to recommendations of a non-intervention policy, one in which monitoring is allowed to track the ecosystems through the dramatic changes in which they indulge with a disturbing frequency. Their ability to bounce back from climatic perturbations and animal impact is striking, and the metaphor of the "fragile ecosystem" is losing its meaning. Any laissez-faire attitude to management is usually criticised. However, it may be unwise to apply the danger signals of habitat degredation taught to ecologists in northern biomes and wield the remedial bludgeon when a temperate threshold is past. The judgements of many "pathological" situations have been based not on an understanding of the "natural" dynamic state, but often purely visual criteria—there are fewer trees now than five years ago; the grass cover is only 30 per cent; 40 per cent of the hartebeeste died last year; the erosion rate is high . . . Ecological and earth science studies in East Africa are beginning to put such observations in perspective. □

THE CONCEPT AND PRACTICE OF ECOLOGICAL MONITORING OVER LARGE AREAS OF LAND: THE SYSTEMATIC RECONNAISSANCE FLIGHT (SRF)

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This paper was presented at the

IBADAN/GAROUA INTERNATIONAL

SYMPOSIUM ON WILDLIFE MANAGEMENT

IN SAVANNA WOODLAND

held at the University of Ibadan,

Nigeria, on September 23-25, 1975

ABSTRACT

The concept and methods of ecological monitoring have evolved in East Africa largely under pressures from government administrative organizations. These are frequently concerned with the costs and benefits involved in developing large tracts of rangeland, either by improving livestock husbandry or by generating income from wildlife. A first step in assessing the potential of a resource is to measure its current supply.

In East Africa, rangelands are today assessed and studied from three operational levels - from the ground, from light aircraft, and from remote satellite sensors in space. In this paper, we consider the middle tier. In view of constraints of limited funds and possibly limited expertise in some areas, we argue that the Systematic Reconnaissance Flight (SRF) is a logical and efficient first step in ecological monitoring and resource assessment.

We examine the context and scope of ecological monitoring, the organization of an SRF programme, some of the costs involved, the technical aspects of the SRF and the types of results produced. We stress that investigators can obtain useful results quickly and inexpensively without complex analytical facilities. As funds and expertise allow, it is possible to expand an initial SRF project into a full-scale ecological monitoring programme.

INTRODUCTION

Resource management organizations in East Africa, such as the Range Management Divisions, Game Departments and National Parks, require large scale ecological data on which to base utilization and development programmes for extensive tracts of non-urban land. This demand has encouraged the gradual development within East Africa of the ecological monitoring concept, from the beginning when methods were sought to answer simple questions (e.g., how many animals are there?) to the present when complex land-use management questions are being posed.

The need for information on a large scale had led to the development of techniques for data gathering which are efficient and inexpensive enough to be applied repeatedly over large areas. Considering the difficulties caused by the dynamic state of rangeland ecosystems which experience both long and short term climatic cycles, the new methods of data gathering and data handling have been most successful (Norton-Griffiths, 1972; Cobb, 1975).

In Kenya, we have an approach whereby we look at the land's biological resources from three levels - from the ground, from the air and from space through the eyes of satellites. In this paper we will consider only the middle tier - aerial reconnaissance (Gwynne and Croze, 1975).

When considering monitoring strategy for a region about which little is known, the initial emphasis should be on the use of aerial techniques because aerial survey is the logical first field step in the resource assessment of any new large development. The techniques used can provide useful quantified quick-look data at low cost (Watson, 1969). In any case, the deployment of more traditional ground techniques may be usefully considered as a function of the aerial strategy. Similarly, the interpretation of satellite imagery can be done in the spatial framework of the aerial reconnaissance.

The basis of the method is the ecosystem approach, the underlying aim of which is to determine the spatial and temporal pattern of primary and secondary productivity within a particular ecosystem or self-contained land unit.

At this symposium you will have heard in detail about this concept as currently practised in specific areas of East Africa - mainly National Parks. What may not be so readily apparent from these discussions is that the system can be applied at different levels of complexity from the simple to the comprehensive, and that it is as applicable to non-park areas as it is to the parks and reserves. What determines the level of application are the primary objectives of the survey, the funds and time available, the physical nature of the terrain, and the personnel that can be used in the survey and their technical skills.

A clear understanding of the requirement limitations is absolutely essential to the planning of any aerial monitoring strategy as they will determine the kind of ecological data that should be collected. In any monitoring programme it is as inefficient, both in terms of costs and man-power utilization, to collect too many data as it is to collect too few.

Care must be taken before a survey to ensure that the methods of data analysis proposed are compatable with the actual means and skills available. Un-analysed data are wasted data. It is no use becoming involved in a complex monitoring strategy dependent upon technical skills and computer facilities for data analysis that are simply not available to the project. In such a case it is more practical to attempt a much lower level of data collection and interpretation which will provide immediately useful ecological management information.

It is the purpose of this paper to suggest how simple aerial monitoring programmes may be planned for use in areas where long term background habitat data are not available, and where trained scientists, technicians and analytical facilities are all in short supply.

AERIAL MONITORING

Information categories

Ecological monitoring uses information from three general categories:

Environmental:	including information on climate, hydrology, topography, soils and floristic dynamics.
Faunal:	including information on wildlife and livestock numbers, distribution, population dynamics and habitat utilization.
Economical/ Political:	including land-use forms, projected land demands, and national development goals.

The last category is normally supplied by the agency that has requested monitoring data. It will usually state what the projected land-use demands for the study area might be in relation to the national development goals. Depending on the political situation, the state of the economy, and the level of existing knowledge of the area, this statement of development intent can take several different forms. For example:

1. It is government's intention to increase the livestock capability of the region.

2. Recognizing the livestock production potential of the region, it is, nevertheless, government's intention to exploit fully the wildlife resource of the same region.

3. The region is recognized as being one of great wildlife interest; it is government's intention to investigate the possibility of establishing within it one or more national parks as reserves to enhance the nation's tourist attraction potential.

4. Government is uncertain of the development potential of the region and seeks advice on possible biological resource development strategies.

The form of the statement of development intent will make it clear to the investigators what the administrators see as the development ideal for the region. This in turn will help the survey team choose the appropriate habitat parameters for monitoring, paying particular attention to those which are necessary to determine whether or not the administrators' development ideas are viable.

As the monitoring approach is essentially an ecosystem one, an initial step is to decide whether or not the area to be examined is in fact an ecosystem. Gazetted boundaries are almost invariably political rather than ecological so that they do not normally encompass organically and energetically self sufficient units. It is necessary, therefore, to know whether the study area is part of one or more larger ecosystems or contains one or more smaller self-contained ecosystem units, or, most rarely, is an ecosystem unit on its own (Fig. 1).

This can be ascertained in general terms by taking the limits of movement of the largest animal biomass components as marking the approximate ecosystem boundaries (Pennycuick, 1975). Such animal movements are caused by various factors and it is part of the problem to determine these factors. To do this the ecologist has to describe the static structure of the ecosystem (topography, drainage, soils, vegetation, plant and animal community components), as well as to analyse the dynamics of the system (changes in time and space of climate and productivity, shifts in community structure, etc.). If attempted in its entirety this can be a formidable task which can only be accomplished with careful planning and a systematic approach.

Measurable habitat attributes

The choice of a collecting or sampling strategy will depend on the spatial and temporal distribution of the phenomena being measured. It is convenient, therefore, to classify ecosystem attributes along a continuum of change from those which remain more or less constant over the long term to those which alter appreciably between sample periods, viz.

Permanent attributes	- topography - soils - drainage - waterholes - static animal features such as termite mounds
Semi-permanent attributes	- plant physiognomy (cover vegetation type, etc.) - plant community composition - zoogenic features (wallows, salt licks, etc.) - distribution of non-migratory large mammal species - human settlement (villages, roads, farms, ranches, etc.)
Ephemeral or seasonal attributes	- rainfall - insolation - soil moisture - evapotranspiration - plant phenology (greenness) - plant productivity (biomass part composition, energy content, etc.) - distribution of migratory large mammal species - large mammal population structure - fire - surface water

Note that useful data on most of these attributes may be collected from our three operationally separate levels - from the ground, from the air, and from space via one of the earth resources assessment satellites.

Survey frequency and costs

The frequency of aerial surveys of the type being considered here is a function of cost and the rapidity of seasonal changes - every month, every two months, every quarter and every major season have been used. At the moment (1975) the operating cost of such a survey in East Africa is about US\$50/1000 km^2, not including salaries and the costs of capital equipment (aircraft, etc.), minor equipment (recorders, cameras) and consumable items (films, recording tape).

Habitat data recording

Useful habitat data can be recorded from the air in any of these forms:

i. Presence or absence in each of the sub-units on a transect, e.g. surface water, fires, flowing rivers, villages, etc.

ii. On a scale of subjective estimates determined and agreed upon in the pre-survey reconnaissance phase. These can then be related to actual conditions by checking on the ground: e.g., a five-value greenness scale can be used to indicate the physiognomic stage of grass growth; similar five-value percentage scales can be used to express bush (i.e. woody dicotyledon) cover and grass cover. These subjective scale estimates can be very useful and consistent if made with care.

iii. Actual counts within the sample unit which allow estimates of the absolute numbers of features to be made in the same way as animal population estimates are derived, e.g., features such as termite mounds, salt licks, water pans, villages, huts, etc. Care should be taken to avoid having the observers recording too many types of features in one survey as this may result in the confounding of their animal searching images with consequent enlargement of the errors in the animal population estimates.

Examples of these forms of data recording are illustrated in Gwynne and Croze (1975).

Observers and observer variance

It is customary at present to use an air crew of four per aircraft - a pilot, a front observer and two rear observers. Their exact duties will be discussed later. At this stage, however, it is important to consider the human element as most of the data will be collected by the observers on what is essentially nothing more than a subjective basis.

The greatest single source of error in current aerial census and monitoring surveys is the human observer (Savidge, 1973; Cobb, 1975). Individuals vary widely both in their ability to remain alert and fully functional when concentration is required for long periods, and in their ability to perceive objects as patterns with consistency. Few men will readily admit to being less efficient than their colleagues where mental ability is concerned, and skill in counting animals from the air is no exception to this. So far comparatively little attention has been paid to this factor in monitoring programmes, particularly those which have been carried out by large units such as Game Departments where staff are freely and indescriminately changed around.

Observer variance can be reduced by assessing their ability in a series of ground and aerial tests prior to the survey (see Watson, Freeman and Jolly, 1969; Watson, Jolly and Graham, 1969) - getting each to count quickly the animals in a series of colour slides shown on a screen is one such simple test. The score of each observer can then be related to the actual numbers of animals present and correction factors worked out. Further, from a number of pre-flight practice sessions it is possible to improve an observer's ability to estimate the numbers of animals in a group.

Some people are unsuited to this repetitive monotonous work due to variability in perception. Similar difficulties are encountered in other research fields such as microscope work for rumen content and blood smear analyses. Such people should not be used as observers in an aerial survey programme. Other people are unsuitable because of chronic air-sickness.

Observer variance can be reduced by careful selection, prior to the survey, of the habitat data to be collected, with agreement on the definition of the character grades within each category: e.g. what does Greenness Category 5 really look like? What does 20% bush cover look like? Much of this can be done with the aid of coloured photographic slides which can be used to train the observers.

Further reduction in observer variance can be obtained by using wherever possible, the same aircrew on each repetitive survey. The data from successive surveys are, therefore, more comparable.

The problem of observer alertness can be reduced by ensuring that the flight times are not too long and that there is a short in-flight break between ending one transect and starting another. It is useful to ensure that the observers are recording at least one habitat parameter in addition to counting animals. This will ensure that they are obliged to concentrate and record data even over those regions which are devoid of animals; in other words recording activity helps combat boredom (Cobb, 1975).

It should not be thought that aerial surveys can only be carried out by trained biologists and that it is always necessary to have plane loads of graduates flying over the countryside. If the recording categories are well thought out and an observer training programme has been used there is no reason why junior staff cannot be observers, thus enabling the senior man to spend more time on data analysis. In a country where there is a shortage of trained biologists this approach may make the difference between being able or not being able to start a monitoring programme.

There are, however, drawbacks to using junior staff in this way and it is as well to be aware of them. The most serious is their possible lack of motivation stemming from disinterest in the project. This creates a tendency to regard observing as just another way of earning wages. The result may be continual lack of alertness and even invention of recorded data. Care in the selection and training of observers coupled with a system of checks and possibly special monetary inducement help eliminate this possible source of bias.

THE SYSTEMATIC RECONNAISSANCE FLIGHT (SRF)

The Flight Pattern

For most general census and monitoring purposes the best data gathering plan is to overfly the area on sampling flights using a systematic flight pattern: e.g., the aircraft should fly over the study area on parallel flight lines 10 km apart (Fig. 2). These flight patterns can be repeated at different ecologically significant times (e.g., wet season, dry season).

Systematic flights allow data to be gathered in a form that permits quantification and at the same time shows how the animals and features are distributed spatially. Thus, for example, it is possible to obtain reasonable population estimates of the more abundant (and therefore important) large mammal species in the study area and to be able to follow their season movements in response to changing ecological conditions, such as grass growth, availability of water, etc.

Precise and accurate population estimates

A cause of confusion to those considering aerial sampling of animal populations for the first time is the indiscriminate use of the terms "precise" and "accurate" when talking of animal population numbers. By convention, in recent years, these have come to have an exact meaning (Caughley, 1972; Norton-Griffiths, 1973). A precise population estimate is one that has a small standard error but which may be wide of the true animal population present, that, is, it is biased up or down. An accurate population estimate is one that is very close to the true numbers of animals, present (very little bias) but whose standard error is large. The ideal estimate is one that is both precise and accurate, but for both biological and sampling reasons this is rarely attained and the norm is an estimate that is less accurate and less precise than the ideal. The ultimate aims and funds available for any survey must govern whether the investigator strives for precision or accuracy - precision is best for detecting changes in population numbers with time whereas accuracy is best for considering large mammal biomass, primary production offtake by large mammals, etc. (Caughley, 1974).

The SRF system of sampling normally provides less precise population estimates than other forms of aerial sampling, but the decrease in precision is more than offset by the value of the additional distribution data gained. If, however, the sampling transects are of sufficient length, even this defect is overcome producing population estimates whose confidence limits can be sufficiently small to be quite acceptable to the most discriminating population biologist.

<u>Pre-SRF area familiarisation</u>

Before embarking on an SRF programme it is essential for the pilot and crew to familiarise themselves with the survey area and its major features. This should be done by:

- study of available topographic maps
- study of available aerial photographs

  If these can be assembled into print lay-down photo-mosaics, so much the better for they have more impact in this form. Study of satellite imagery is also worthwhile at this stage bearing in mind the very large scale which is used.

- One or more general reconnaissance flights over the area, flown at a much greater height above ground level than during an SRF. Altitudes varying from 300 m (1000 feet) to 600 m (2000 feet) have been found most suitable as these permit a broader overview than is possible at current SRF operational altitude (100 m).

<u>SRF organization</u>

Details of an SRF will vary depending on factors such as terrain, vegetation type, local seasons and the investigator's particular brief. Standardisation of technique as much as possible is desirable, however, because it facilitates comparison between ecosystems - a typical SRF programme as practiced in East Africa usually takes the following form.

Pre-flight planning

A map of the study area is overlaid with a reference grid such as the UTM 10 x 10 km grid system so that the grid, suitably numbered and lettered, can be used for orientation during flying and for presenting and analysing distribution data. This grid can often usefully be broken down into four smaller sub-units each of 5 x 5 km (Fig. 2).

Systematic flight lines 10 km apart (e.g., centred on the grid, system) are drawn on a 1:250,000 topographical map of the study area. A certain amount of latitude in placing these flight lines is permissable and advantage can be taken of this to locate commencement points in relation to prominent features such as river and road bends thus allowing the transects to be relocated on subsequent SRF's. Flight lines are normally oriented North-South or East-West as the shape of the area and wind conditions dictate. In general, however, it is best to avoid cross-wind flight lines (because of the problem of pilot navigation), very short flight lines (because of the problem of statistical treatment of data), and very long (over 100 km) flight lines (because of the problem of observer fatigue).

Flights should not be planned for very early or late hours because of the lack of light and the deep shadows which result. Flights should also not normally be planned for the mid-day period (1000-1500 hours), the time of maximum solar radiation during which many herbivores retreat into the shade for rest and rumination and are, therefore, not easily seen from the air. This behaviour pattern is modified by seasonal variation in cloud cover so that longer daily flight times can be considered for cloudy weather.

A decision should be made on the types of habitat data to be collected and the form in which these data are to be recorded bearing in mind the objectives of the SRF programme, the abilities of the observers and the terrain types to be overflown.

The organizational procedure for initiating an SRF is shown diagramatically in Figure 3.

Aircraft operation

In East Africa most SRF's are flown by a crew of four in a single-engine, high wing aircraft; those most normally used are the Cessna series (180, 182, 185). Some workers, however, have used smaller two-seat, slower flying aircraft, such as the Piper Super-cub, but these are now normally used for special supplementary surveys such as the careful examination of hilly country for infrequent cryptic species such as Greater Kudu (*Tragelaphus strepsiceros* Pallas).

In a crew of four the pilot is responsible for air speed maintenance, height control, navigation and spatial location and for informing the crew of both transect numbers and sub-divisions every 10 km flown. The front right observer, next to the pilot, documents habitat information (topography, drainage, vegetation type and cover, etc., as well as greenness of vegetation, grazing intensity, presence of water, fire and other seasonal features). In a series of SRF's made during a monitoring programme, the 'permanent' features need only be recorded once during an early flight.

The two rear seats are occupied by observers who mainly count animals by species between streamers or rods, two being fixed to the wing struts on either side of the aircraft. The streamers are so spaced that at a particular height they subtend a strip of known width (e.g. 250 m) on either side of the aircraft, thus along the flight lines the crew is counting animals (and features) in transects of known areas. By proportionality, therefore, estimates of population size and variances can be made (Jolly, 1969). Animal species and numbers together with transect and sub-division coordinates are recorded by the observers using portable tape-recorders. Animal groups too large to count accurately (more than 20; e.g., herds of livestock) are photographed using a hand-held 35 mm camera. An automatic exposure, motorised, large magazine (250 picture) camera is ideal for this purpose though not essential.

Height control is critical since changes in altitude lead to fluctuations in strip width and thus to errors in counting animals - a rise causes the strip width to widen and a fall causes it to narrow (Fig. 4). Height is best maintained by using a radar altimeter. In some circumstances, such as over flat terrain, an ordinary pressure altimeter can be used by relating it to contours and checking it periodically for diurnal pressure changes during the SRF by making low passes (2-3 m) over open ground whose altitude is known.

Navigation over flat featureless terrain is difficult. Aircraft can, however, be fitted with a Very Low Frequency (VLF) navigation system which permits transects to be flown with great accuracy. Repetative flights along the same transect are possible, therefore, provided the starting point of each flight line can be re-located. The VLF navigation system is global in coverage so that it is only the aircraft instrumentation that is needed. This is expensive but its use is recommended, particularly over remote terrain where navigational errors could seriously jeopardise the results and their interpretation (Gwynne and Croze, 1975).

Data analysis

The data are all recorded with reference to a sub-unit on a flight transect, that is within a particular 10x10 km grid square. On return from the flight the data are transcribed from the tape machines directly on to data sheets or computer coding sheets. At this stage, distribution of animals and the occurrence of habitat features such as greenness, water and vegetation type, may be plotted by hand on to gridded working maps of the area. The data may also be punched on to computer cards and transferred to magnetic tapes for storage and analysis. Programmes are now in use which file the data and produce line-printed distribution maps as well as animal population and biomass estimates (Norton-Griffiths and Pennycuick, 1973, Cobb, 1975).

As you will have heard at this symposium computers save time and labour at this stage but they are not absolutely necessary to a monitoring programme. Indeed, many of the early monitoring programmes did not use them at all. Suitable gridded sketch maps for plotting distribution data, a portable electronic calculator with square root capability, and a knowledge of standard statistical techniques are all that is required. One of the new very small programmable electronic calculators with built-in statistical analysis capability would be ideal; the cost of these is now quite low (US$ 1000) and well within the budget of most projects. It must be emphasised again at this point, that the data collected should not exceed the analytical capabilities of the investigating team and should relate to the objectives of the programme. Failure to ensure this will lead not only to a waste of man-time and funds but will create a risk that nothing will be analysed and the programme will confuse rather than clarify land-use issues.

Results

A Systematic Reconnaissance Flight monitoring programme organised along the lines presented here and using very little in the way of sophisticated equipment ought to be able to produce at least:

1. Estimates of the numbers and densities of the major herbivore species, both domestic and wild.

2. A picture of the seasonal movements of the major herbivore species (this is dependent upon there being more than one SRF) leading ultimately to the development of probability of use maps.

3. A broad scale vegetation map expressed in terms of plant physiognomy and/or plant cover.

4. A broad scale soil map expressed in terms of colour types.

5. An outline of the areas that are important for wildlife which could be used to de-limit, if required, possible reserves and parks.

6. An outline of the areas that are important to livestock. Such information could be used for the planned control of stock numbers and in rangeland development programmes.

7. A land-use map(s) in terms of human occupance, showing activities in rangeland, agriculture, forestry, etc.

8. If the SRF programme is continued over several seasons, a delineation of productive and non-productive areas.

All these are types of information that are important to land and resource management and have real practical value to the development planners. The results are, however, all base line descriptions. For causal relationships and for the details of the interactions we see from the air, we must eventually get back to earth. We begin then to think of initiating a full scale scientific ecological monitoring programme which will include all the necessary ground investigations. And, at the far end of the scale of ecological management ambitions we must begin to delve deeper into the possibilities that the sophisticated satellite sensors offer (Gwynne and Croze, 1975).

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LEGENDS FOR FIGURES

Figure 1: The study area shown in relation to the distribution of different possible component ecosystems. The study area is shown as:

A - Part of a single larger ecosystem.

B - Containing parts of two larger ecosystems.

C - Forming part of two larger ecosystems and also containing completely two smaller ecosystems.

D - Containing completely three smaller ecosystems.

E - Forming a complete ecosystem in itself.

Figure 2: The study area shown with the Systematic Reconnaissance Flight grid system imposed together with the aircraft flight tract (dotted line) for an SRF.

Figure 3: An organizational flow-chart for initiating a Systematic Reconnaissance Flight Programme.

Figure 4: The effect of changing flying altitude above ground level on the effective sample strip width. A, B and C represent different ground surfaces over which the aircraft is flying at heights $h_{a,b,c}$ respectively. The strip width ($S_{a,b,c}$) varies proportionally with change in h. Thus in:

A. The aircraft is flying too low resulting in a decrease in strip width. Animal population estimates will be biased downward leading to an underestimate of animal numbers.

B. The aircraft is flying at the correct altitude for the required strip width.

C. The aircraft is flying too high resulting in an increase in strip width. Animal population estimates will be biased upward leading to an over-estimate of animal numbers.

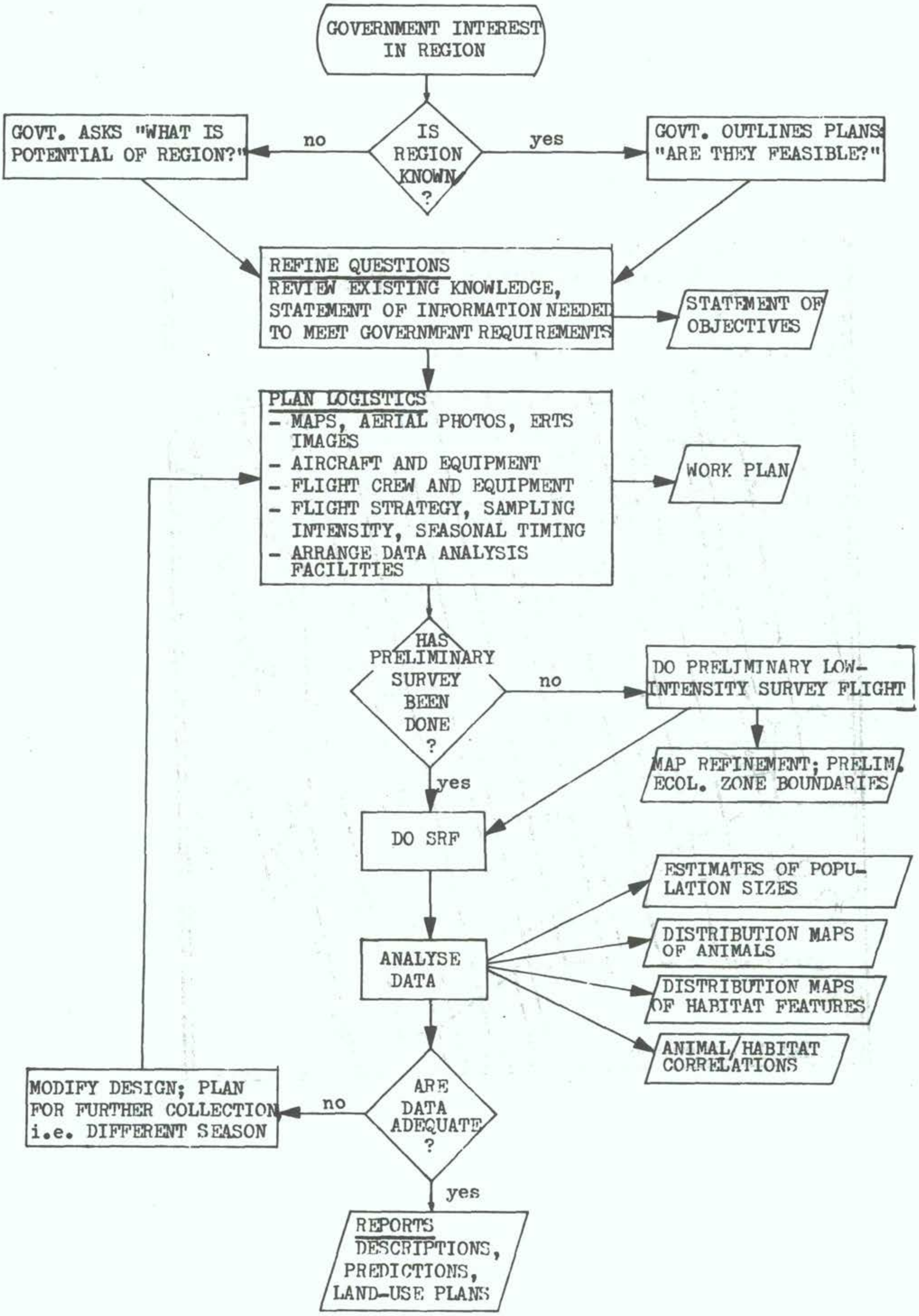
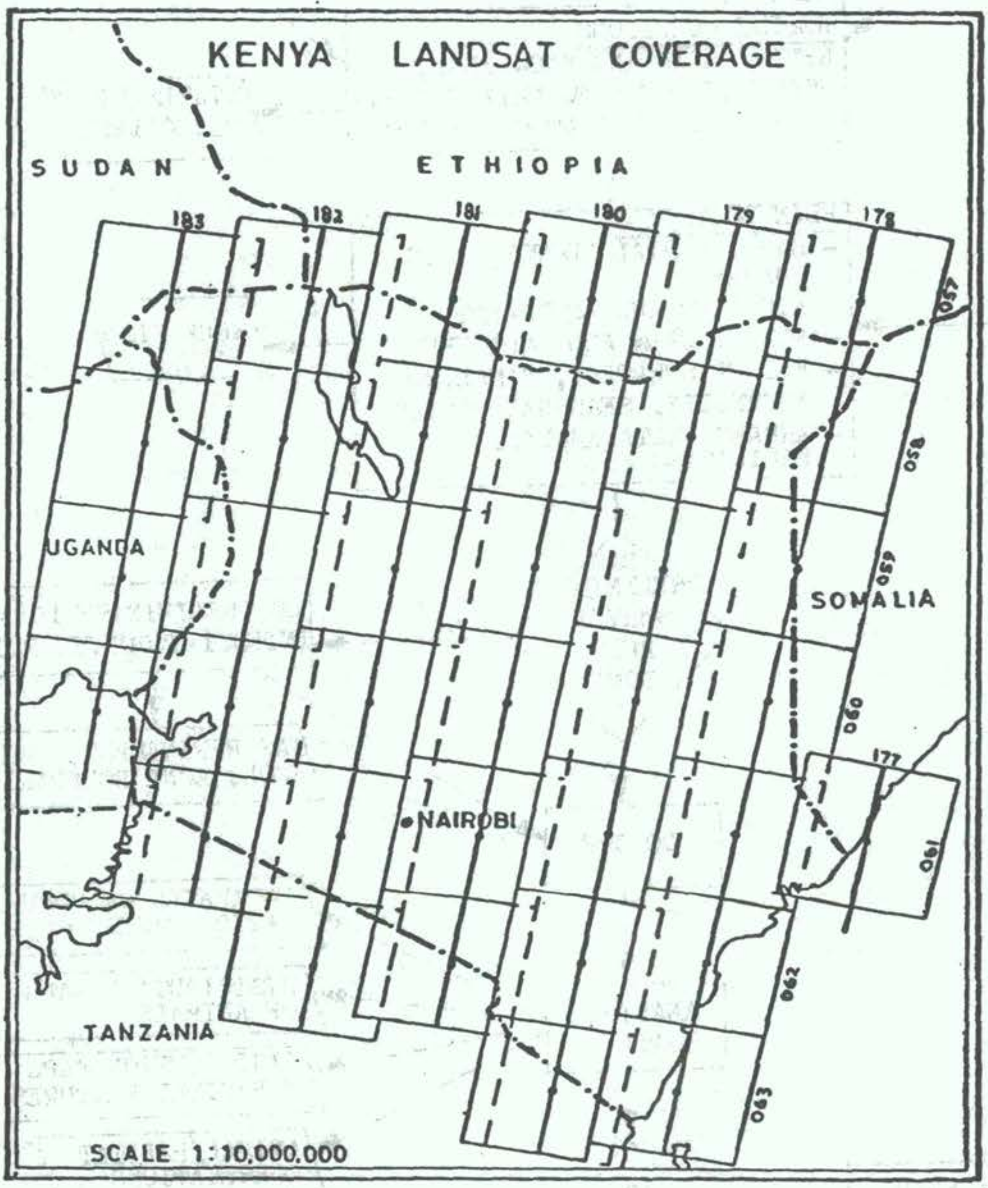

GOVERNMENT INTEREST IN REGION
IS REGION KNOWN ?
no
yes
GOVT. ASKS "WHAT IS POTENTIAL OF REGION?"
GOVT. OUTLINES PLANS: "ARE THEY FEASIBLE?"
REFINE QUESTIONS
REVIEW EXISTING KNOWLEDGE, STATEMENT OF INFORMATION NEEDED TO MEET GOVERNMENT REQUIREMENTS
STATEMENT OF OBJECTIVES
PLAN LOGISTICS
- MAPS, AERIAL PHOTOS, ERTS IMAGES
- AIRCRAFT AND EQUIPMENT
- FLIGHT CREW AND EQUIPMENT
- FLIGHT STRATEGY, SAMPLING INTENSITY, SEASONAL TIMING
- ARRANGE DATA ANALYSIS FACILITIES
WORK PLAN
HAS PRELIMINARY SURVEY BEEN DONE ?
no
DO PRELIMINARY LOW-INTENSITY SURVEY FLIGHT
MAP REFINEMENT; PRELIM. ECOL. ZONE BOUNDARIES
yes
DO SRF
ANALYSE DATA
ESTIMATES OF POPULATION SIZES
DISTRIBUTION MAPS OF ANIMALS
DISTRIBUTION MAPS OF HABITAT FEATURES
ANIMAL/HABITAT CORRELATIONS
ARE DATA ADEQUATE ?
no
MODIFY DESIGN; PLAN FOR FURTHER COLLECTION i.e. DIFFERENT SEASON
yes
REPORTS
DESCRIPTIONS, PREDICTIONS, LAND-USE PLANS

Fig. 3


KENYA LANDSAT COVERAGE
SUDAN
ETHIOPIA
183
182
181
180
179
178
057
058
UGANDA
059
SOMALIA
060
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NAIROBI
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TANZANIA
063
SCALE 1:10,000,000

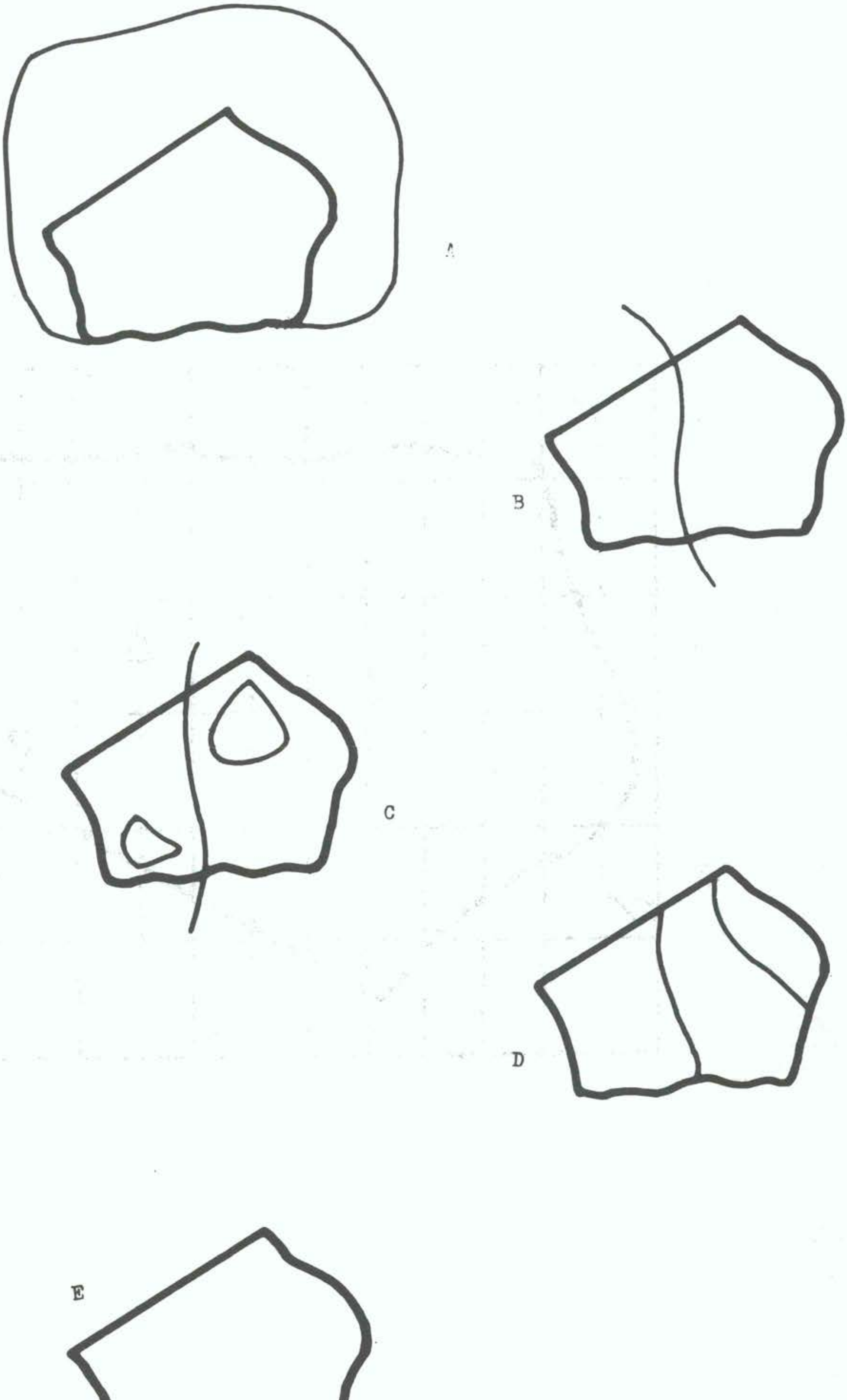

Fig 1

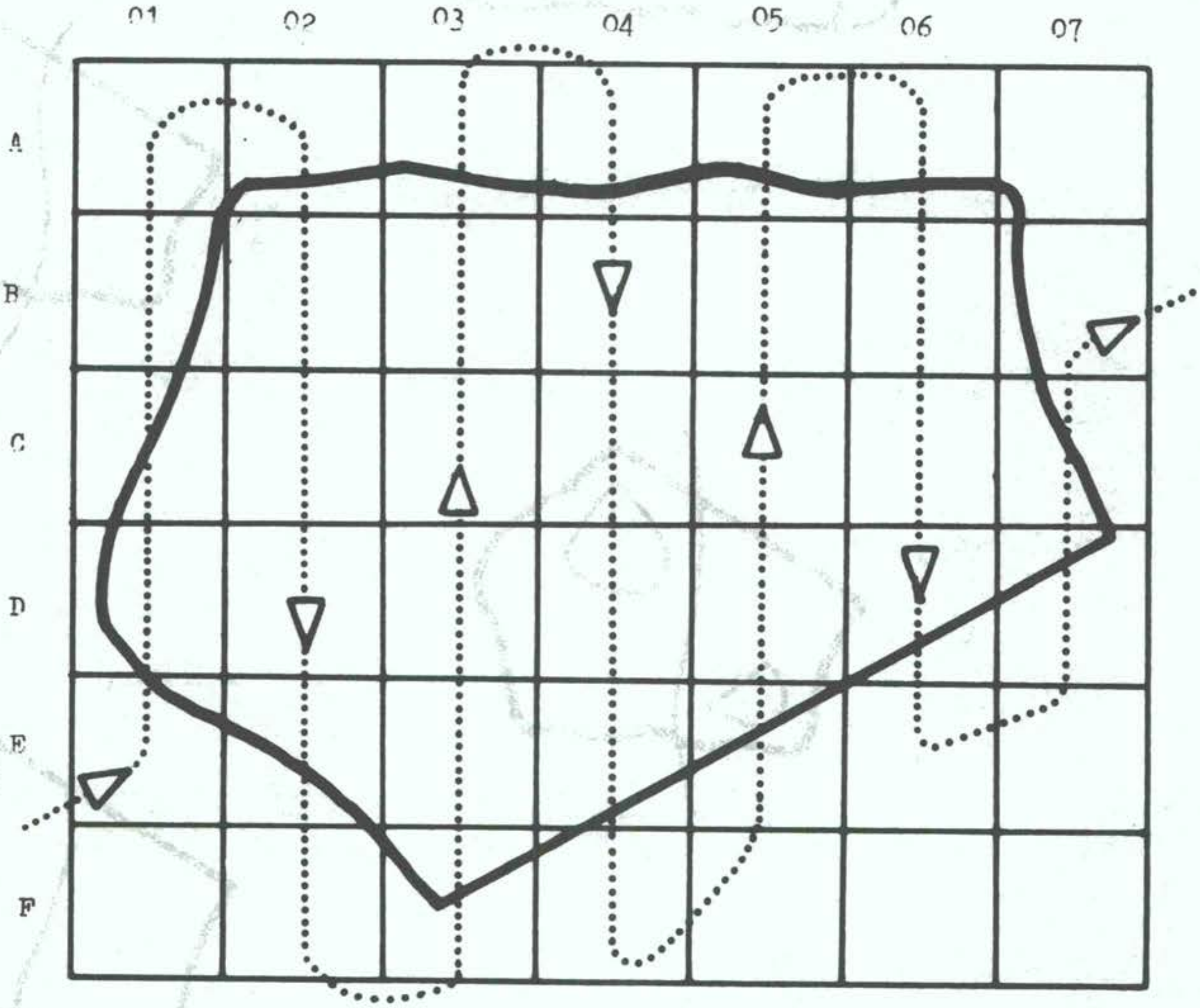

Fig 2

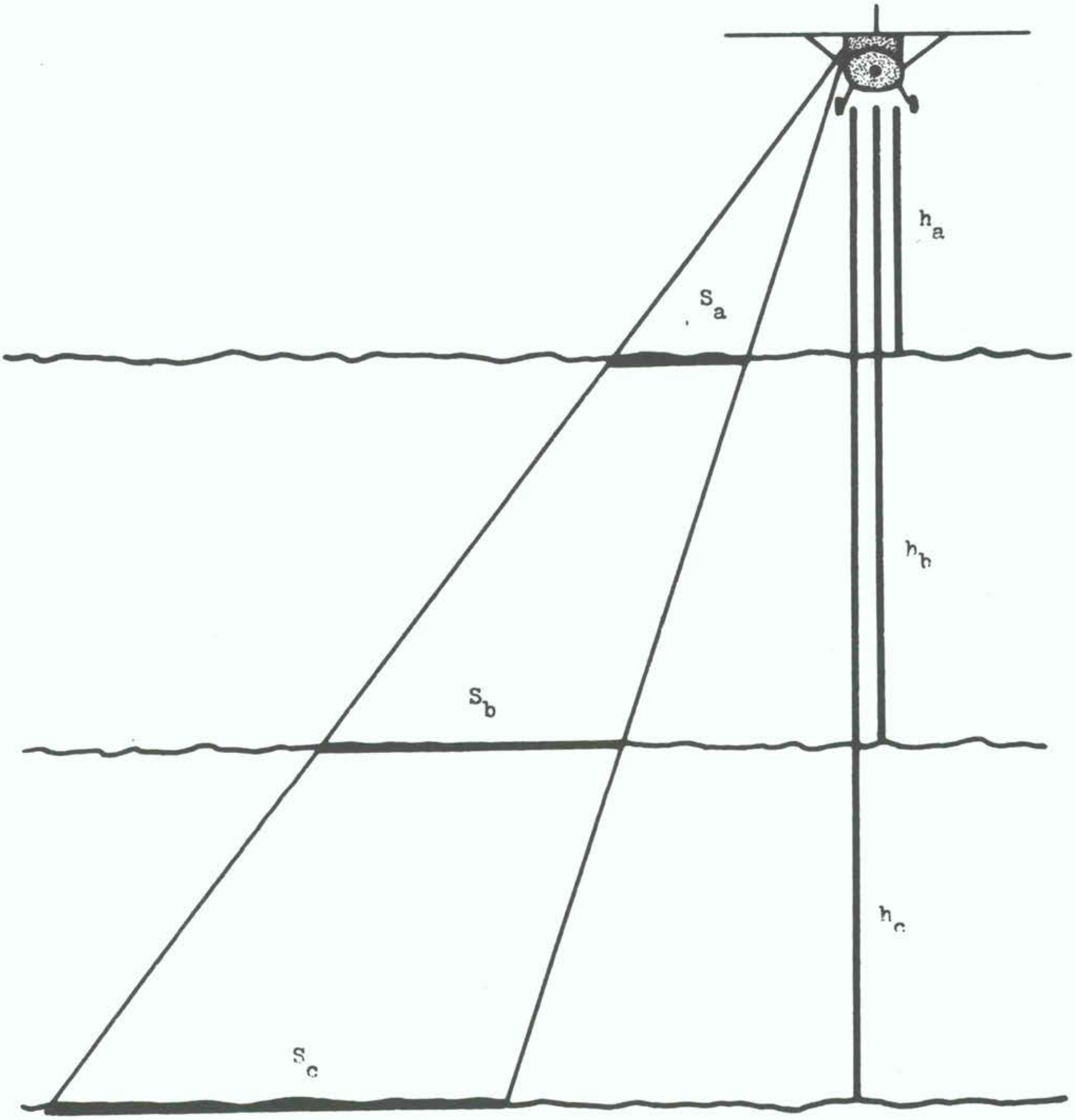

Fig 4

EAST AFRICAN HABITAT MONITORING PRACTICE: A REVIEW OF METHODS AND APPLICATION

M.D. GWYNNE* and H. CROZE**

SUMMARY

Methods of large-scale ecological monitoring have been developed and used in East Africa over the past few years. Systematic sampling techniques have proved most promising for producing the spatial and temporal ecological data necessary to manage or develop large stretches of low and erratic rainfall lands.

In this paper we present a review of some methodologies currently in use; the types of result it is possible to obtain; uses to which the result may be put; and a synthesis of strategy that combines ground, aerial and space technologies into an Ecological Monitoring Unit. We argue that such a unit, the prototype of which will shortly be operational in Kenya, is able to provide descriptive and predictive information on the life-support capacity (productivity: actual and potential) of most regions of the earth's surface.

INTRODUCTION

During the past decade the emphasis of ecological research in East Africa has shifted away from single species investigation (e.g. Kruuk, 1972; Schaller, 1972; Watson, 1967) towards ecosystem studies. This upswing in the synecological approach has occurred largely in response to the request of resource management organisations (Game Departments, National Parks, Range Management Divisions, tourist development bodies and irrigation schemes) that require large-scale ecological data on which to base utilization programmes for extensive tracts of non-urban land. Efficient utilization requires optimization of the balance between life-support attributes of the land and the type of land-use (e.g. livestock range, agriculture, game reserves), both of which depend on its actual and potential productivity. In general, the more arid the land, the smaller the choice of land-use possibilities.

Determination of productivity, both primary and secondary, is a problem for the ecologist. Obtaining such data is obviously an enormous undertaking and can only be accomplished by a single investigator if he concentrates on a relatively small area (e.g. Western, 1973). Larger regions, such as the East African National Parks and their surrounding ecosystems, can only be efficiently investigated by a multidisciplinary team that includes ecologists, botanists, soil scientists, geologists and hydrologists. Such an approach was first attempted in East Africa in the Serengeti National Park (Tanzania) in the early 1960's (Watson, 1967) and evolved into the Serengeti Ecological Monitoring Programme under the general direction of Norton-Griffiths (1972). This programme endeavoured to collect long-term data on climate, woodlands, fire, and animal and human populations.

The underlying aim of the ecosystem approach is to determine the spatial and temporal pattern of primary and secondary productivity in a particular ecosystem. The first operational question to ask in a synecological study is whether the area to be studied is an ecosystem. This usually means: Do the boundaries drawn on a map actually encompass a more or less organically and energetically self-sufficient unit? The gazetted boundaries are almost invariably political rather than ecological. To ecologists, however, the boundaries to the ecosystem are traditionally determined by the limits of the movement of the largest biomass components (Pennycuick, 1974), which of course may change with time. These movements are caused by something — and part of the problem is to determine what. Hence the synecologist is faced with having to describe the static structure of the ecosystem (topography, drainage, soils, vegetation, plant and animal community components) as well as analyse the dynamics of the system (changes in time and space of climate, productivity, shifts in community structure, etc.). In an

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area of many thousands of square kilometers this can be a formidable task and can only be accomplished with careful planning and a systematic approach.

The result has been the gradual development within East Africa of the ecological monitoring concept, from its beginning when methods were sought to answer simple questions (e.g. How many animals are there ?), through the intermediate (e.g. Where are the animals located, and when do they move ?), to the complex (e.g. Why are there so many animals, and why do they move in the patterns they do, when they do ?), culminating in the present, where land-use management questions are being asked (e.g. What will happen to the ecology of the area if it is developed for ranching, or is turned into a National Park ?). This demand for information on a large scale has necessitated the development of techniques that are efficient and inexpensive enough to be applied repeatedly over large areas. Considering the difficulties caused by the rangeland ecosystem being in a dynamic state, constantly changing in response to short- and long-term climatic cycles, the methods of data gathering and data handling developed have been most successful.

Many parts of the world's arid and semi-arid areas are over-populated by both humans and livestock in relation to the available resources. Every low rainfall year threatens catastrophe. The prolonged and severe droughts of Sahelian Africa, the desiccation of northern Kenya and the current crises in northern Ethiopia and in Somalia all emphasise the frequency with which such human misery can and will occur (cf. Ehrlich, 1968). These situations can undoubtedly be eased by the judicious supply of relief aid, but such rescue operations, though dramatic, are only short-term and do nothing to remove the ultimate cause of the problem. A more rational approach is to persuade governments to attempt to optimise land-use in the sensitive zones. To do this successfully, however, they must have simple, quick and relatively easily applied methods that will enable them to determine the demands being made on the land now ; its capacity for supporting human life ; and the future of that land under different forms of management, both year-long and long-term (Croze, Gwynne and Jarman, 1973). Most of the methodology required to provide governments with the means to make these determinations already exists, and in Kenya, for example, where much of it was developed, is already being put into practice. An understanding of the practical benefits of the ecological monitoring concept has led the Government of Kenya to establish the Kenya Rangeland Ecological Monitoring Unit (KREMU), which is jointly staffed by the Ministry of Tourism and Wildlife and the Ministry of Agriculture.

Although widely applied in East Africa (Fig. 1) the ecological monitoring methods used are not well understood elsewhere. It is the purpose of this paper, therefore, to provide a brief outline of the East African methodology and the type of results that can be obtained *.

(*) Sufficient references and contact addresses of monitoring personnel to enable interested readers to enter the field with the minimum of difficulty may be obtained upon request from the authors.

METHODS

I. The nature of ecosystem data

Ecological monitoring uses data from three general categories :

i. Environmental - including data on climate, soils, topography, hydrology and floristic dynamics.

ii. Faunal - including data on wildlife and livestock numbers, distribution, population dynamics and habitat utilization.

iii. Economical/political - including data on current land-use forms, projected land demands and national development goals.

This paper will only consider the operational aspects of collecting, analysing and interpreting some of the data from the first two categories. Choice of a collecting or sampling strategy obviously depends on the spatial and temporal distribution of the phenomena being measured. It is convenient to classify ecosystem attributes along a continuum of mutability, viz :

"Permanent attributes" :
- topography
- soils
- drainage
- water holes
- static animal features such as termite mounds

"Semi-permanent attributes"
- plant physiognomy (cover, vegetation type, etc.)
- plant community composition
- zoogenic features (wallows, salt licks, etc.)
- distribution of non-migratory large mammal species
- human settlement (villages, roads, farms, ranches)

"Ephemeral or seasonal attributes"
- rainfall
- insolation
- soil moisture
- evapotranspiration
- plant phenology (greenness)
- plant productivity (biomass, part composition, chemical composition, energy content, etc.)
- distribution of migratory large mammal species
- large mammal productivity (biomass, reproductive state, condition, food offtake, etc.)
- large mammal population structure
- fire
- surface water

Finally, data may be collected from three operationally separate levels — from the ground, from the air, and from space via satellite (e.g. Earth Resources Technology Satellite). Aerial sampling will be discussed first because the deployment of more traditional ground techniques may be profitably considered as a function of the aerial strategy, and similarly the interpretation of the satellite imagery may be done in the spatial framework of the aerial reconnaissance. Aerial survey is, in any case, the logical first field step in the resource assessment of any new large development area, and the techniques used for aerial monitoring can provide useful quantified quick-look data at low cost (see also Watson, 1969 b).

II. Aerial techniques

A. *Systematic Reconnaissance Flights (SRF)*

Ecological data collecting from light aircraft is now widely accepted as being both necessary and efficient (Zaphiro, 1959; Swank, Watson, Freeman and Jones, 1969; Pennycuick and Jolly, 1974), as it is possible to collect large quantities of data from extensive areas of land quickly and for small cost. Floral and faunal ecosystem components must be measured periodically since they are usually cyclic or serial (see also Cobb, 1975).

Although the details of an SRF will vary from area to area, depending on terrain, vegetation type, local seasons and an investigator's particular brief, we may construct a typical method currently in use in East Africa. Standardisation of technique is, in any event, desirable because it facilitates comparison between ecosystems.

The first step is to overlay the study area with a reference grid such as the UTM 10 × 10 km grid system. The grid squares can then be used for orientation during flying and for presenting and analysing distribution data.

Systematic flight lines 10 km apart, e.g. centered on the grid squares, are drawn on a 1:250,000 topographical map of the study area. The flight lines are orientated north-south or east-west as the shape of the area and wind conditions dictate. In general it is best to avoid cross-wind flight lines (problem of pilot navigation), very short flight lines (problem of statistical treatment of the data), and very long (> 100 km) flight lines (problem of observer fatigue).

The flights should not be made during very early or very late hours because of insufficient light and deep shadows. They should also not normally be made during the mid-day period (1000-1500 hours), because this is the time of maximum solar radiation during which many herbivore species retreat into the shade for rest and rumination and are therefore not easily seen from the air; this behaviour pattern is modified, however, by seasonal variations in cloud cover (Gwynne and Robertshaw, in preparation), which permit longer daily flight times.

The SRF's are flown by a crew of four in a single-engine aircraft at a speed of ca. 150 kph and a height of, for example, 100 m above ground level. The pilot is responsible for height control, navigation and spatial location, informing the crew of both transect numbers and subdivisions every 10 km flown. All data are recorded by subdivision (i.e. grid square). KREMU aircraft are also equipped with a Very Low Frequency (VLF) navigation system that reduces navigation errors and permits transects to be flown over flat featureless terrain with great accuracy; repetitive flights along the same transect are, therefore, possible provided the starting point of each flight line can be re-located.

Height control is critical (and is best maintained by radar altimeters, although a simple shadow meter can be used: Pennycuick, 1973) because the two rear observers are counting animals by species between two streamers fixed to the wing struts on either side of the aircraft. The streamers are so spaced that at a particular height they subtend a strip of known width (say 250 m) on either side of the aircraft (Pennycuick, 1974). Thus along the flight-lines the crew is counting animals (and features) in transects of known area. By proportionality, estimates of population size and variances may be made (Jolly, 1969 a and b; Norton-Griffiths, 1973; Sinclair, 1971). Using portable tape recorders, the rear observers record transect and subdivision numbers together with species and numbers of animals observed. Animal groups too large to count accurately (> 20; e.g. herds of sheep and goats) are photographed using a large magazine, motorised, automatic exposure 35 mm camera (R. Bell *et al.*, 1973; Norton-Griffiths, 1973 and 1974).

The front right observer next to the pilot also uses a tape recorder and camera to document habitat information — topography, drainage, vegetation type, cover and other "permanent" features, as well as greenness of vegetation, grass height, intensity of grazing, presence of water and other seasonal features. In a series of SRF's made during a monitoring programme, the "permanent" features need only be recorded once during an initial flight.

The adaptation of high resolution colour videotape recorders (VTR) for use in place of the rear observers is also under development (Gwynne, 1972). The re-usable video tape's virtually frameless format and its instant play-back and stop motion abilities make it particularly suitable for monitoring work. Use of the VTR allows all animal counting to be done on the ground free from flight fatigue and consequent observer bias, while at the same time permitting the collection of quantifiable data on other ecological parameters, e.g. vegetation composition and cover, surface water area, burn area and human settlement activities. A video-tape library of suitably selected flight transects can be built up, thus allowing past surveys to be re-examined using updated analytical techniques.

However, the current high capital cost of professional VTR and necessary ancillary ground equipment may reduce the applicability of the VTR method. An alternative system also under development in Kenya involves the use of 35 mm photographic colour film and/or small size ciné film, with the camera controlled by an intervalometer and individual frames being exposed at intervals of one every five seconds to one every seven seconds, depending on the aircraft ground speed. This method has some of the advantages of the VTR system together with low initial capital cost. The major disadvantages are the processing time required before census and monitoring data can be obtained, and higher operating cost per SRF (in terms of film and processing). The use of image analysing computers may aid in the extraction of data from SRF photographs.

The frequency of SRF's is a function of cost and the rapidity of seasonal changes — every month, every two months, every quarter and every major season have been used. The cost of flying such a survey is currently about US $ 50/1,000 km², not including observer time and cost of films and recording equipment.

The data are all recorded with reference to a sub-unit on a transect, that is, within a particular 10×10 km grid square. The data are transcribed from the tape machines directly onto computer coding sheets. At this stage, distribution of animals, greenness, water, vegetation type, etc., may be plotted by hand onto gridded working maps of the study area (see "Results"). The data may also be punched onto computer cards and transferred to magnetic tape for storage and analysis. Programmes are now in use which file the data and produce line-printed distribution maps as well as animal population and biomass estimates (e.g. by Norton-Griffiths and Pennycuick, 1973; Cobb and Western, ANPR Programme, personal communications). A computer is not necessary, but it saves much time and labour. The Serengeti Research Institute programme, for example, dealt with 34 pieces of temporal, spatial, faunal and habitat information for each of the 300 grid squares of the Serengeti ecosystem that were overflown monthly over a period of three years. Further, a computer facilitates more complex analysis of the data-species associations, multiple correlations, trend surface analysis, cluster and multiple discriminant analysis, etc.

We have outlined the systematic aerial survey strategy in some detail, for although currently much in use in East Africa (Fig. 1), it is not well known elsewhere. There exist as well, however, numerous other specialised uses of light aircraft for census and monitoring purposes — a few examples of which are given below.

B. *Aerial sampling for large mammal population estimates*

Ecologists are frequently faced with the problem of determining the size or density of a particular species population. Although such information may be extracted from a series of SRF's (Croze, in preparation), often because of the small sampling fraction (e.g. $< 5\%$) the confidence limits of the estimates can be quite large. Clearly, to detect a change in population size from, say, year to year, the population estimates should be as precise as possible.

If we know the movement range of a particular population or are able to delineate concentration areas from the distribution data of an SRF, we may then concentrate sampling effort over that particular area. Both systematic flights at a greater intensity (i.e. flight lines spaced 5 km or 2.5 km apart) and stratified random samples have been used (Jolly, 1969 a; Pennycuick, 1969; Watson, 1969 a, 1969 c and 1972; Western, 1973). In general, precision is a function of sampling intensity (Caughley, 1972; Norton-Griffiths, 1973), and only with precise population estimates can we monitor short-term population fluctuations.

C. *Large mammal population parameters from low-level aerial photography*

Aerial photography, as we have already seen, plays an important role in increasing the accuracy of counts. Sinclair (1969) used low-level oblique photographs of buffalo (*Syncerus caffer Sparrman*) breeding herds to monitor recruitment through the proportion of first-year animals in known herds. Croze (1972) used measurements of elephant back-lengths from vertical aerial photographs to determine the age structure of elephant populations; and Western (unpublished data) used pre- and post-drought colour (Ektachrome) photographs of Maasai cattle herds to assess colour-morph-specific mortality rates.

D. *Habitat information from high-level aerial photography*

The large-scale (ca. 1:50,000) aerial photograph is an important tool of geologists, cartographers, soil scientists, landscape ecologists and botanists. Virtually all geological, topographical, soil and vegetation maps are compiled initially from black and white, and more recently, false colour (near infra-red colour) aerial photography (cf. UNDP/FAO Kenya Range Management Project Rangeland Surveys, FAO, 1967-73).

Sequences of aerial photographs taken of the same region at different times can be used to enumerate gross changes in vegetation physiognomy (e.g. the rate of loss of woodland trees: Croze, 1974).

E. *Landscape classification*

We usually think of mapping a study area according to specialists' needs: soil maps, geological maps, vegetation maps, or very general low-resolution ecological zone maps (e.g. Pratt, Greenway and Gwynne, 1966). A little-known corner of aerial ecological technique is occupied with strategies of landscape classification (e.g. Beckett and Webster, 1965; Scott, Webster and Lawrance, 1971; Gerrisheim, 1974). The approach develops ramifying systems by which large land units are subdivided into smaller ones according to the relative homogeneity of morphology, soil and hydrology, and vegetation. The classifier delineates apparently homogenous areas on large-scale aerial photographs and then checks the delineation on the ground. The product — standardised, identified units of landscape — come in various sizes and are suitable for different levels of management or research. **Land Regions** are useful units of organisation for an ecosystem study of management plan; the smaller **Land Facet** is sufficiently homogenous over its extent that it could be managed uniformly for all but the most intensive kinds of land-use; the **Land Elements** of which the **Facet** is composed are only sufficient, for example, to describe the range of one rodent population.

Without doubt the technique as practised now is subjective and requires "an expert's eye" to identify unit boundaries; and conceivably not everyone can acquire the knack. The problem of individual variations may be solved by using numerical classification and descriptive techniques such as cluster analysis and trend surface analysis.

III. Ground sampling strategies

Ground sampling techniques are, of course, those most frequently used by ecologists, and although we can collect much data from the air, we must eventually come back to earth. Geology, cartography, hydrology, soil science and descriptive botany are all specialised disciplines, sophisticated and well-documented. These data are clearly vital to the complete understanding of the structure and dynamics of an ecosystem. For our purposes they provide more or less static descriptions of what we have chosen to call the "permanent" features of an ecosystem. Over these features we lay our reference grid described in the previous section and proceed to monitor biotic dynamics. It is important to note that productivity can be monitored without the "permanent" data, but investigations of causation are incomplete without them.

A. *Rainfall*

Productivity depends temporally and proximally on water — surface, sub-surface and precipitation — taxed by transpiration and evaporation. In the arid and semi-arid tropics it is the availability of this water that becomes important rather than the supply, as often these areas receive a higher annual rainfall than more temperate regions (Gwynne, 1966). Meteorological methods and equipment for estimating rainfall are well known (Monteith, 1972 ; Munn, 1970 ; HMSO, 1956 ; WMO, 1965). Ideally, meteorological stations ranging from simple monthly storage rain gauges to complete hydromet installations and automatic weather stations (Leese, Strangeways and Templeman, 1973) should be spaced evenly over the ecosystem. Rain gauge distribution at a density of 1:1,000 km^2 is desirable, but some workers recommend even greater densities, e.g. 1:500 km^2 (Grimsdell, 1975). Consideration of site accessibility and cost, however, render the attainment of this goal unusual, particularly if very large areas are involved, as in a nationwide monitoring programme. Fortunately, there are useful statistical techniques such as trend surface analysis (Norton-Griffiths, Herlocker and Pennycuick, 1975) that allow extrapolation and isohyet delineation from irregularly placed stations.

B. *Soil Moisture*

The amount of water available to plants is a major factor affecting their productivity. As the majority of this water is that which is present in the soil within the plant root range, after the physical requirements of the soil have been met, it is important in a monitoring programme to follow seasonal changes in soil moisture throughout the soil profile, preferably at sites close to the rain gauges. These sites should also be chosen with regard to the prevailing soil type (which will influence soil permeability and the physical retention of water in the soil) and position in the soil-vegetation catena (e.g. hill summit, hill slope, valley sump).

Water availability patterns can be obtained from the logarithm of the resistance in ohms of plaster-of-Paris blocks buried in the soil at different depths (Pereira, 1951 ; Pereira and Hosegood, 1962). A more useful and rapid method for obtaining quantifiable data, however, is to use a neutron probe. The probe is lowered into a permanently installed aluminium tube in the soil and readings taken at appropriate depth intervals (usually 15 cm or 30 cm for a total depth of at least 2 m). In this method fast neutrons are emitted from the radioactive probe source and are scattered and slowed by collisions with soil element atomic nuclei, mainly the hydrogen of soil water. These slow neutrons are detected by the probe and converted into pulses, which are displayed as the count rate (the wetter the soil, the higher the count rate). The count rate is thus related to the hydrogen content of the soil and changes in moisture content (J. Bell, 1973). The instrument has to be calibrated for each soil type.

C. *Systematic Ground Survey (SGS)*

The strategy for SGS is essentially similar to that of SRF except that more detailed data are collected for a disproportionate increase in cost. Cost aside, however, there is as yet no aerial substitute for SGS at the finer levels of resolution (Jarman, 1971 ; Western, 1973 ; Rodgers, 1974). The survey lines are seldom as regular as in the SRF because the observer's ground mobility is restricted by the nature of the terrain and the density of the vegetation cover (Rainy, 1969). SGS sample site lines, therefore, tend in many areas to parallel existing game trails, paths and roads. The observer uses the time-saving advantage afforded by the tracks and places the recording sites in the undisturbed habitat to one side of the path. Site intervals of 0.5 and 1 km have been used in East Africa for SGS monitoring transects. Data recorded at sample points include, for example, grass phenology, height, species, species density and cover ; woody plant species, growth stage, density and cover (and intensity of browsing or grazing by large mammals). Samples are collected for chemical composition and energy content determinations. The Point-Centered Quarter (PCQ) technique, a plotless sampling strategy, provides a very rapid method of determining plant species density provided the species being measured are not too contiguously distributed (Cooper, 1963 ; Dix, 1961 ; Heyting, 1968 ; Croze, 1974).

Ground sampling by vehicle and on foot has been done by Rodgers in the Selous Game Reserve, Tanzania ; by Western in Amboseli National Park (formerly Amboseli Game Reserve), Kenya ; by Rainy in Samburu District, Kenya ; and by Gwynne in South Turkana and Lamu District, Kenya.

If the area monitored is very large and widely spaced sampling sites such as the 250 ground truth stations of the KREMU (see below) are used instead of transects, then aircraft are used to transport the field teams wherever possible.

Data collected by SGS must always be related to existing cartographic, geological, soil, vegetation and land system maps, climatic data acquisition sites or mean annual rainfall, rainfall probability and potential evaporation data (e.g. Rijks and Owen, 1965 ; Woodhead, 1968 a and b).

D. *Primary production biomass and use*

Various methods for estimating above-ground primary production of grasslands are given by Milner and Hughes (1968) and for forests and woodlands by Newbould (1967), but these methods are more successful for grassland than for woodland and forest. Traditional methods involve destructive sampling by clipping quadrats of appropriate size, sorting into species and plant part (e.g. leaf, sheath, stem, inflorescence, etc.), followed by dry weight determination and chemical analysis. This is both time-consuming and tedious, so that other techniques have been sought. One of the most useful has proved to be the canopy intercept method (Goodhall, 1952 ; Warren-Wilson, 1960 and 1963) normally used to calculate cover and leaf area index. Suitably calibrated it will give biomass data by species on green leaf, green stem, dry leaf, dry stem and any other plant component needed. It is most applicable to grassland and has been used very successfully by MacNaughton in the Serengeti (unpublished data). Similarly in the Amboseli area of Kenya, Western (unpublished data) has developed a relationship between biomass density, grass height (culm or leaf) and plant density ; this method has also been used by Cobb in the Tsavo National Park, Kenya. Both of these methods are rapid to use and non-destructive, but neither gives data on chemical content, for which separate samples must be clipped. They do permit routine determinations of grass standing crop at frequent intervals, both temporally and spatially (e.g. monthly and every 0.5 km), along lengthy monitoring transects.

A new monitoring technique for green biomass determinations based on canopy spectroreflectance (Pearson and Miller, 1973 ; Tucker, Miller and Pearson, 1974) is at present in use in East Africa, having been introduced at the Serengeti Research Institute by MacNaughton. The ratio of chlorophyll reflectance (8,000 Å) to absorption (6,750 Å) has, in the grass layer at least, a linear relationship to green biomass density. The relationship for woodland species is more complex and remains to be elucidated as it is affected, for example, by the depth of canopy and the amount of chlorophyll contained in the bark. The use of the ratio is necessary to reduce the effect on the reflectance values of the light bands by factors such as cloud cover, time of day and sun angle. The instrument (a digital spectral photometer with a sensing probe for each wave band) must always be calibrated against actual harvest determinations prior to use in any new ecosystem. It can be used on the ground for sample green biomass estimates, and from aircraft. MacNaughton (unpublished data) has used green biomass determinations made from the air to construct seasonal green biomass density maps for the Serengeti National Park (Figs. 12 a and b).

The use of primary productivity by livestock or wildlife species can be determined a) by clipping and weighing grass within and without an animal-proof exclosure (e.g. Bell, 1971 ; Western, 1973) ; b) by inspecting vegetation for signs of grazing (e.g. Vesey Fitzgerald, 1969 and 1974) or browsing (e.g. Vesey Fitzgerald, 1973 ; Croze, 1974) ; c) by direct observation of the animals feeding (e.g. Goddard, 1970 ; Leuthold, 1970 ; Field, 1971 ; Jarman, 1971) ; or d) by the use of direct sampling of ingested food items by means of œsophageal fistulation (e.g. Van Dyne and Torell, 1964 ; McKay and Frandsen, 1969 ; Duncan, 1974 ; Kreulen, 1975), rumen fistulation (Kreulen, 1975) and more recently, repetitive trocar sampling (Fellis and Spillett, 1972). It has proved difficult to quantify categories b) and c) in terms of absolute biomass used — but the increased use of remote sensing techniques should soon eliminate this problem.

E. *Ground acquisition of large mammal data*

Ground surveys to establish animal population parameters are not normally necessary if SRF data are available for the species concerned, unless the vegetation structure is such that animal concealment leads to major bias (Watson, 1969 ; 1972). Population estimates of some animal species not readily seen from the air, such as those at the small end of the size spectrum (e.g. oribi, *Ourebia ourebi*) and those that spend the day largely in concealment (e.g. greater kudu, *Tragelaphus strepsiceros*) can best be made from the ground (e.g. Lamprey, 1963), as can checks on herd structure and composition. Data on age structure, growth rate and reproductive history and recruitment can be most reliably gathered from collected specimens (Laws, 1966, 1969 ; Grimsdell, 1973) and ground observations (Sinclair, 1973 a and b).

Small samples of slaughtered animals will also produce information of food offtake derived from rumen content analyses (Gwynne and Bell, 1968 ; Field, 1972 ; Jarman and Gwynne, 1976) and faecal analysis (Stewart, 1967), although results obtained by these methods must be treated with caution in view of differential digestion effects (Thornton and Minson, 1973 ; Duncan, 1974). Such results can be related to ground observation of feeding behaviours and quantitative determinations of vegetation on offer (Jarman and Gwynne, 1976). Estimates of body condition can be made using muscle-to-bone ratios, kidney fat and bone marrow condition (Sinclair and Duncan, 1972).

F. *Ground checks on SRF data*

Although SRF surveys can operate independently, they are of more value for resource measurement and ecological monitoring if they are closely linked to ground truth data. Interpretation of SRF information becomes easier when data from ground studies are available (cf. III-A-E), and many investigators wish at the end of the first 2-3 years that they had spent more time devising adequate ground sampling techniques, particularly with regard to vegetation production, growth stage and animal herd composition.

IV. Remote sensing from satellites

A. *Satellite Imagery*

The earliest remote sensing device was a camera attached to a balloon, which flew in 1858 (Rabchevsky, 1970). Since then a series of sensing platforms have been launched (Colvocoresses, 1974) to record or monitor events on or near the earth's surface, using photography or electromagnetic spectral sensors. Now weather ; crop condition ; forest diseases ; air, sea and fresh water pollution (Colwell, 1971) ; and more recently primary production (Carneggie and De Gloria, 1974 and personal communication) are all being monitored, mostly on an experimental basis, via satellite (see also Bale *et al.*, 1974).

Since 23 July 1972 the first Earth Resources Technology Satellite (ERTS-1) has been orbiting the earth at a height of 900 km, passing over the same place on the surface every 18 days. On this vehicle is a multispectral scanner that senses the wavelength and intensity of light reflected from the earth's surface features in units with a resolution of about

80 × 80 m. The information in four spectral bands is coded into magnetic tape on the ERTS and transmitted to earth receiving stations in digital form (Rabchevsky, 1970 ; Colwell, 1971 ; CENTRO, 1971).

For the ecologist the ERTS output has two important formats :

1. picture-like images (false colour composites ; black and white positive or negative in each of four spectral bands) that appear as aerial photographs, each depicting a 185 × 185 km area of the earth's surface.

2. digital output of the intensity and wavelength of light reflected from any 80 × 80 m portion of the earth's surface.

The images show clearly all major land features — drainage lines, mountains and faults. Spectral band 7 (0.8 - 1.1 μ) emphasises soil boundaries, while spectral band S (0.6 - 0.7 μ) enhances green vegetation (which appears red on false colour images).

Essentially the same data, only with a finer possible resolution and accuracy of interpretation are contained in the digital output — indeed the digital information from the multispectral scanning device is integrated by a computer to produce the image. For example, a false colour image will show an area of green grassland as bright red and an area of drying grassland as bright pink. The digital analogs are reflectance intensities in band S, the red portion of the electromagnetic spectrum, for the two areas. Clearly, these numbers can be calibrated to primary production biomass density (Carneggie, 1974 and personal communication) ; Rouse and Riter, 1973). Thus subsequent estimates of regional primary production may be made using data collected from a height of 900 km. Since the satellite passes overhead every 18 days, it is possible to monitor the ebb and flow of primary production over an entire ecosystem. Animal biomass distribution data from Systematic Reconnaissance Flights may then be correlated directly to absolute estimates of primary production.

RESULTS AND ANALYSIS

In this section we will review a selection of the types of results it is possible to obtain using the methodologies outlined in the previous section. The data are taken from studies recently completed or currently in progress in East Africa. We will present them in this order — ground, air and space — keeping in mind that we ultimately want to integrate the three types of results into a synoptic view of the ecosystem. No model-constructs or simulation results will be presented, for the simple reason that none are yet available for East Africa (an exception on a small scale is Norton-Griffiths, in preparation, a construction of ecological regions using a cluster and multiple discriminant analysis). We will, however, discuss a few of the analytical techniques.

I. Results from ground monitoring

A. *Rainfall isohyets using Trend Surface Analysis*

Norton-Griffiths *et al.* (1975, in press) constructed rainfall isohyet maps for the 25,000 km² Serengeti ecosystem (Figs. 2 a and b), using data from 62 irregularly spaced monthly storage rain gauges. He subjected the data to trend surface analysis (e.g. Gittins, 1968), a multiple regression technique that finds the polynomial equation describing the " surface of best fit " for a continuous variable in two-dimensional space. Regular contours of the surface are, in this case, rainfall isohyets. The advantage of the method is that it presents a rainfall map, which, unlike the products of more subjective techniques, has been tested with an analysis of variance. One can also use data on rainfall variability, evapotranspiration and climatic indices.

B. *The response of large grazing mammals to pasture growth stage*

Each large mammal herbivore species has a specific feeding mechanism, a combination of anatomical and behavioural characteristics, which enables it to feed off a particular physiognomic vegetative type that is optimal for the species in terms of ensuring the maximum food intake for the minimum expenditure of energy (Gwynne, 1971). In the sequential grass species growth that follows the onset of rain (Cobb and Gwynne, unpublished data) grazers move from grass species to grass species as each approaches the physiognomic state optimal to that animal species. This utilization by grazing animals is closely related to changes with age in grass leaf tensile strength (Gwynne, in press). An indication of the effect of physiognomic vegetation stage on feeding efficiency can be seen in Fig. 3, which shows that among sheep an increase in grass height results in an increase in time/bite. Goats feeding in the same area at the same time showed the same relationship, but consistently took longer per bite than the sheep ; in neither case was bite size quantified (Gwynne, 1974). Monitoring of vegetation physiognomic state is essential in understanding large mammal feeding habitat utilization.

C. *Elephant use of wooded-grassland tree species*

In a study of elephant-woodland interaction, Croze (1974) measured woodland composition and elephant-browsed trees using an extremely efficient ground sampling technique known as the Point-Centered Quarter (PCQ) method (e.g. Heyting, 1968). A comparison of tree species used with tree species availability (Fig. 4) showed that one out of six species was taken preferentially, one was avoided, and the rest were taken as expected by proportionality. One can only talk about preferential use of pasture components if the relative availability of the components is known.

II. Results from Systematic - Reconnaissance Flights

A. *SRF : large mammal distribution by season and vegetation type*

As has been outlined under " Methods ", large mammal distribution as recorded on an SRF can be ranked into density classes (Norton-Griffiths, 1972) and plotted on maps according to the sub-unit of observation. Plotting can either be done manually or with one of the various computer programmes available (e.g. ANPR of Cobb and Western, cf. "Methods") where distribution is given in the form of a density-ranked digital printout map. Figs. 5 a and b illustrate the actual dry season distribution of two closely related Alcelaphine antelopes, the topi (*Damaliscus korrigum*) and the little-known Hunter's antelope (*Damaliscus hunteri*) in the Lamu-Garissa area of Kenya. These distribution maps clearly indicate that at this season the two species occupy contiguous areas. Comparison with an SRF-generated broad scale vegetation map (Fig. 6 ; cf. II-C) shows that the Hunter's antelope is more or less restricted to a low rainfall area of *Acacia* dry thorn bushland, with the topi occupying an ecotone zone of woodland with grassland glades. Neither species occurs in forest or in areas of dense woodland (Duncan, Gwynne and Jarman, in press). Further analysis suggests that the dry season distribution of the topi is closely related to the occurrence of permanent surface water.

Similar seasonal distribution data from SRF's can be subjected to trend surface analysis (Norton-Griffiths and Pennycuick, 1973) to show the basic underlying distribution patterns. Figs. 7 a and b give wet and dry season surfaces of best fit ($p. < 0.01$) for the Hunter's antelope. These show that in the wet season the species is in two local concentrations, both occurring in the *Acacia* dry thorn bushland, with outliers extending well into the higher rainfall wooded grassland ecotone also occupied by the topi. Thus the two species can overlap at this time. In the dry season the eastern population disappears, presumably by retreat into Somalia, while the western group moves to the northwest, closer to the river Tana. Similar seasonal distribution data for cattle (Figs. 8 a and b) show that there is little change in the overall occurrence pattern with season, the animals mainly being found on the woodland-grassland ecotone complex between the dry thorn bushland and the forest and dense woodland. The higher concentrations in the dry thorn bushland of the northwest, near the Tana river, are due to livestock moving through the area along stock routes (cf. Fig. 9). The increase in wet season cattle numbers in the centre of the map is closely correlated with green grass availability as shown by SRF greenness estimates (cf. Figs. 17 and 18). The wet season absence of stock from zones in the northeast and southwest is due to apparent avoidance of dense forest and floodlands, respectively (Duncan, Gwynne and Jarman, in press).

These few examples from one area of Kenya illustrate some of the types of large mammal distribution information that can be obtained from SRF's quickly and at relatively little cost ; that which is presented here represents only a small portion of the total gathered. Similar data are available from each of the areas in East Africa being monitored at present. Such data can be used to construct habitat utilization probability maps showing the likelihood of any particular area being used as feeding grounds for a particular species or complex of animal species (e.g. domestic livestock, wildebeest, etc.) in a manner directly analogous to the better known rainfall probability maps (e.g. Glover, Robinson and Henderson, 1954).

B. *Patterns of use by large mammals*

Large mammals repeatedly walking over the same route to and from water or grazing grounds soon abrade the vegetation, leaving obvious trails, often eroded deep into the soil. From the air most rangelands are seen as a maze of inter-connected minor game and livestock paths that sometimes merge to form large, very well defined routes for long distances. The causal species can often be inferred from the characteristics of the route alone, e.g. the broad, smooth, dung-littered, often deeply worn highways of the elephant, and the wide, parallel-ribbed tracks of herds of driven domestic cattle (Fig. 10). These major routes can be mapped during SRF by having each observer note the position of the track when it is crossed by the flight line and record the approximate direction of the track according to cardinal and half-cardinal compass lines (e.g. E-W, NE-SW, N-S). The route net becomes apparent when these are plotted on the SRF grid map. The direction of trail use can be ascertained by actual observation of animals using the trail or inferred from other data. Fig. 9 shows a cattle stock route map for the Lamu District, Southern Garissa District area of Kenya, constructed from data collected by this method during the course of a routine SRF in 1973. The dotted line indicates a very well defined trail now overgrown and no longer in use ; its course follows closely that of a track already marked on the 1:250,000 map sheets of the area (Gwynne, unpublished data). The fine arrows indicate the general direction of minor trails too numerous to show in detail.

C. *SRF : Preliminary vegetation mapping*

If the rear observers during an SRF are requested to record vegetation type by structure (cf. Pratt, Greenway and Gwynne, 1966), then a preliminary vegetation map of the survey area may be compiled very quickly. Fig. 11 is such a map for the Ilkisongo region of Southern Kajiado District in Kenya. Four broad vegetation types are distinguishable — grassland/swamps, bushed grassland, mixed bushed/wooded grassland, and forest. Intrusion of cultivation into the area is also mapped. A knowledge of the local species allows species lists for zones to be compiled from the air. An SRF-generated vegetation map can serve as a useful temporary working basis before detailed aerial photographic and ground work. Fig. 11 involved 15 hours of flying and represents only a fraction of the information gathered during the flight.

D. *Green biomass estimation*

Figs. 12a and b show seasonal green biomass density isopleth (gms/m^2) maps prepared by MacNaughton (unpublished data) for the Serengeti National Park in 1974, using the digital spectrometer "Biometer" (cf. "Methods", D) carried in a light aircraft. Flight lines were approximately north-south, with the meter readings being taken at approximately regular intervals. When values showed that the green biomass gradient was rising, the interval between readings was shortened and adjacent flight lines run to delimit the steep gradient boundary. Map isopleth lines were fitted by eye (McNaughton, unpublished data). This powerful new tool represents a major advance in monitoring technology, even though at present it can only be satisfactorily used over grassland and wooded grassland (green biomass values for forest and woodland are minimum values ; however, as such they are still useful). The development potential for this method is very great.

E. *Trend surface analysis of non-systematic distribution data*

It should be obvious by now that we are in general advocating systematic methods of data collection. Occasions may arise, however, when one must deal with unsystematic data. In some instances, they may be analysed in systematic ways. Croze (1973) surveyed parts of Northern Kenya to determine the instantaneous dry season elephant distribution. Time was limited, so it was necessary to ignore stretches of completely dry country and restrict the survey to green areas where elephants were expected. 57 % of the total 368 10×10 km UTM grid squares in a portion of Samburu District were overflown. Data from this partial coverage were analysed with trend surface analysis (see above). Surface equations were generated, and from the analysis of variance the quartic surface (Fig. 13) was chosen as the surface of best fit ($p < 0.01$). Such a technique could well be applied to unsystematic historical distribution data to fill in gaps from before the initiation of an ecological monitoring programme.

F. *Population parameters from aerial photography*

Croze (1972) illustrated a method for assessing the age structure of African elephant populations using low-level vertical aerial photography (Fig. 14). The method depends on a growth-curve for elephants, which has been obtained from post-mortem (i.e. ground) studies. The age structure may be used in the usual ways — for determining the biomass density of a population the size of which has been estimated by aerial sampling ("Methods", above), for assessing the "health" of a population, and as a basis for deductions about recruitment and population growth.

G. *Habitat dynamics from aerial photography*

The change of the structure and abundance of woody vegetation may be monitored using sequential low-level aerial photography. Fig. 15 shows the striking reduction in thicket vegetation in the north of the Serengeti National Park (after Gerresheim in Norton-Griffiths, 1972). Relative changes in wooded grassland may be determined by means of a grid sampling method (e.g. Norton-Griffiths, Bunning and Kurji, 1973) or by direct count in sample plots on the photographs (e.g. Croze, 1974). The results, of course, are descriptive. If the results are combined with concurrent monitoring of modifying factors (animals and fire) and controlling factors (soils and climate), then causal links may be identified.

III. Results from satellite remote sensing

A. *Soil mapping from ERTS imagery*

ERTS images in the form of false colour composites and monochromes of spectral band 7 (0.8 - 1.1 m) have proved most useful in making exploratory soil surveys of large areas of semi-arid rangeland quickly and at low cost. The drier regions are most suitable, as the sparseness of the vegetation allows the spectral signature of the soil to come through relatively unimpeded. The ground truth necessary to categorise the various soil types can be obtained during ground monitoring programmes, while areas of uncertainty can be checked for soil type by light aircraft reconnaissance flights. Fig. 16 a shows a portion of such a map delimiting the main soil types of the Lamu-Garissa region of Kenya, prepared directly from ERTS images (Fig. 16 b) in this way and related to existing geological data (Gwynne, in preparation). There is good agreement between this map and one of part of the same area prepared at a later date by others using more conventional methods.

B. *Primary productivity monitoring using ERTS imagery*

A comparison of (a) grass-greenness data collected during an SRF in Southern Kajiado District of Kenya (Croze and Western, in preparation) and (b) the subjective colour range of spectral band S from an ERTS image of the same area two weeks later, shows very good agreement (Wilcoxon test, $p < 0.6$; Figs. 17 a and b). The match was not perfect because of a small time lag and because the ERTS scanning device records the greenness of both woody and herbaceous vegetation. The woody vegetation greenness component could be removed by subtracting a dry season (green trees but no grass) standard. Seasonal grass cover reflectance as recorded by ERTS could be correlated with primary productivity on the ground. Then seasonal primary productivity could be monitored for very large areas directly from the satellite imagery and quantified, using the digital output of the ERTS data. For monitoring productivity, productivity model building, and predictions of productivity failure (drought and famine conditions), satellite imagery is becoming invaluable. Fig. 18, showing the distribution of cattle in the Amboseli area at the time that the SRF greenness distribution was determined, should be compared with Figs. 17 a and b.

DISCUSSION

I. Synthesis of methodologies

Long-term synecological monitoring probably first began in 1947, four years after Oxford University received Marley Wood on the Wytham Estate as a gift, and Charles Elton began to lead generations of researchers and students through the Wytham ecosystem. After a quarter of a century of repeated measurements in time and space and the development of a central data storage system, all coordinated by a research committee, Marley Wood, all 4 km^2 of it, must be the best understood ecological system in the world today. In America the systematic, integrated, large-scale team approach was initiated on a grand scale by Van Dyne and his co-workers in investigating temperate grasslands (Van Dyne, 1969, 1972). Elton and Van Dyne have much in common with respect to the conceptual basis of ecosystem research — the differences are in scale of operation and analytical techniques. The approach of the Grassland Biome group is essentially a highly organised network of detailed ground studies aimed at establishing and modelling the cause-effect chains of temperate grasslands.

For many developing countries (with vast stretches of semi-arid or at best dry sub-humid climatic zones) we recommend, initially at least, an approach that combines the three operational levels of ground, air and space. There are at least three things to consider :

1) Few countries, even with international aid, can afford a national commitment of a team of 90 scientists and an annual budget of US \$ 2.0 million to be spent on ecological research (Van Dyne, 1972).

2) Land resource management agencies require practical answers quickly, because of the exponentially increasing demand for land-use plans. Investigations into causation usually take time. If productivity descriptions, correlations and at least preliminary predictions can be made quickly, then so can sensible management plans. Detailed causation studies may be postponed until time and funds allow. The fact that large areas must be surveyed (whole countries) and that large, far-ranging animals (pastoral stock and wildlife) must be accounted for make aerial reconnaissance indispensable.

3) Finally, one might argue that there exists a greater need in xeric tropical regions for baseline data and the monitoring of gross climatic and vegetation dynamics. For one thing, tropical ecology has only been seriously studied in the last decade : few background data are available. For another, we are beginning to suspect that a fundamental process of temperate habitats — that of a seral progression to an equilibrium state — may be the exception rather than the rule in semi-arid to dry sub-humid tropical ecosystems. The type of small-scale study that might give much insight into cause-effect links in a temperate "old field" could lead to false predictions in the tropics, if we fail to recognize that we are in a phase of a dramatic vegetation cycle.

Croze, Gwynne and Jarman (1973) outlined an international Ecological Monitoring Programme that would design, implement and coordinate Ecological Monitoring Units (EMU) in various countries. An initial EMU is about to become operational in Kenya as a joint Kenya Government-Canadian International Development Agency venture. To monitor approximately four-fifths of the country the total cost, including all operating expenses, capital outlay and staff salaries, amounts to just under US \$ 1.0 million per year. If only operating and maintenance costs are considered, however, the outlay reduces to US \$ 200,000 per year, or US \$ 400/1,000 km^2 of country surveyed. The SRF component alone without the associated ground programme will cost about US \$ 50/1,000 km^2 of country surveyed.

Since this first EMU is conceptually and operationally a synthesis of the methodologies already discussed, we shall in the following section present an outline of its structure.

II. An integrated research programme : the Kenya Rangeland Ecological Monitoring Unit (KREMU)

A. *Background*

The land area of Kenya is about 570,000 km^2 and the country has a present population of some 12 million concentrated in three main areas — western Kenya, central Kenya, and along the coastal strip. Currently the population has a geometric growth rate of 3.3 % per annum. The population concentrations roughly coincide with the more fertile and well-watered areas of the country, which account for about 18 % of the surface area of Kenya, leaving over 80 % of the land with a rainfall of less than 750 mm per annum.

This lack of rainfall acts as one of the greatest constraints on the development of huge areas of Kenya, and a major aim of Government is to improve the productivity of these arid and semi-arid areas through a programme of scientific range management. This will involve the phased replacement of traditional nomadism by commercial stock ranching. In addition to supporting pastoralists and their stock, this region also contains very large numbers of herbivorous wildlife species, ranging from the elephant (*Loxodonta africana*) to the very small dik-dik (*Rhynochotragus* spp.), which are distributed according to topography and availability of water and food. The Government is aware of the possible conflict of interests between these two major resources and the consequent need for sound long-term management practices. This has arisen with the change in attitude towards wildlife from the purely protective to one in which wildlife is to be utilized as a resource, either alone or in combination with domestic livestock.

Government has, therefore, decided to establish a Kenya Rangeland Ecological Monitoring Unit to determine the numbers, distribution and seasonal movements of domestic livestock (cattle, sheep, goats, camels, donkeys) and the major wildlife herbivores (about 15 species). This unit will also monitor climatic parameters, habitat features and changes in human land-use. The incoming quantitative data will be used to construct models for the various ecosystems and self-contained land units involved, and these in turn will be used to generate management policy and plans.

To establish the KREMU, Government has entered into a bilateral aid programme with the Canadian Government for the initiation and staffing of the KREMU for an initial 4-year period, after which it will be run entirely by Kenyan personnel. Additional expertise is being supplied by the United Nations Food and Agriculture Organisation.

The KREMU will be inter-ministry in composition and outlook and will make its findings available to all Government agencies. Pre-project activities (organisation, ground-unit delineation, etc.) have started ; it is expected that routine sampling will commence early in 1976.

The KREMU will use methodology developed in East Africa during the last decade for small-scale (under 25,000 km^2) habitat monitoring programmes and already outlined in this paper. This involves a systems approach to data collection and handling and the use of both field teams and regular systematic reconnaissance flights.

The KREMU will thus be amassing a large amount of ground truth data. Such data will also be used to develop methods for quantifying multi-spectral satellite images such that the resultant data can be used in the regular updating of the ecosystems models. If this proves successful it will mean a great saving in manpower and will allow the extension of the EMU concept to other areas that have an even more severe shortage of trained personnel than Kenya, e.g. parts of Sahelian Africa. In fact, with suitable technical modifications, any world ecosystem — marine or terrestrial — may be monitored using the EMU strategy.

B. *Objectives*

The function of the KREMU is to describe in quantifiable terms what animals and what human land-uses occur on a specified area and how they are distributed in relation to each other and to measured and described parameters of the environment such as vegetation, surface water, rainfall, etc. Extending the descriptions over time will provide information on the dynamic aspects of the relationship. This is, therefore, basically a systems approach to synecological community analysis. If properly established the KREMU will be able both to forecast and to detect the responses of the ecosystem to changes resulting from natural climatic extremes and from deliberate, human-induced changes, and will enable practical land-use solutions to be generated quickly.

To obtain and process these data and produce the findings in a form useful to land management, the KREMU will take the following operational steps :

1. Identification of the sampling areas, wherever possible on ecological rather than administrative grounds, so that ideally they represent ecosystems of self-contained land-units.

2. Intensive collection of base-line and non-variant data within the sampling areas ; in some cases this would lead to further stratification for sampling purposes.

3. Collection of variant data on environmental parameters, land-uses, and human, livestock and wildlife populations, using a 3-tier approach and techniques :

a) Ground level, using field teams, ground situations, plots, transects, etc.

b) Underflight, using specially equipped and instrumented light aircraft.

c) Overflight, using remote sensing from ERTS-type satellites.

4. Analyses and interpretation of data to reveal the current status of the relationships between the variables and non-variables.

5. Development of a strategy of data storage, processing and recall to ensure rapid analysis and promulgation of monitoring data for prompt and efficient implementation of management plans.

6. Dissemination of these findings (4 & 5) to concerned operant agencies within Government.

It will be possible to relate incoming KREMU information to ERTS data in such a way that some of the required quantitative data can be generated directly from the images. The most important of these are :

1. Plant dry matter production on a seasonal basis

a. Grass and forbs (the most important)

b. Woody plants (> 1 m tall)

2. Rainfall

3. Surface water

4. Stored soil moisture

These four are interrelated and must be worked on together. Other useful quantifiable variables to be obtained from ERTS images include :

5. Cultivation in pastoral areas

6. Human settlement distribution and areas

7. Soil and erosion patterns.

C. *Approach*

Pastoral Kenya will be divided into a number of ecosystems or self-contained land units, e.g. Amboseli, Samburu, Lamu-Garissa. The ecological zone maps of Kenya (Pratt, Greenway & Gwynne, 1966 ; Pratt and Gwynne, 1975, in press) will serve as a basis with sub-division on other existent base-line and research data. The first 4 months of the KREMU will include an underflight survey in light aircraft (ca. 625 hrs) of the whole area to refine sub-division boundaries and to determine major unit characteristics, and thus to allow determination of underflights and field team sampling frequencies.

1. *Ground truth*

Ground truth sampling plots (up to 250) on a 40×40 km grid will be located, marked and photographed from ca. 10,000 feet. Plot size will be about 2 hectares, but the exact size and shape will depend on the length of the local catena ; it is proposed to sub-sample the catena summit, mid-point, and sump at each plot site. It is not envisaged that the catena length will extend beyond 7 km. Final number of installed plots will depend on the accessibility of the sites, the ecological zone, and the ability of the KREMU resources to handle the incoming data.

At each ground truth station there will be a basic site description (description of topography, land system/facet, and drainage including erosion) ; the establishment of soil pits and a description of the soil profile, physical properties and the catena ; and a description of the initial plant cover and plant species composition. While this is being done plot markers, neutron probe tubes and storage rain gauges will be installed, and access tracks and air strips (remote areas only : each 400 m long) cleared.

Once a plot is established, monitoring of climatic and botanical parameters will commence. Plant composition will be measured periodically with respect to herbaceous/grass cover ; standing crop ; leaf table height ; physiognomy and phenology ; and plant part composition.

In addition, within each ecosystem or self-contained land unit the following will be obtained on a periodic basis, the frequency of which will be dependent on prevailing local conditions. Small samples of domestic stock and major wildlife herbivores will be slaughtered to provide data on body condition, reproductive state and diet. Ground estimates will be made on the population structure of both wild and domestic herbivores with respect, for example, to age, sex and herd composition.

2. *Underflight*

Prior to starting routine survey, the following will take place :

a) Tests to measure :

correction factors for bank and turbulence, correction factors for crab, best horizontal angle, effect of fixed versus free transect streamers, and best methods for low-level flight determination of plant greenness and cover.

b) Factor experiment to test variation in method by an analysis of variance involving the following factors :

height, speed, time of day — lighting, time of day — turbulence, strip width, transect length, habitat, number of species counted, observer experience, and observer fatigue.

c) Observer screening programme with respect to visual acuity and propensity towards air sickness (cf. Savidge, 1973), and a training period involving method practice (briefing and inflight), estimating animal numbers, and an accuracy check with a known number of animals or models and/or against experienced observers.

Past experience has shown an air speed of 150 km/h, a height of ca. 100 m and a strip width of 200-250 m to be the most suitable, but final choice for any one area will depend on the outcome of the pre-survey tests, the nature of the habitat, etc. Systematic sampling with transects 10 km or 5 km apart will be used initially, with accuracy of flight course assured by the use of long-wave radio navigation and altitude by radar altimeter.

In addition to obtaining precise and accurate estimates of animal numbers and densities, the underflights will record for each flight line sub-division (5 or 10 km lengths) the data categories already listed in "Methods".

3. *ERTS Data*

We should emphasise at this point that the value of an EMU is not *dependent* on remote sensing data, but it is undoubtedly *enhanced* by them. The fact that the operational programmes we have reviewed have produced results without satellite imagery should make this clear. The point of ecological monitoring techniques is that they are relatively simple, inexpensive and productive. Therefore access to remote sensing data should not be a deciding factor in the question of establishment of an EMU. However, since ERTS coverage is global, there is no reason why any country should not take advantage of it.

a. Data receiving facility

The success of the ERTS segment of the Kenya rangeland monitoring activity depends on the ability of the research team to receive near-complete coverage of the pastoral areas of the country on a regular short interval basis ; intervals longer than 18 days would reduce sensitivity in detecting short-term changes in vegetation.

To facilitate the Kenya ERTS programme the Kenya Government will probably implement one or both of the following courses of action :

a) Modify the existing receiving facility of the Italian San Marco Project satellite launching station at Malindi on the Kenya coast. To enable this station to receive transmission from ERTS additional specialised equipment will be needed, the specifications of which will depend upon whether the incoming data are to be processed by NASA in the normal way, by the Italians at their Rome space centre, or by international agencies at some other space centre to be established in Africa (e.g. at Kinshasa). This will result in an ERTS station capable of receiving spectral data relating to an area of eastern Africa of a radius of 1,200 km centred on Malindi ;

b) To establish a new international ERTS data receiving and processing centre at Nairobi which will cover, in addition to Kenya, an area of Africa of a radius of 2,775 km centred on Nairobi.

b. Data handling plan

i. *Imagery*

Incoming 70 mm black and white positive transparencies or "chips" will be examined visually to elucidate both permanent and transient features. For this purpose correlative ground truth will be available from the regular underflight and field team activity of the KREMU.

Suitable cloud-free imagery of good definition will be used to develop permanent feature maps for pastoral Kenya at a scale of 1 : 500,000 or 1 : 1 million, showing land system boundaries, drainage systems and surface soil complexes.

Chips of appropriate spectral bands will be examined regularly to monitor short-term changes in such habitat variables of economic importance as vegetation growth flush, large surface water pools and local flooding, and grass and woodland burning. A synoptic view of these features will be of value to agriculture, rangeland utilization and tourism. Data in the form of distribution maps will, therefore, be constructed. For example, in these remote areas of low and erratic rainfall, a sudden relatively localised vegetation flush usually indicates local rainfall ; such information passed promptly to the Ministry of Agriculture will allow its Livestock Marketing Division to alter its stock routes accordingly, with consequent financial savings.

Imagery will also be examined to determine long-term changes within the pastoral areas, such as encroachment of agriculture activities, irrigation scheme development, burning/removal of forest stands, development of forestry plantations, and any other detectable major change in land-use.

Finally, imagery will be used to determine visually the coordinates of particular test areas in regions of interest, such as localised growth flushes, so that they can be more quickly identified on the computer compatible tapes.

ii. *Digital data*

Visual interpretation of ERTS colour composites will be used to determine areas of active plant growth on or near one or more of the test sites of the Kenya Rangeland Ecological Monitoring Unit. Routine ground truth acquisition from these sites will supply quantitative plant production data on a phenological and a plant composition basis (dry weight, part, crude protein, crude fibre, energy).

Spectral reflectance measurements of the chosen test areas (size to be determined in the field) will be made from the ground throughout the development period and these values graphed against time. Elsewhere it has been found that the ratio of spectral reflectance values associated with wavelength bands 8,000 and 6,750 Å shows a high degree of correlation with changes in the phenology and condition (i.e. greenness/dryness). Attempts will be made, therefore, to see whether similar relationships hold for tropical semi-arid rangelands and whether the plant productivity curves are similarly correlated. If they are, tests will be made to see whether the irradiance spectral curves can be used to estimate plant biomass (standing crop) as total vegetation and (with suitable ground sampling) in terms of plant parts (leaves, stems, etc.).

ERTS irradiance data will then be extracted from the computer compatible tapes for the test sites, the spectral values being obtained for each individual picture element (80 × 80 m on the ground) in each of the four spectral bands. These values, plotted against time, will be compared with phenology, condition and standing crop values, and with the ground-obtained irradiation curves.

If the results are satisfactory the possibility of using ERTS irradiation data as a means of determining plant standing crop directly will be further tested, and a computer programme developed for determining the standing crop values directly from the NASA-ERTS computer compatible tape. These output data will then be supplied directly to the data centre of the Kenya Rangeland Ecological Monitoring Unit for routine incorporation in its ecosystem models.

Initial programmes for locating specific areas on the computer compatible data tapes and extracting the individual picture element spectral values for each spectral band have already been developed (e.g. at the Space Science Laboratory of the University of California; Remote Sensing Centre, Texas A and M University; Oregon State University). Further computer programme development will be done with the cooperation of the Computing Centre of the University of Nairobi, using both University and Kenya Government computers and with possible aid from overseas facilities.

Again we would emphasise that it is possible to produce the above without access to satellite-collected data — it would cost more and take considerably more time. If, however, the ground productivity/ERTS spectral value correlates can be made, the productivity of an entire country could be monitored at a resolution and frequency never before imagined.

D. *Data handling by computer*

1. *Storage and analysis*

The vast amounts of data collected by KREMU can only be processed with the help of a digital computer. There are several in operation in Nairobi (KREMU headquarters), varying in size from an ICL 1902 A with 16 K capacity to an ICL 1905 F with 112 K capacity. Data filing programmes will have to be written using standard file packages as a basis. At least two programmes are locally available for initial treatment (plotting numbers and density estimates) of SRF data (e.g. ANPR of Cobb and Western, unpublished). Finally, there are standard statistical packages for various multivariate analytical techniques. In short, if one has access to the hardware, the basic components of the software already exist. They need, of course to be tailored into a working package for the KREMU's specific purposes.

2. *Predictive models*

From recent East African research, there are already enough inductive data to construct a first-generation semi-arid ecosystem simulation model (cf. Jeffers, 1972, especially pages 249-344). A model is simply a set of reasonable rules for complex processes, such as the workings of an ecosystem, which are expressed mathematically so that work can be done by computer. The computer is primed with the rules of the model, variables and constants, all consistent with the data already collected, and asked to process them according to the rules. The state at the end of the process is a prediction, which may then be compared to the real-world ecosystem that we are monitoring. If agreement is good, then it is likely that the model simulates the processes of the real ecosystem. Models are rarely good ones the first time round and must be continually updated with new monitoring data and intelligent guesses. Once we have a model that gives predictions of maximum likelihood, we may then begin to make management predictions. If, for example, the model predicts increased and sustained productivity as a result of a particular management action (equivalent to an experimental change in the variable input to the model), then that course may be worth pursuing. If, however, the model predicts an ecological disaster, we may think again and try out an alternative.

III. Practical applications of ecological monitoring

So far we have stressed the potential uses of systematic ecological monitoring; we will now give examples of how ecological data have been put to use by management agencies in tropical ecosystems. The examples are admittedly few, if only because the art is new.

A. *Management plans for national parks*

Ecological research organisations frequently find a niche in a national park, viz: the Uganda Institute of Ecology in the Ruwenzori National Park, Uganda (formerly the Nuffield Unit of Tropical Animal Ecology in Queen Elizabeth National Park, Uganda); the Serengeti Research Institute in Serengeti National Park, Tanzania; and the Tsavo Research Project in Tsavo National Park East, Kenya. National parks are able to afford such institutions because they are relatively well funded from overseas donations and tourist spending. Moreover, there is a recognized need for ecological data from which to plan management of the parks (cf. Huxley, 1962; Starker-Leopold, 1970).

As a result of ecological research, the Serengeti Research Institute drafted management proposals for the Serengeti National Park. The topics covered included : ecological zone development (Kruuk, 1970), road development (Braun, 1970), fire control (Norton-Griffiths, 1970), and elephant problems (Croze, 1970). These reports are complemented with statements from management personnel on poaching (Turner, 1970) and tourist lodge development (Owen, 1970). Thus within one year of the inception of the Serengeti Ecological Monitoring Programme, operational management suggestions were produced.

More recently, as a consequence of the monitoring and research activities of Western (1973), comprehensive policies for management and development have been implemented by the Kenya National Parks for the Amboseli National Park area (Western and Thresher, 1973 ; Western, 1974). Similarly, the boundaries for the proposed new County Council Game Reserves now being considered in the Lamu-Garissa area of Kenya are based on data gained during SRF and monitoring activities (Gwynne and Smith, 1974 a-c). The more data that are collected, the finer will be the detail of the management plans and the more precisely will National Parks be able to predict the outcome of any policy they may eventually adopt. Similar relationships hold for other development enterprises such as ranching.

As we have shown, ecological monitoring is a powerful tool for development and resource assessment purposes. It is not, however, a universal panacea for all the development problems of rangelands and must be used with care and common sense, not followed blindly. In monitoring it is often, for example, as bad to collect too much data as not to collect enough (Cobb, 1975). Monitoring leans heavily on mathematics in the treatment of data but the mathematics can only be as good as the reliability of the data collected and the ability of the EMU to handle them. It is worth remembering the words of the eminent statistician G.E. Yule (1920) :

" If you get on the wrong track with the mathematics for your guide, the only result is that you get to the Valley of Mare's Nests much quicker ; get there so smoothly and easily that you do not realize where you are and it may be hard to unbeguile you. Logic and mathematics are only of service, then, once you have found the right track ; and to find the right track you must exercise faculties quite other than the logical. Observation and Fancy, and Imagination : accurate observation, riotous fancy, and detailed and precise imagination. "

Note : We are indebted to Vincent Quin, Librarian of Balliol College, Oxford for verifying some bibliographic details, and to Mrs. Elma Sayer for her care in typing the manuscript.

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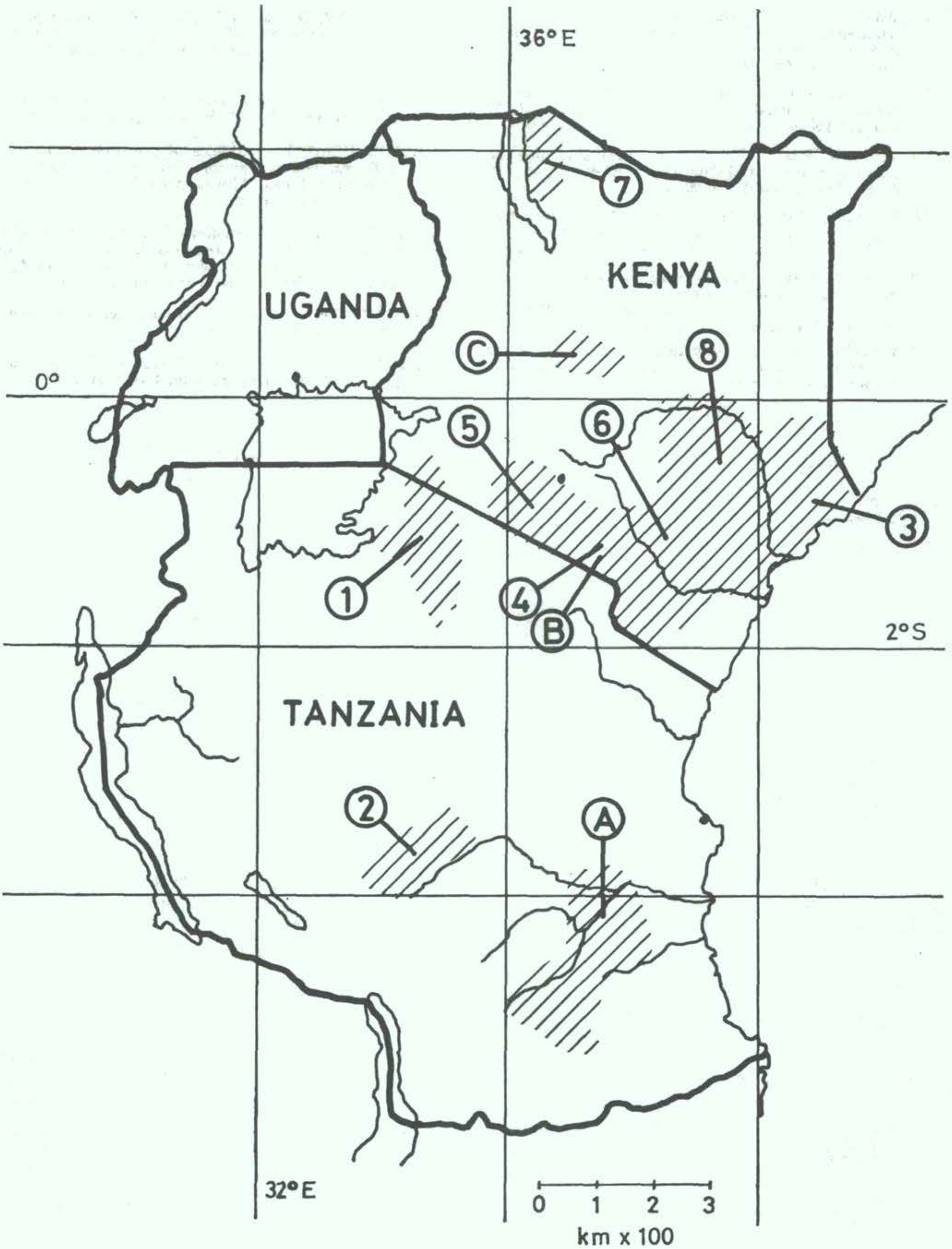
Figure 1



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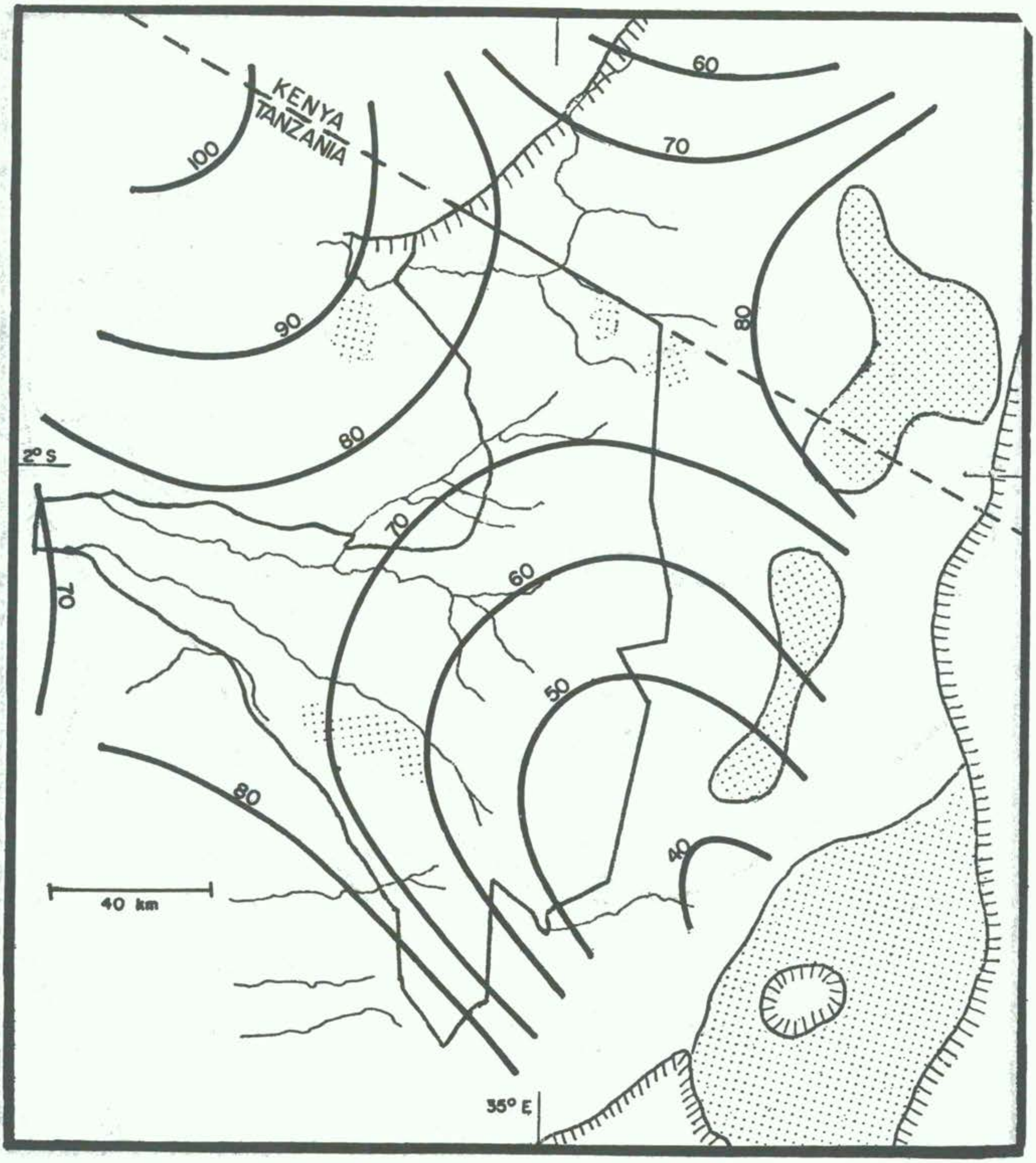

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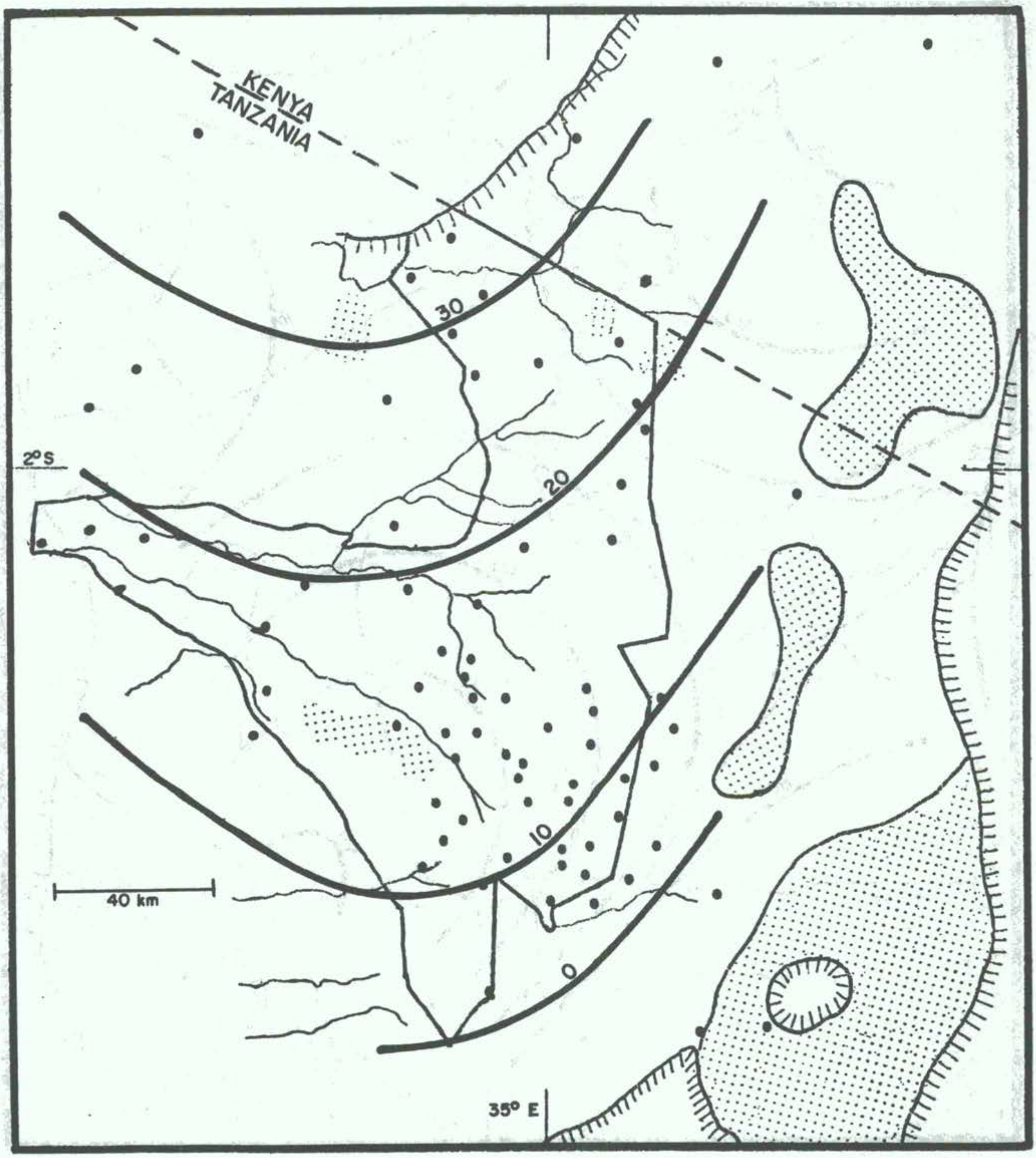

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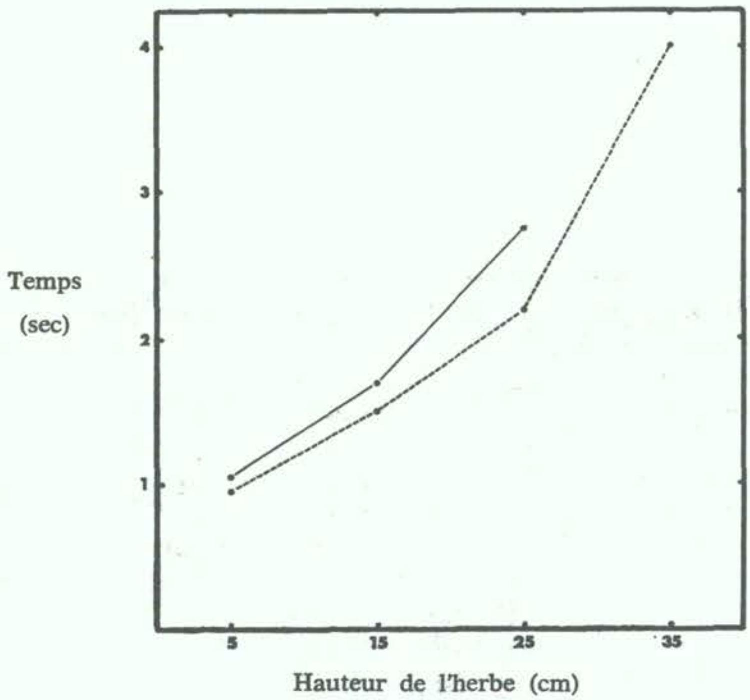

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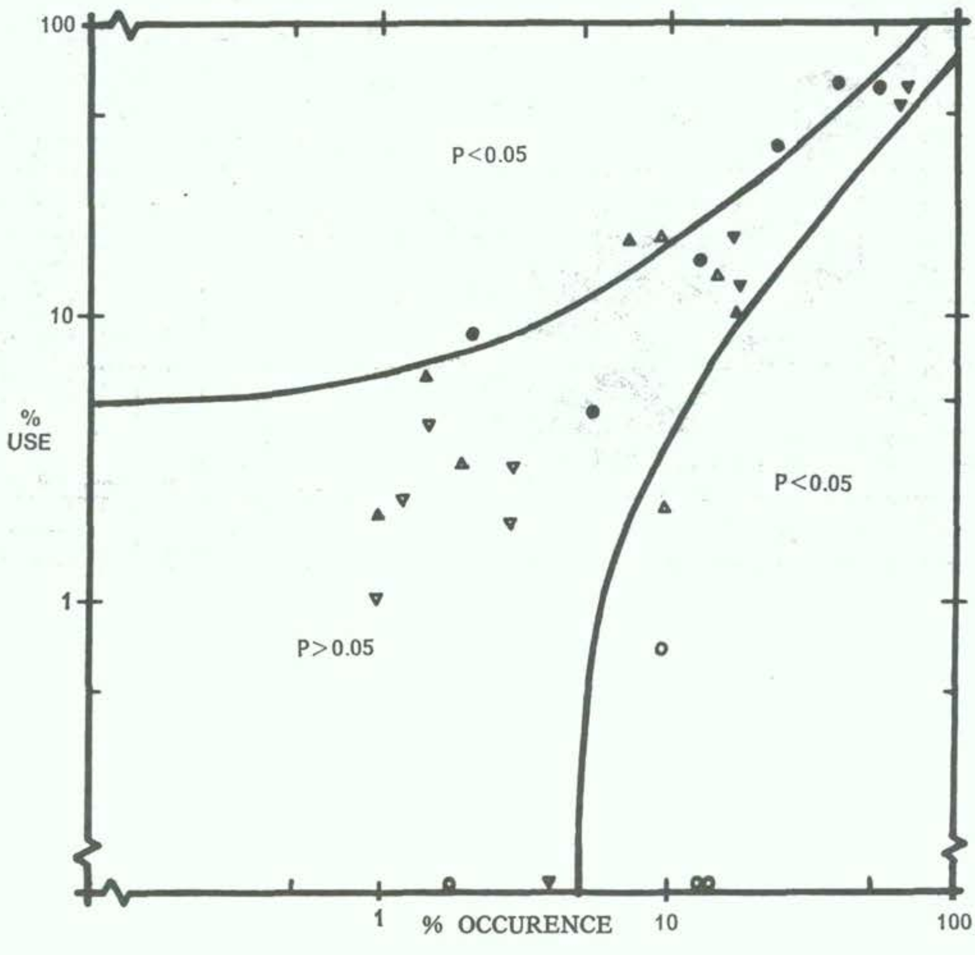
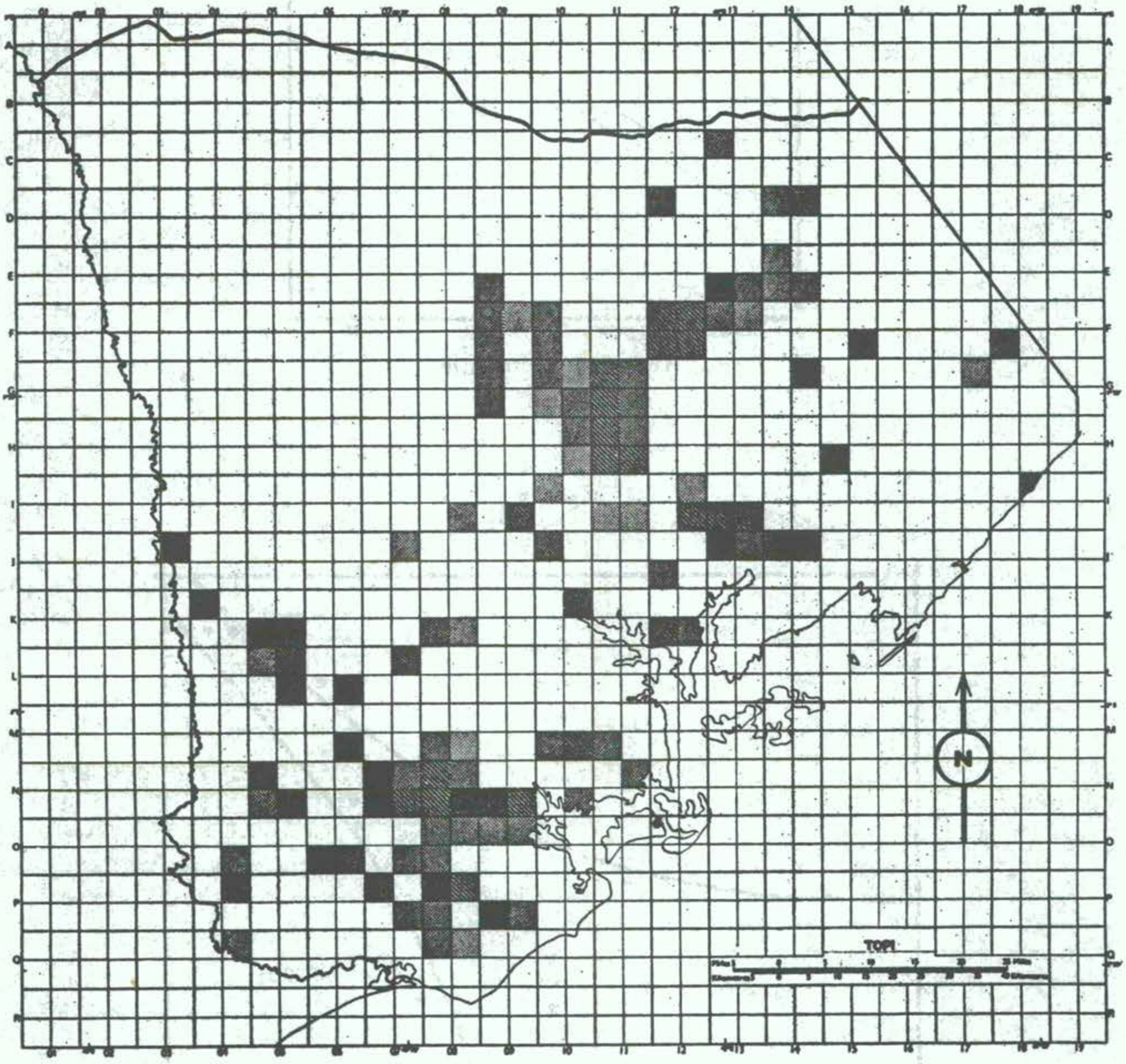


Fig. 5a



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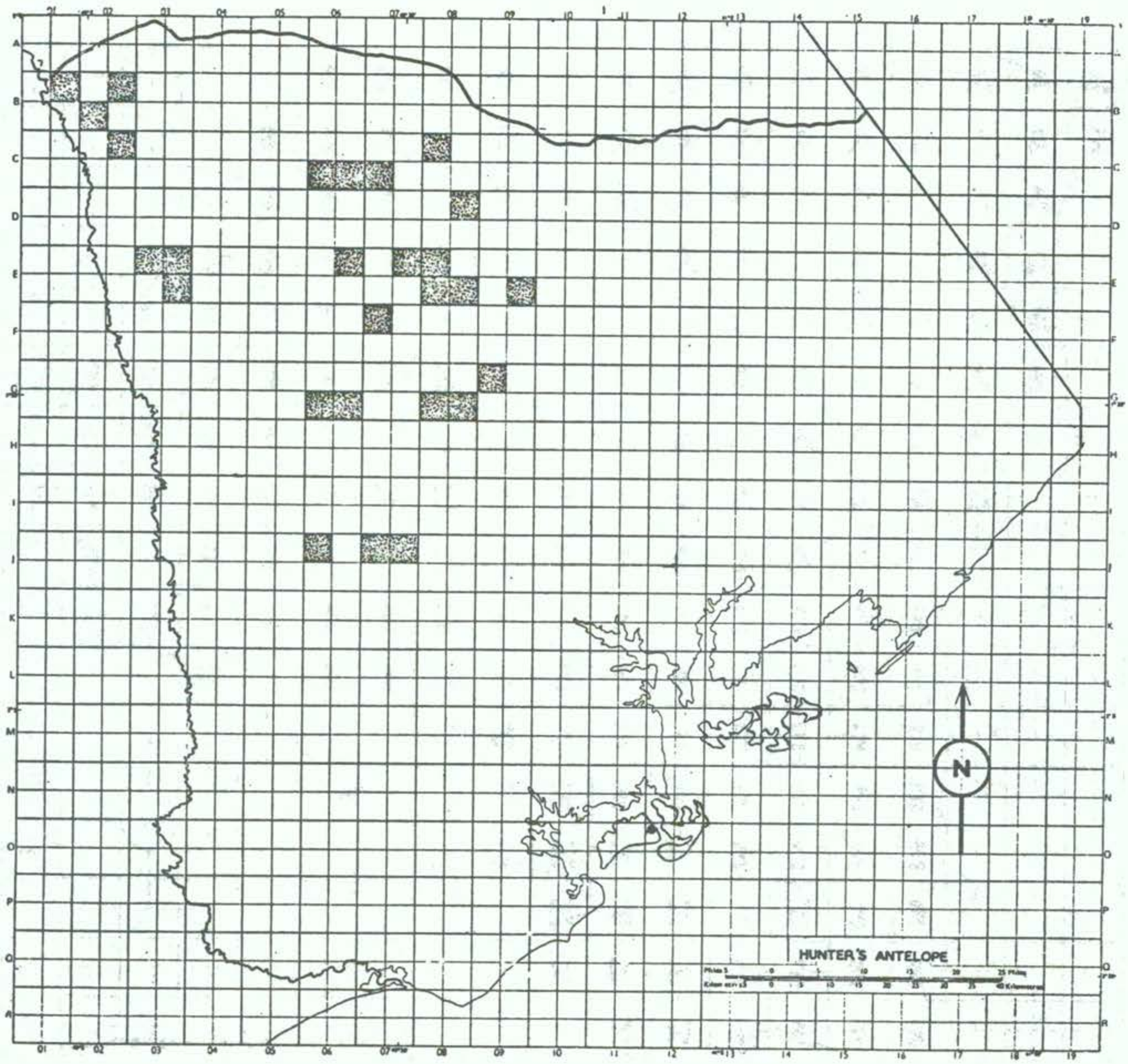

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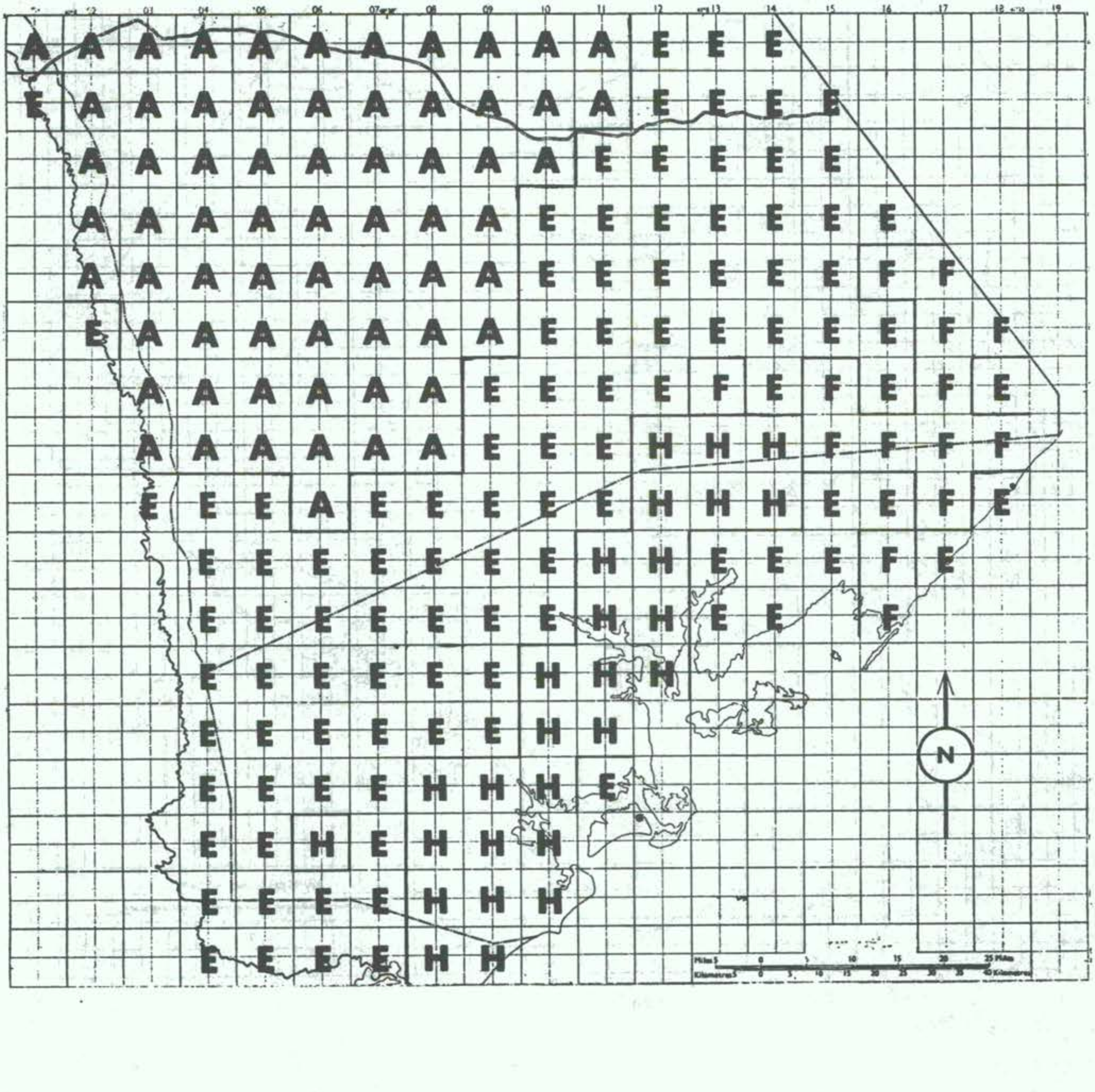
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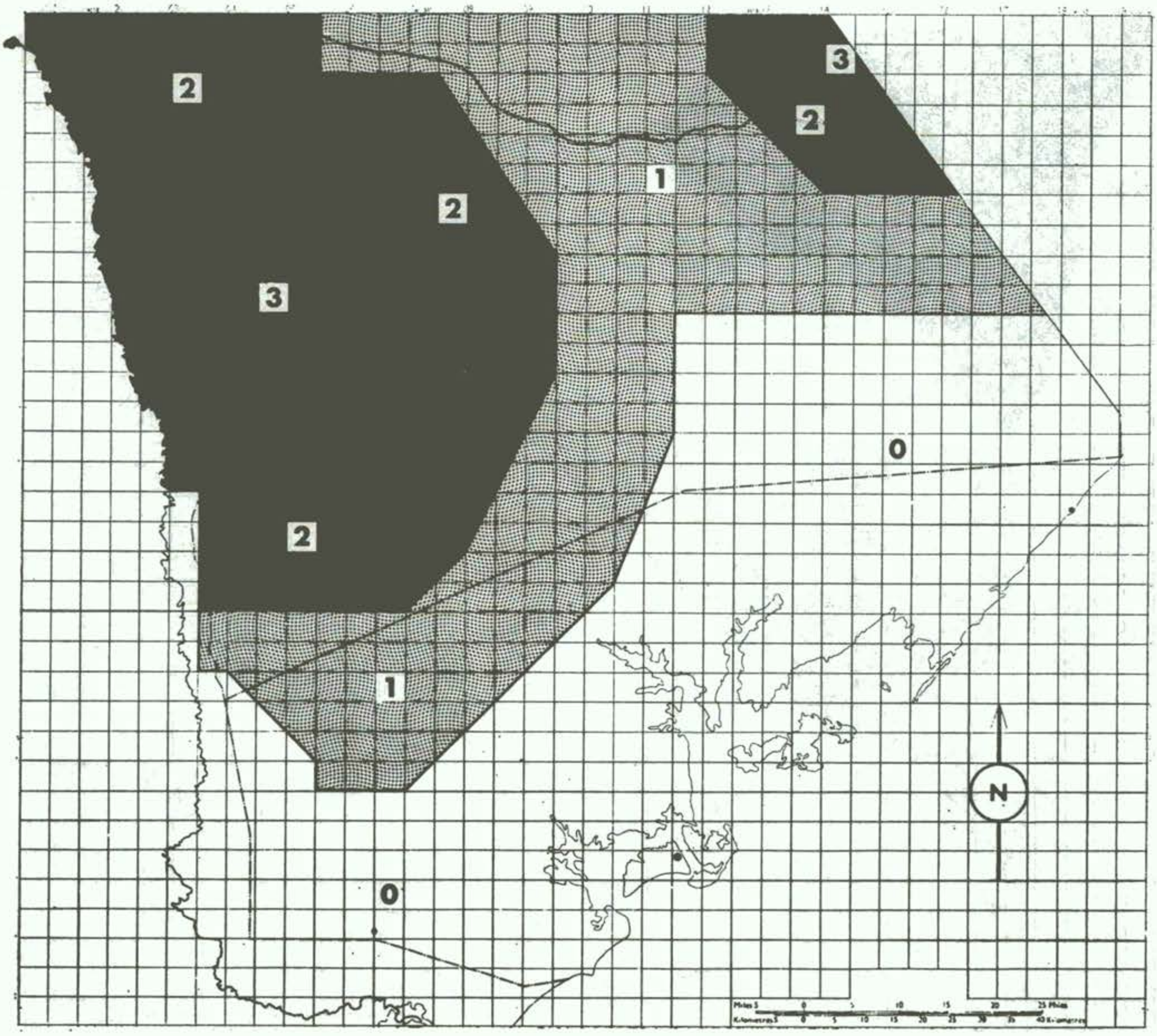
Figure 7a



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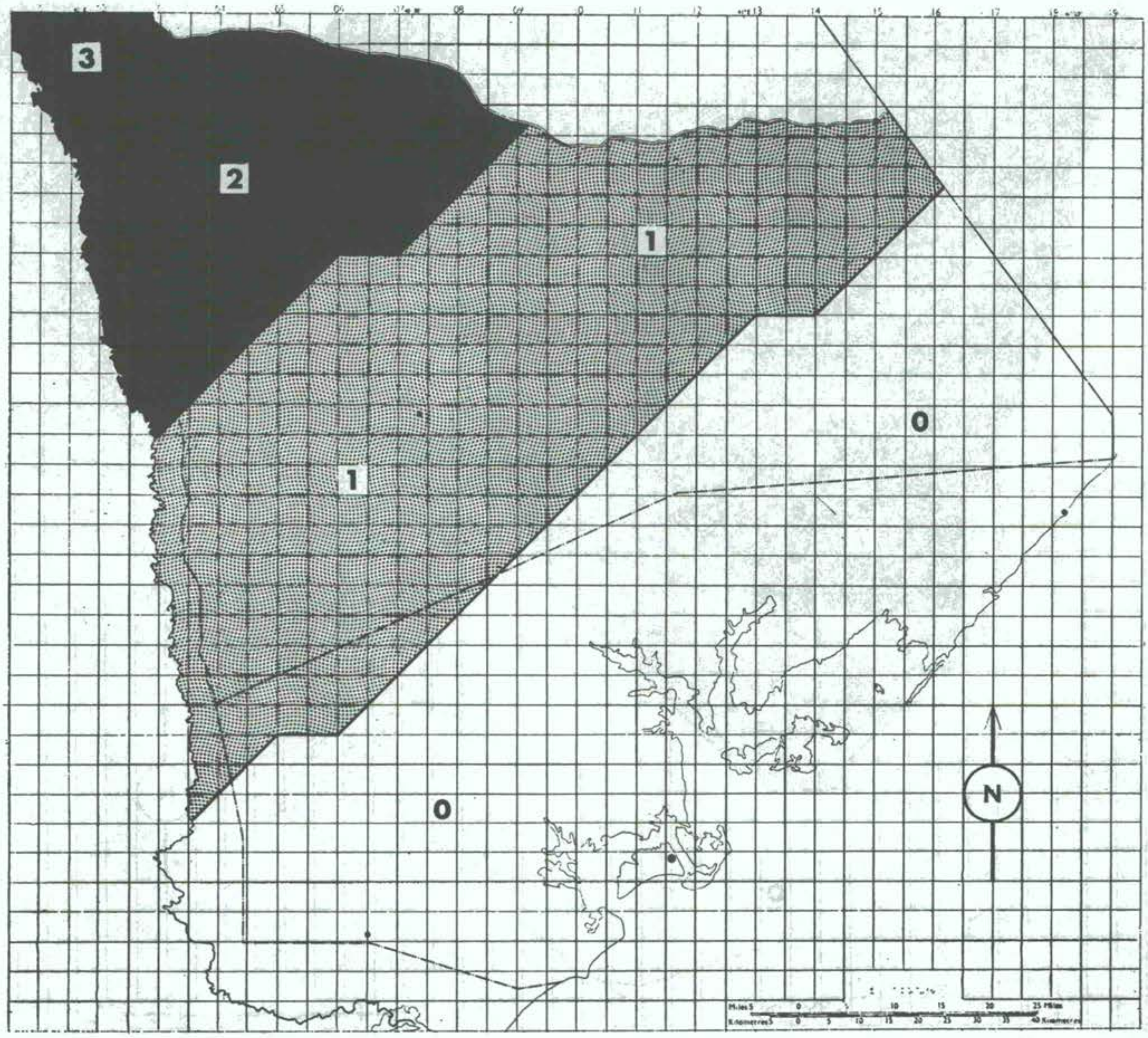

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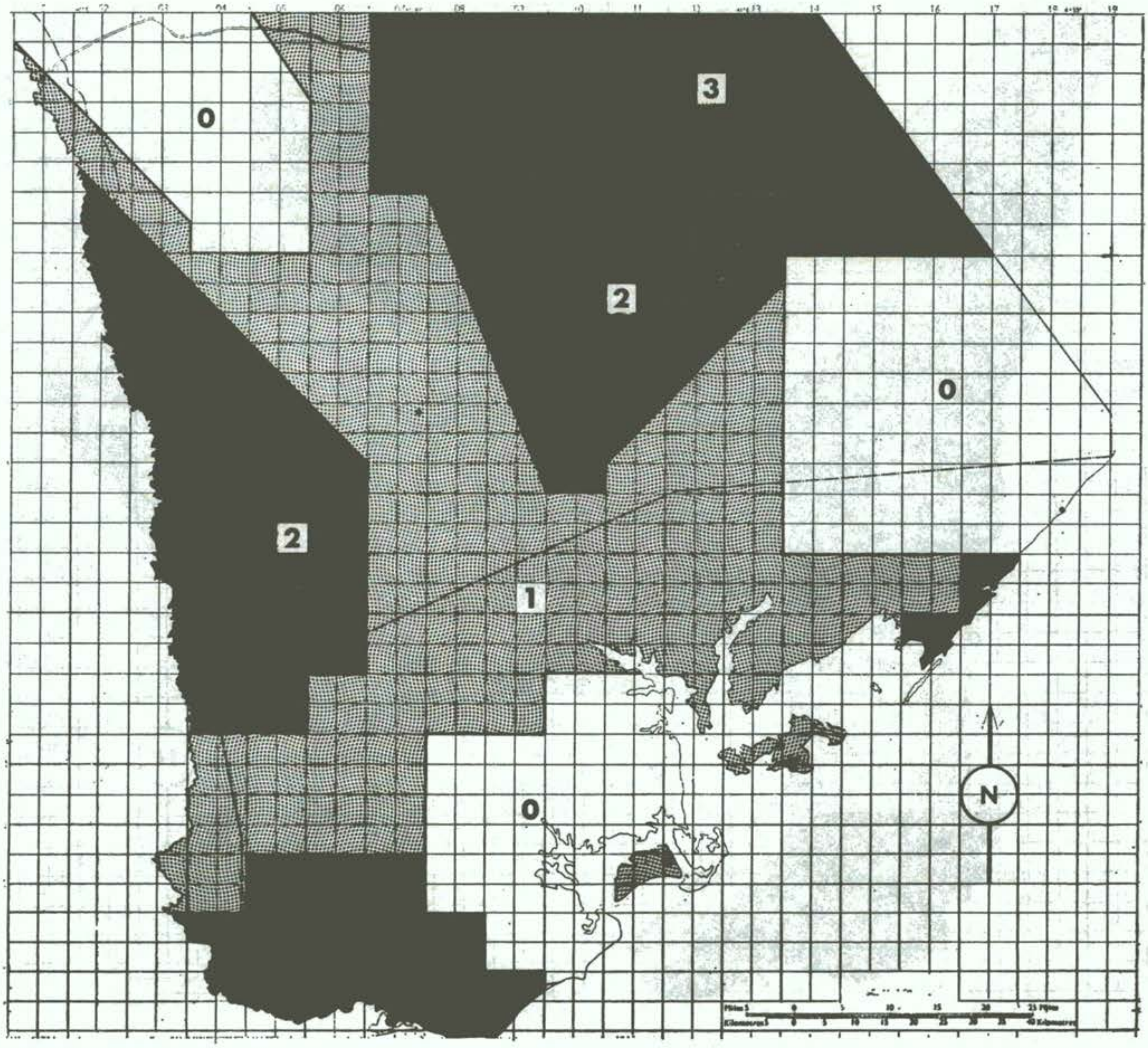

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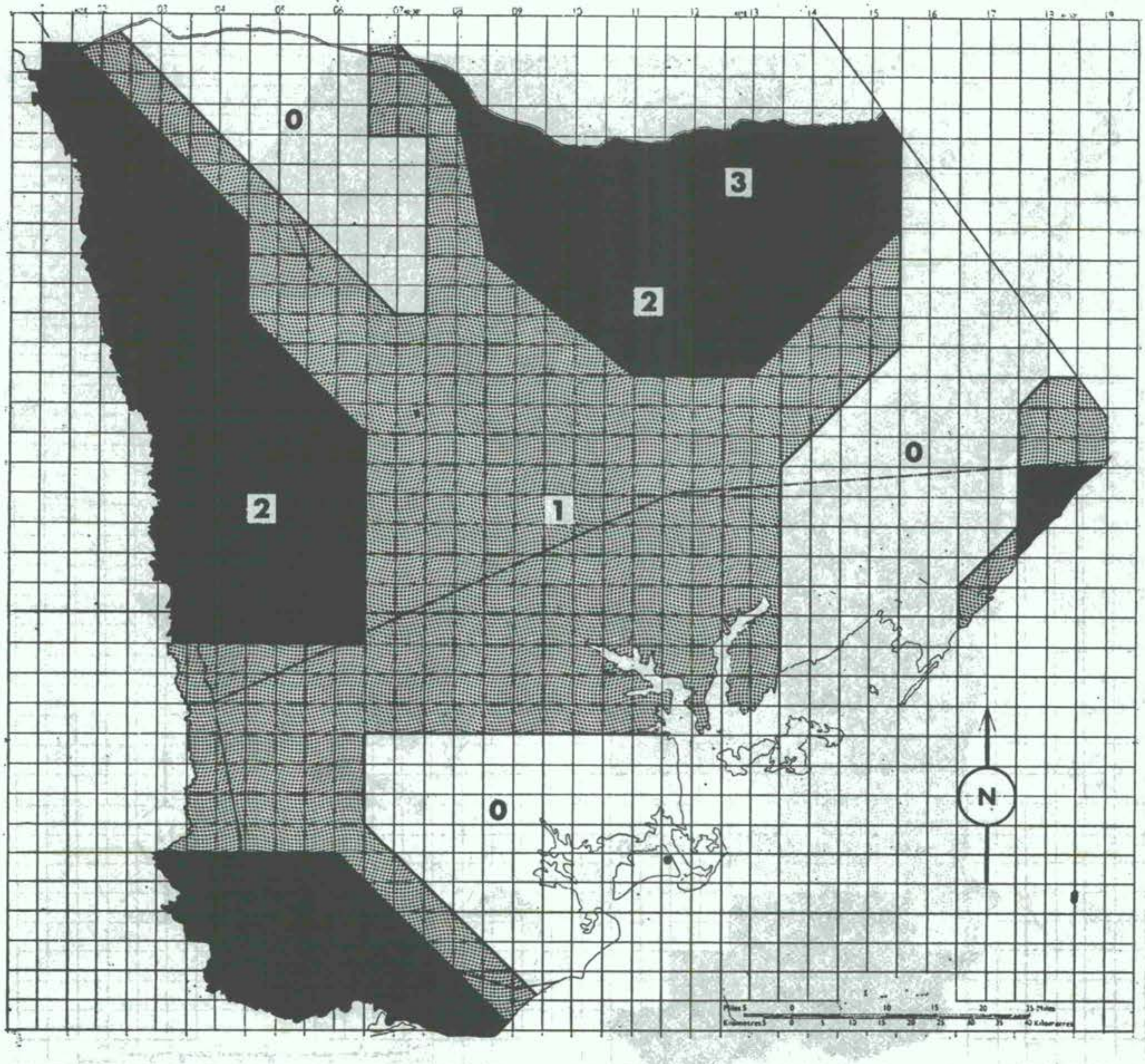

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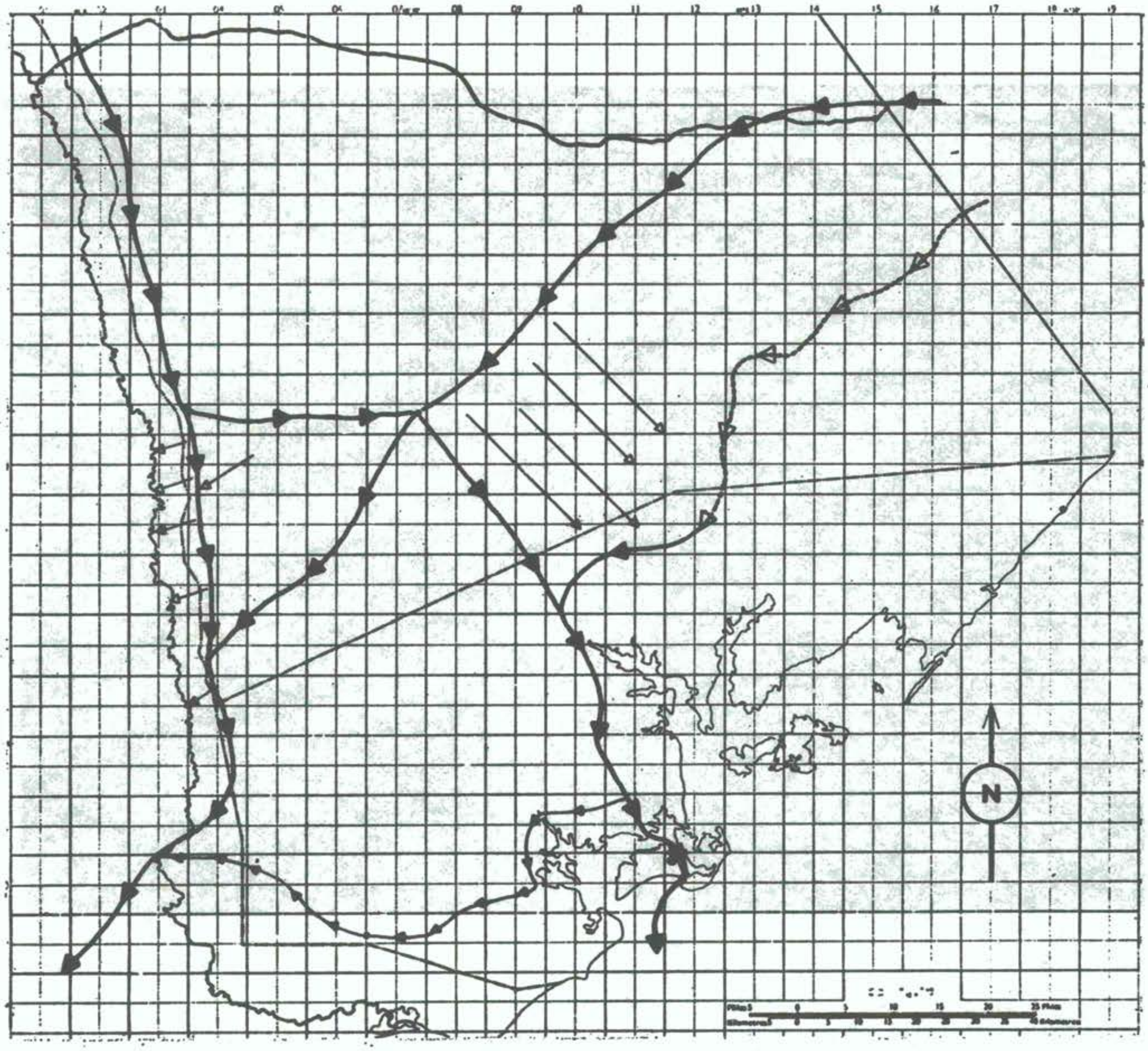

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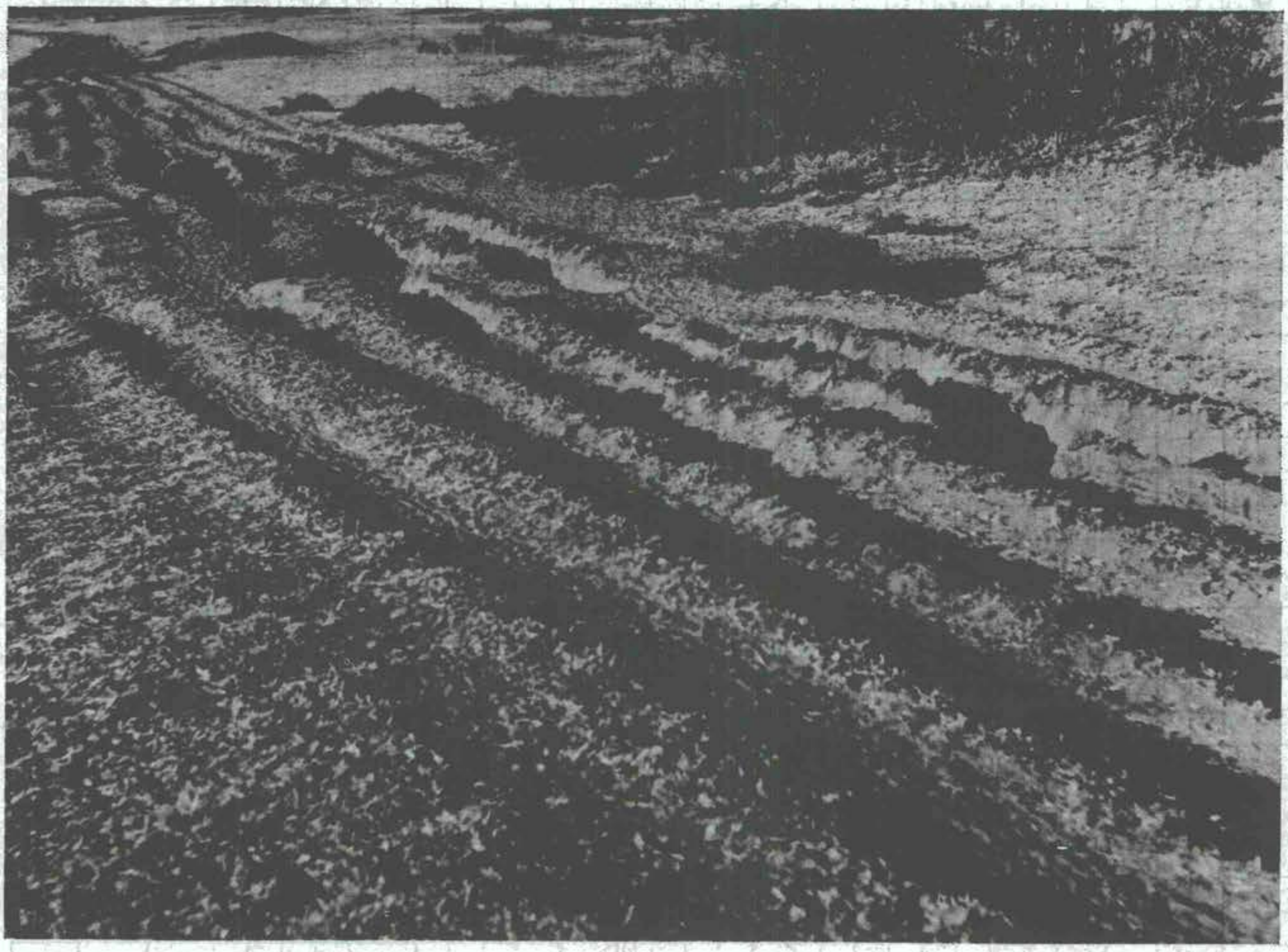

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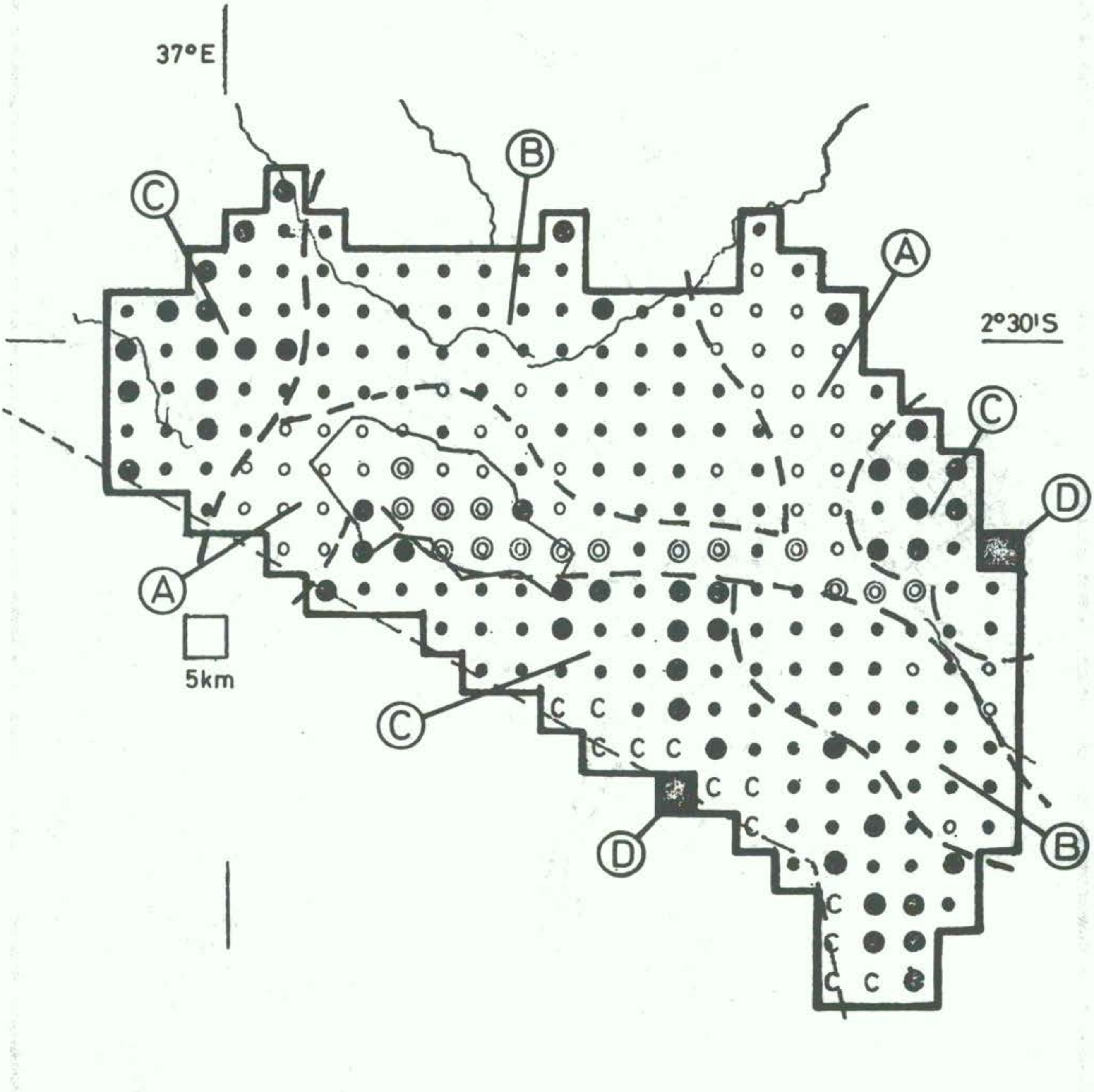

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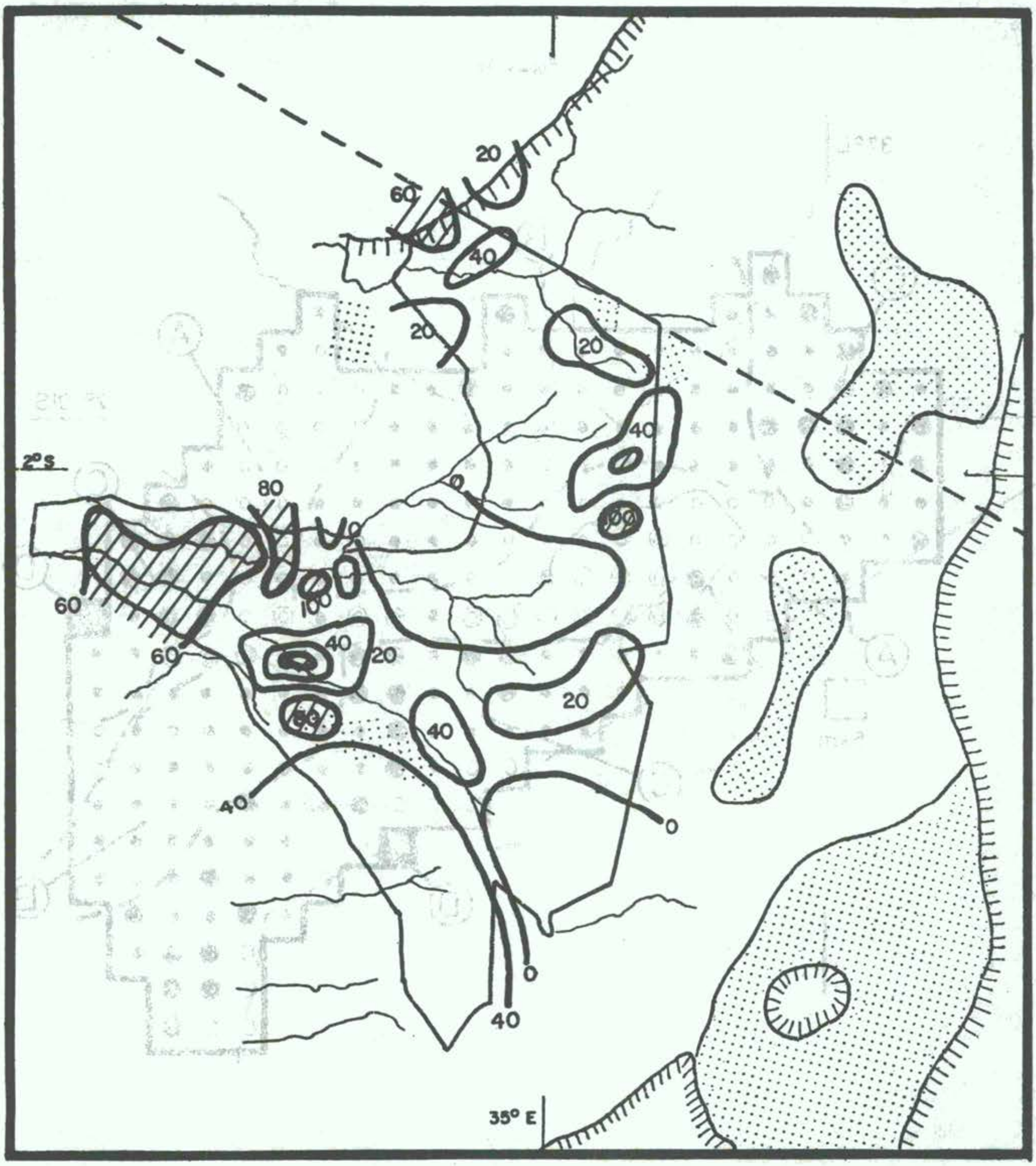

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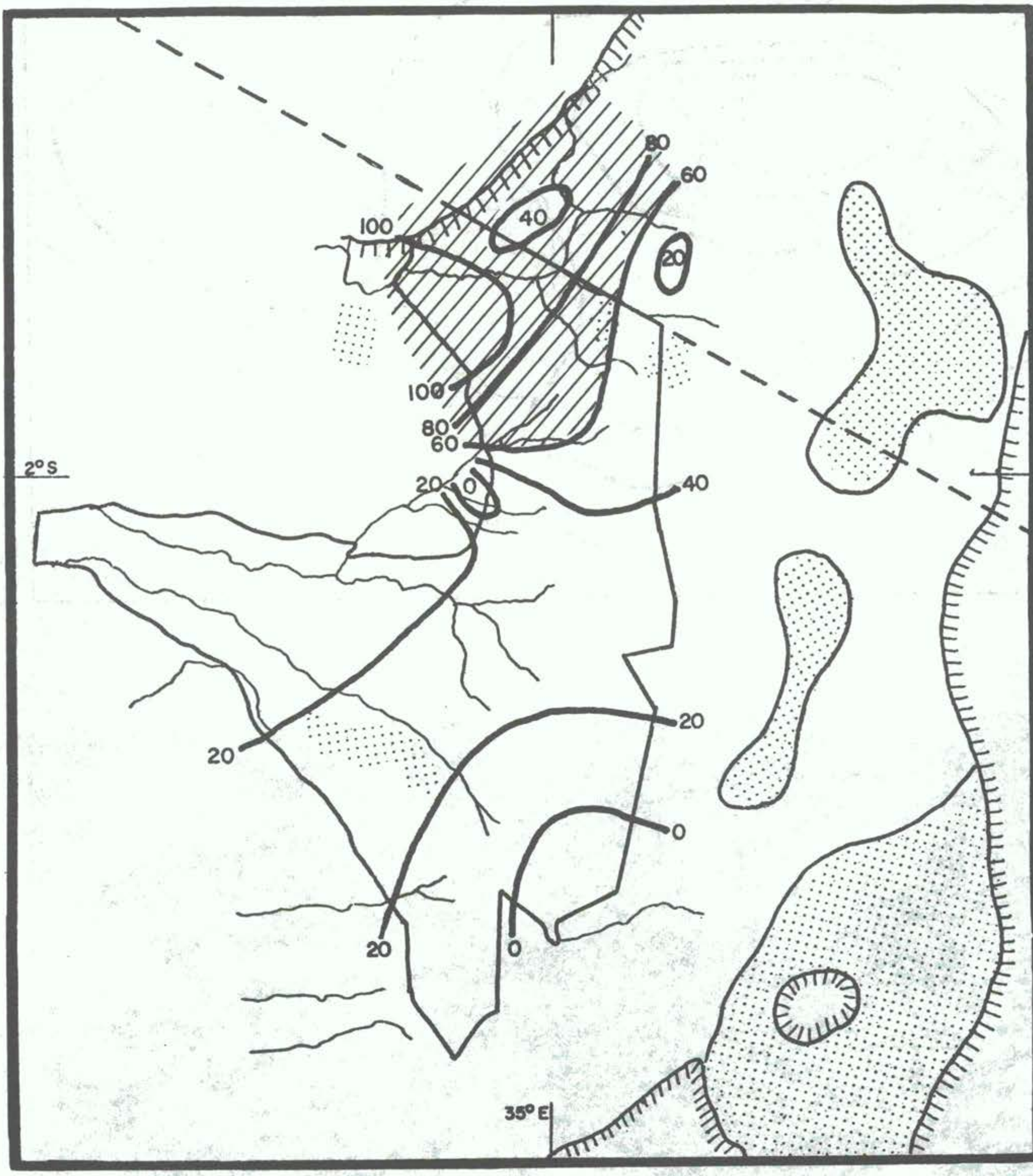

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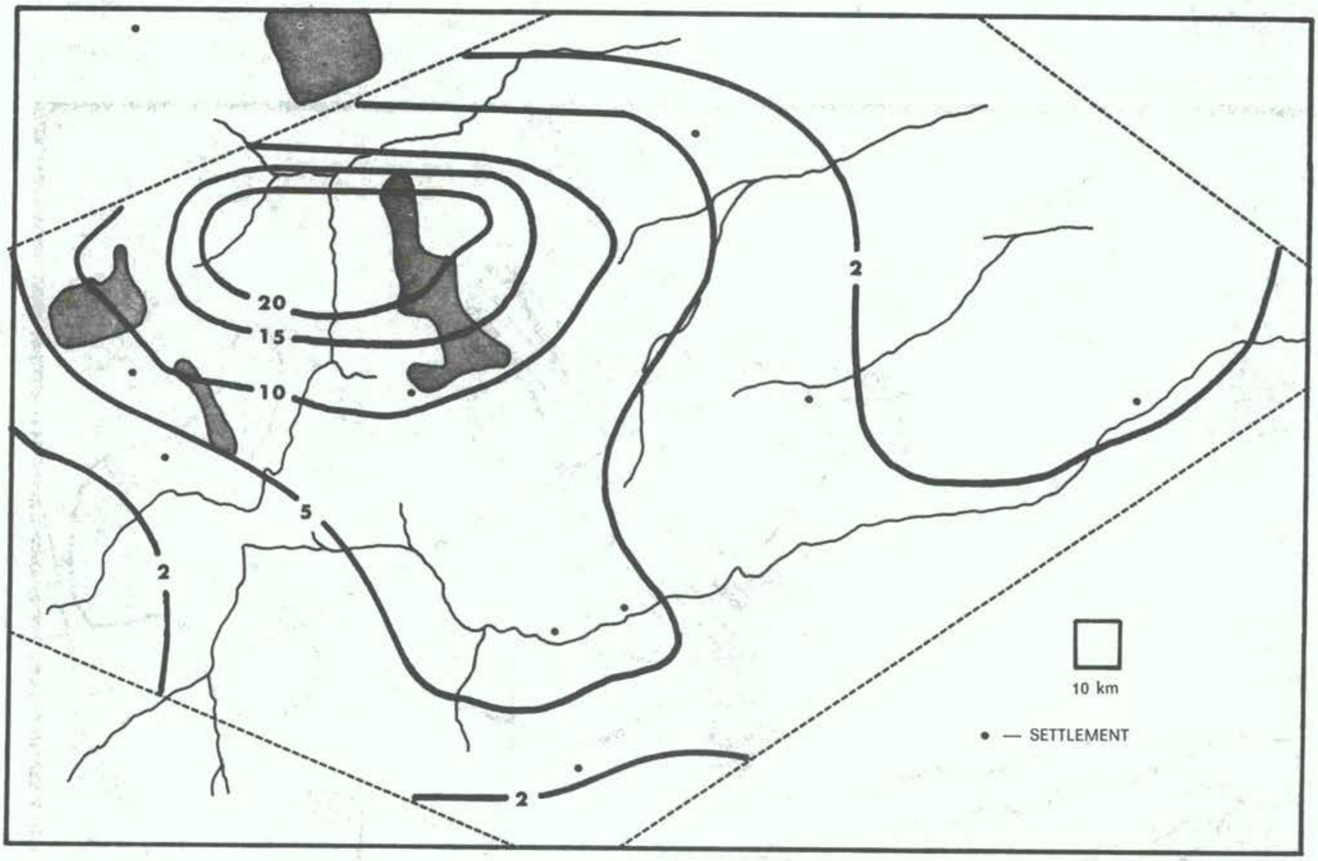

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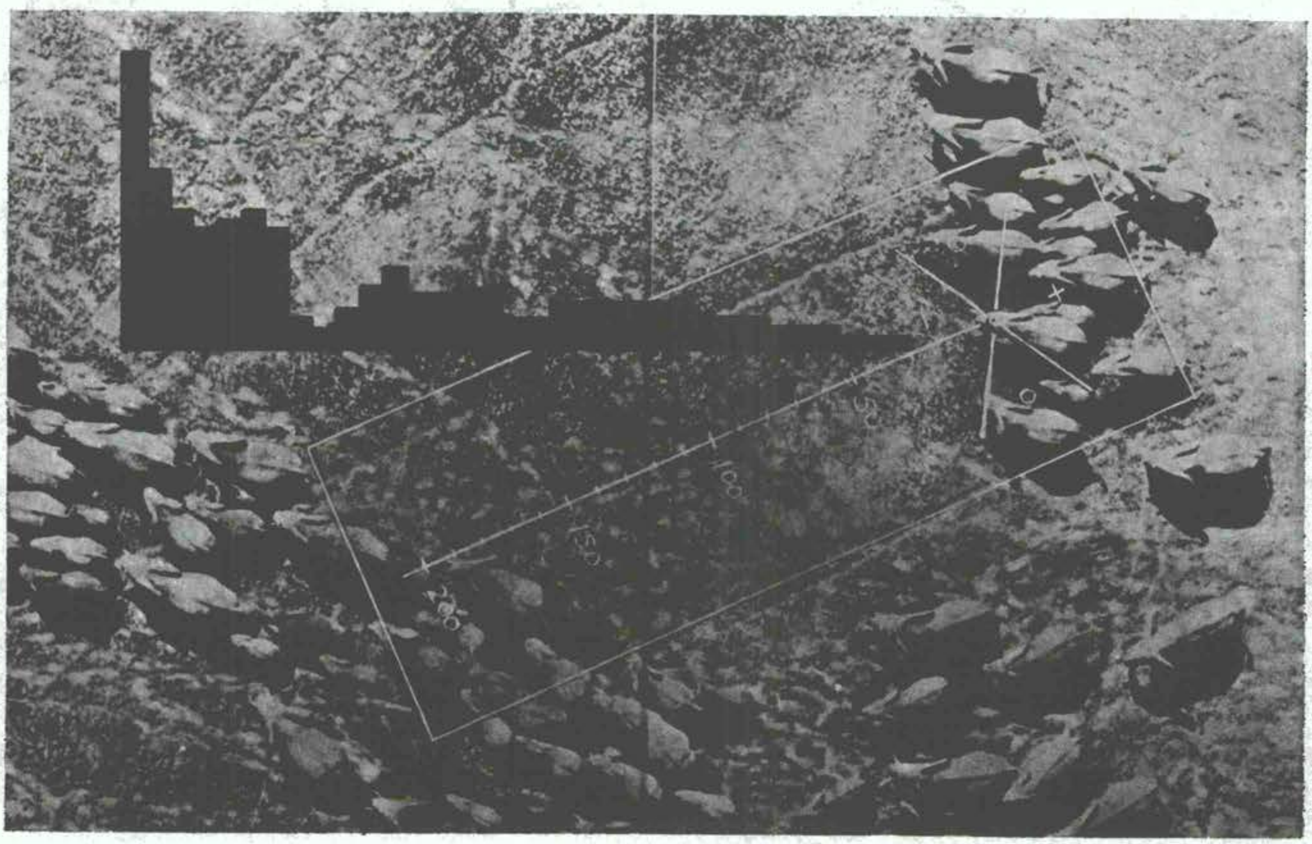

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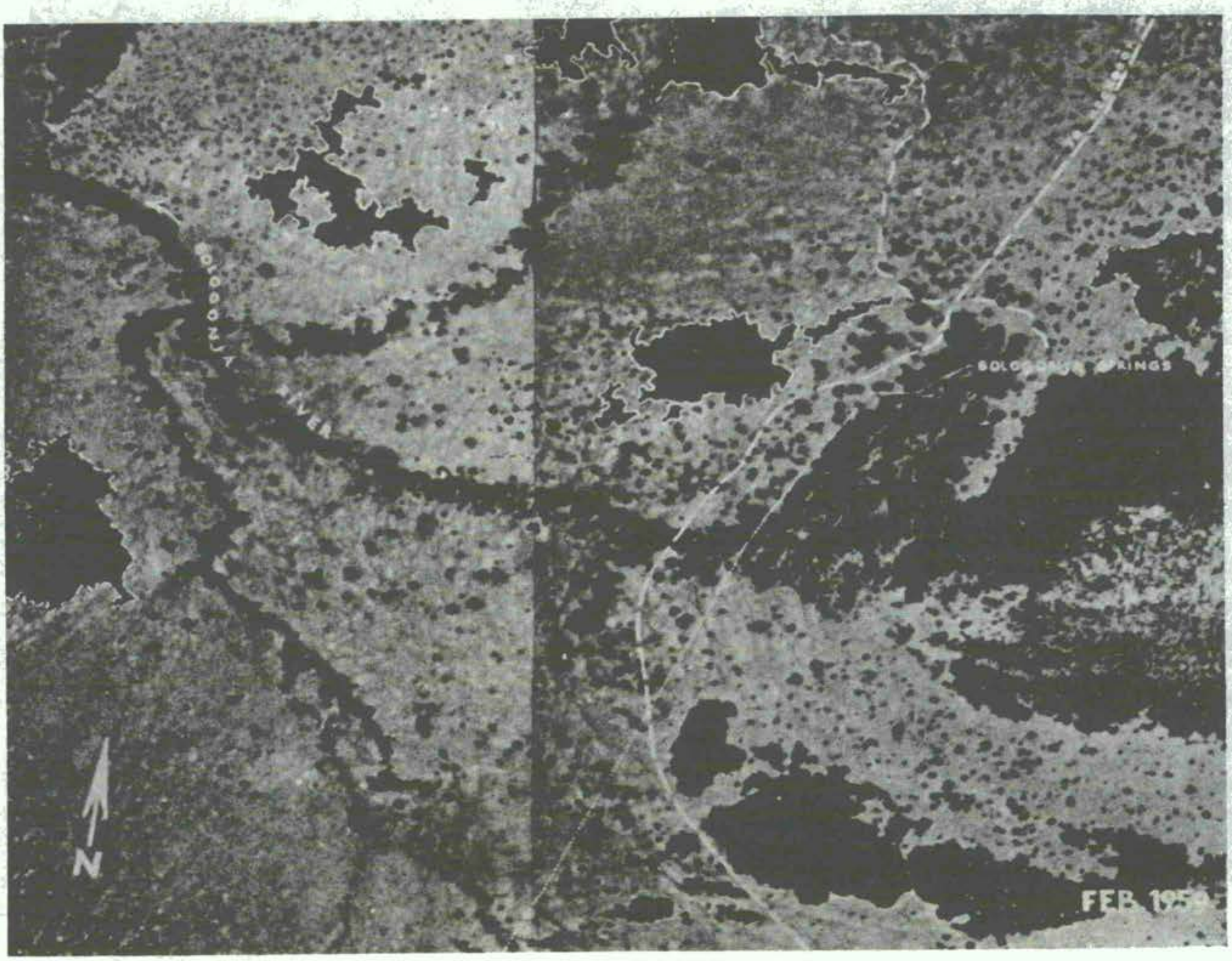

Figure 15b

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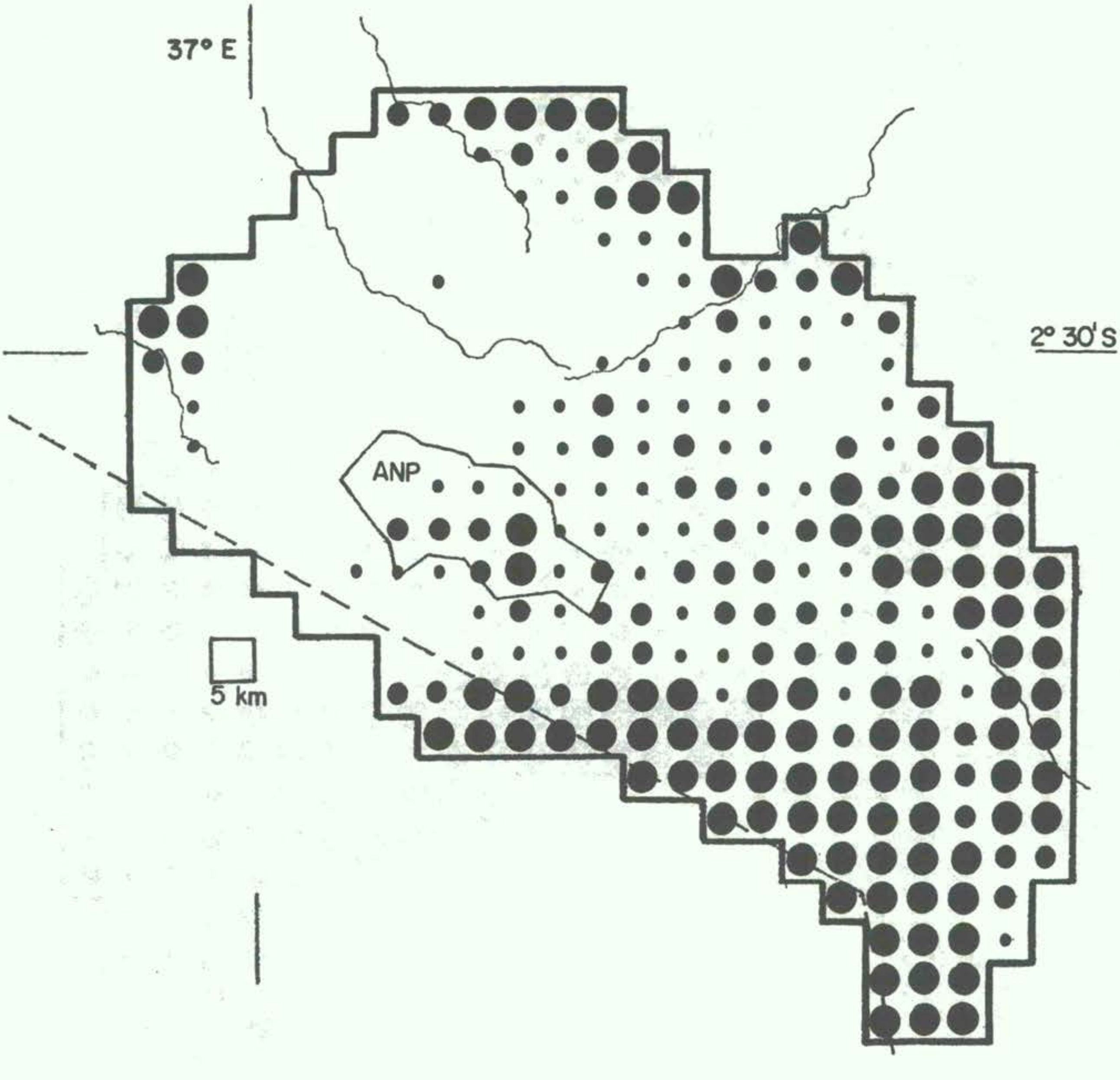

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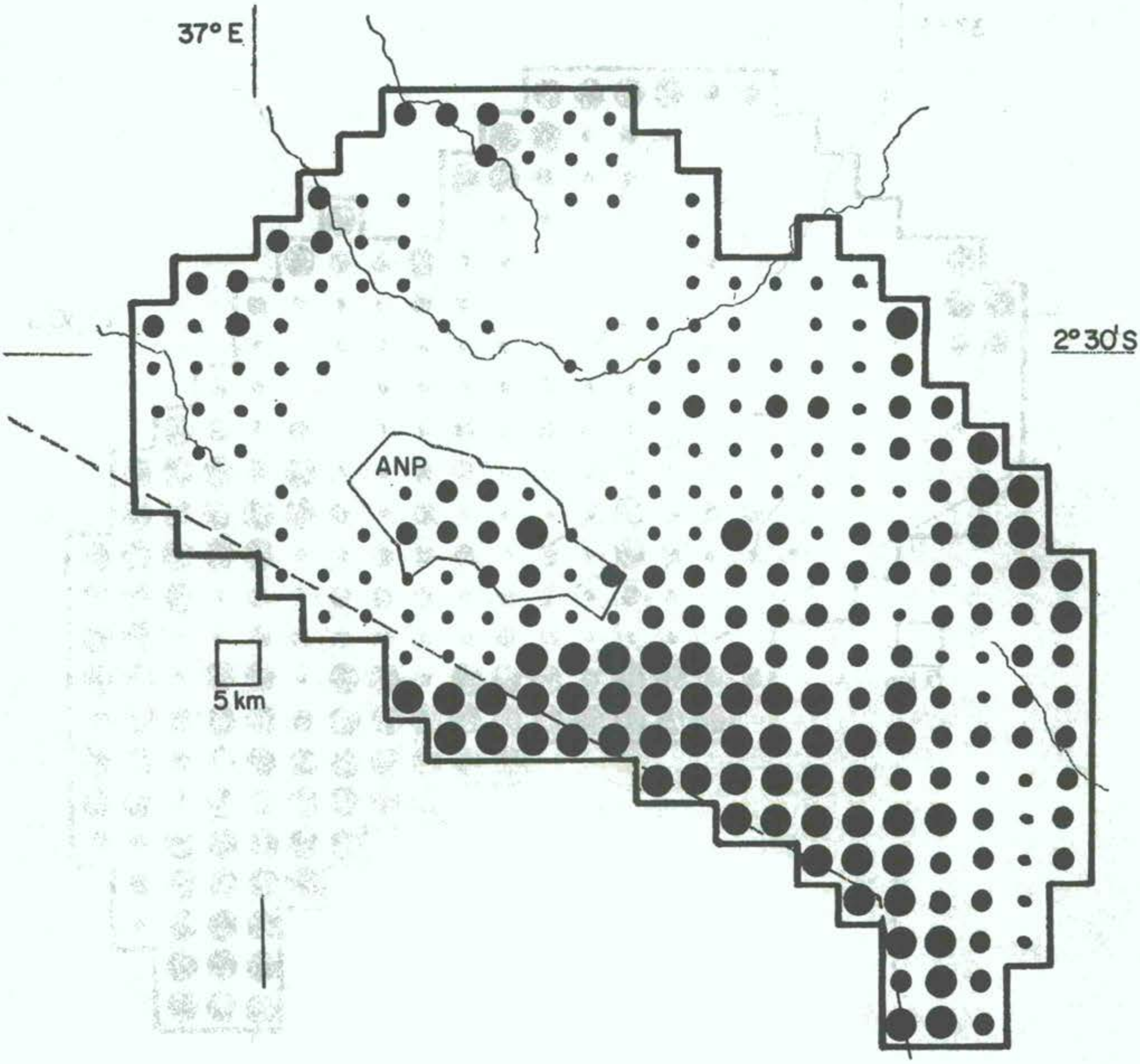

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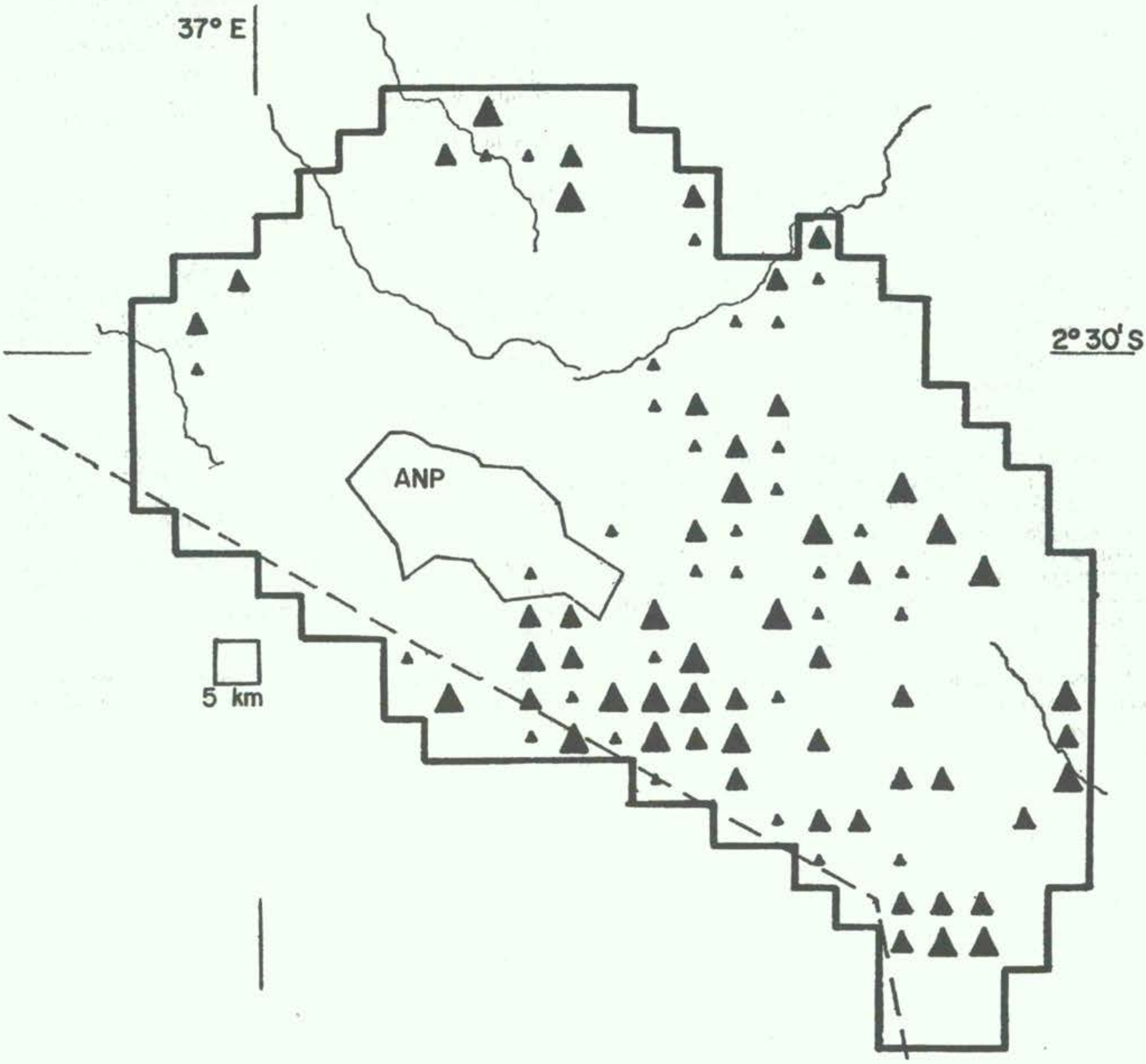

FIGURE LEGENDS

Fig. 1: Map of East Africa showing the areas which have been studied using Systematic Monitoring Techniques. A-C were examined predominantly by Systematic Ground Survey (SGS) supplemented with aerial sample or total counts of animals. 1-8 were monitored using Systematic reconnaissance Flights (SRF) supplemented with ground studies and interpretation of the Earth Resources Technology Satellite (ERTS) imagery.

A. *Selous Game Reserve.* Synecological survey study for the Tanzania Game Division by Rodgers: Department of Zoology, University of Nairobi; 1967 to present.

B. *Amboseli Game Reserve (now National Park).* Synecological study of the structure and dynamics of the Amboseli basin by Western (1973): Department of Zoology, University of Nairobi; 1968 to present.

C. *Samburu.* Study of the ecology of Samburu pastoralism by Rainy: Department of Zoology, University of Nairobi; 1970 to present.

1. *Serengeti ecosystem.* The Ecological Monitoring Programme of the Serengeti Research Institute (cf. Norton-Griffiths, 1972). Multi-disciplinary studies - 1964 to present; SRF - 1969 to 1972.

2. *Ruaha National Park.* SRF for large mammal numbers and distribution (cf. Norton-Griffiths, 1975, in press): Serengeti Research Institute; 1972 to 1973.

3. *Lamu/Southern Garissa District.* SRF by the UNDP/FAO Kenya Range Management Project, UNDP/FAO Habitat Utilization Project, Kenya Game Department and University of Nairobi, combined with ground sampling and ERTS correlations (cf. Duncan, Gwynne, Jarman, in press): 1973 to present.

4. *Southern Kajiado.* Ilkisongo Monitoring Project: an extension of (B) above to include the ecology of the entire Amboseli National Park ecosystem, including Maasai pastoralists; SRF and ERTS correlations; by Western and Croze; Department of Zoology, University of Nairobi and New York Zoological Society; 1973 to present.

5. *Kajiado District.* Investigations of land-use potentials with reference to wildlife populations; SRF and some ground sampling; UNDP/FAO Kenya Wildlife Management Project; 1974 to present.

6. *Tsavo National Park ecosystem.* Ecological monitoring by Cobb (1975) of the Tsavo Research Project; SRF and SGS: Kenya National Parks; 1973 to 1974.

7. *East Rudolf National Park.* SRF for Kenya National Parks: UNDP/FAO Kenya Range Management Project (Gwynne, Norton-Griffiths and Duncan); 1973.

8. *Tana River/Kilifi Districts.* SRF predominantly for elephant data by Allaway (under the supervision of Croze); Department of Zoology, University of Nairobi and the Research Division, Kenya Game Department; 1974 to present.

Fig. 2 a and b: 10 cm isohyets for the mean dry season (a) and mean wet season (b) in the Serengeti National Park, Tanzania, and the surrounding ecosystem. Spots show the location of monthly storage rain gauges; stippling indicates higher ground (1,800 - 1,500 m). From Norton-Griffiths *et al.* (1975).

Fig. 3: Time per bite as affected by grass height. Goats consistently take a longer time per bite and can be considered less efficient at grazing. From Gwynne (1974).

Fig. 4: Elephant use (any form of browsing) of five tree species expressed as a function of the

frequency of each of the tree species recorded in ground sample plots. Datum points above the 5 % chi-square probability line (+) indicate species used more than expected, i.e. preferred; points below (—), less than expected, i.e. avoided. Solid circles - *Acacia senegal*; solid triangles - *Acacia tortilis*; circles - *Commiphora trothe*; triangles - *Albizia harveyi*; squares - *Balanites aegyptiaca*; crosses - *Acacia clavigera*. From Croze (1974).

Fig. 5: Actual dry season distribution of topi (a) and Hunter's antelope (b) in the Lamu - southern Garissa area of Kenya; data obtained during a single SRF survey flight. From Duncan, Gwynne and Jarman (1976).

Fig. 6: Broad scale SRF generated vegetation map of the Lamu - southern Garissa area of Kenya. Animal distribution in Fig. 5 should be compared with this map.

A = dry *Acacia* dominated bushland

E = woodland with grassland glades

F = closed canopy woodland with no grassland

H = woodland with abundant *Hyphaene* palms

From Duncan, Gwynne and Jarman (1976).

Fig. 7: The wet season (a) and dry season (b) surfaces of best fit ($P < 0.01$) for the occurrence of Hunter's antelope in the Lamu - southern Garissa area of Kenya. From Duncan, Gwynne and Jarman (1976).

Fig. 8: The wet season (a) and dry season (b) surfaces of best fit ($P < 0.01$) for cattle distribution in the Lamu - southern Garissa area of Kenya. The distribution of cattle is relatively static as compared with seasonally mobile species such as the topi and Hunter's antelope (cf. Fig. 7). From Duncan, Gwynne and Jarman (1976).

Fig. 9: Livestock routes in the Lamu — southern Garissa area of Kenya as recorded during SRF surveys. (Gwynne, unpublished data.)

Fig. 10: Cattle trail showing the characteristic parallel ribbed appearance which can readily be identified from the air during SRF (photo Gwynne).

Fig. 11: Preliminary vegetation map from a SRF in southern Kajiado District, Kenya. Identified units are:

A - Grassland ○ and perennial swamp ◎

B - Bushed grassland • with wooded grassland ●

C - Mixed wooded grassland/ bushed grassland

D - Forest ■

C = cultivation

(Western and Croze, unpublished data.)

Fig. 12: Green biomass isopleths (20 gm m^{-2}) in the Serengeti National Park, Tanzania, in the early wet season (a) and the dry season (b). Areas of > 60 gm m^{-2} are indicated by hatching. Data collected from quasi-systematic flights using a digital photometer. (After MacNaughton, unpublished data.)

Fig. 13: Quartic surface of dry season elephant distribution in Samburu District, Kenya, from a trend surface analysis of data collected during a non-systematic reconnaissance flight. Isophant lines indicate elephants observed per 10×10 km grid square. From Croze (1973).

Fig. 14: Population parameters from vertical aerial photography. Population age-structures may be calculated from measurements of elephant body lengths made on the photographs. Black inset: vertical axis is frequency; horizontal axis is age (1-60) in years. After Croze (1972).

Fig. 15: Aerial photographs showing change in woody vegetation cover due to the action of fire and elephants, over a nine-year period in the Serengeti National Park, Tanzania. After Gerrisheim in Norton-Griffiths (1972).

Fig. 16: A portion of soil map (a) of the Lamu — southern Garissa area of Kenya prepared from ERTS imagery using both colour composites and single band images. This map may be compared with the ERTS MSS Band 5 image shown (b). (Gwynne, unpublished data.) See colour section at back of book.

Fig. 17: Estimates of grass greenness in the Southern Kajiado District of Kenya from (a) Systematic Reconnaissance Flight and (b) ERTS imagery:

• = 1 - 33 % green

● = 33 - 67 % green

⬤ = 67 - 100 % green

ANP = Amboseli National Park

(Western and Croze, unpublished data.)

Fig. 18: Distribution of Maasai cattle in Southern Kajiado District of Kenya, from a Systematic Reconnaissance Flight (cf. simultaneous grass greenness cf Fig. 17).

▲ = $<$ 50 cattle/km²

▲ = 50-100 cattle/km²

▲ = $>$ 100 cattle/km²

ANP = Amboseli National Park

(Western and Croze, unpublished data.)