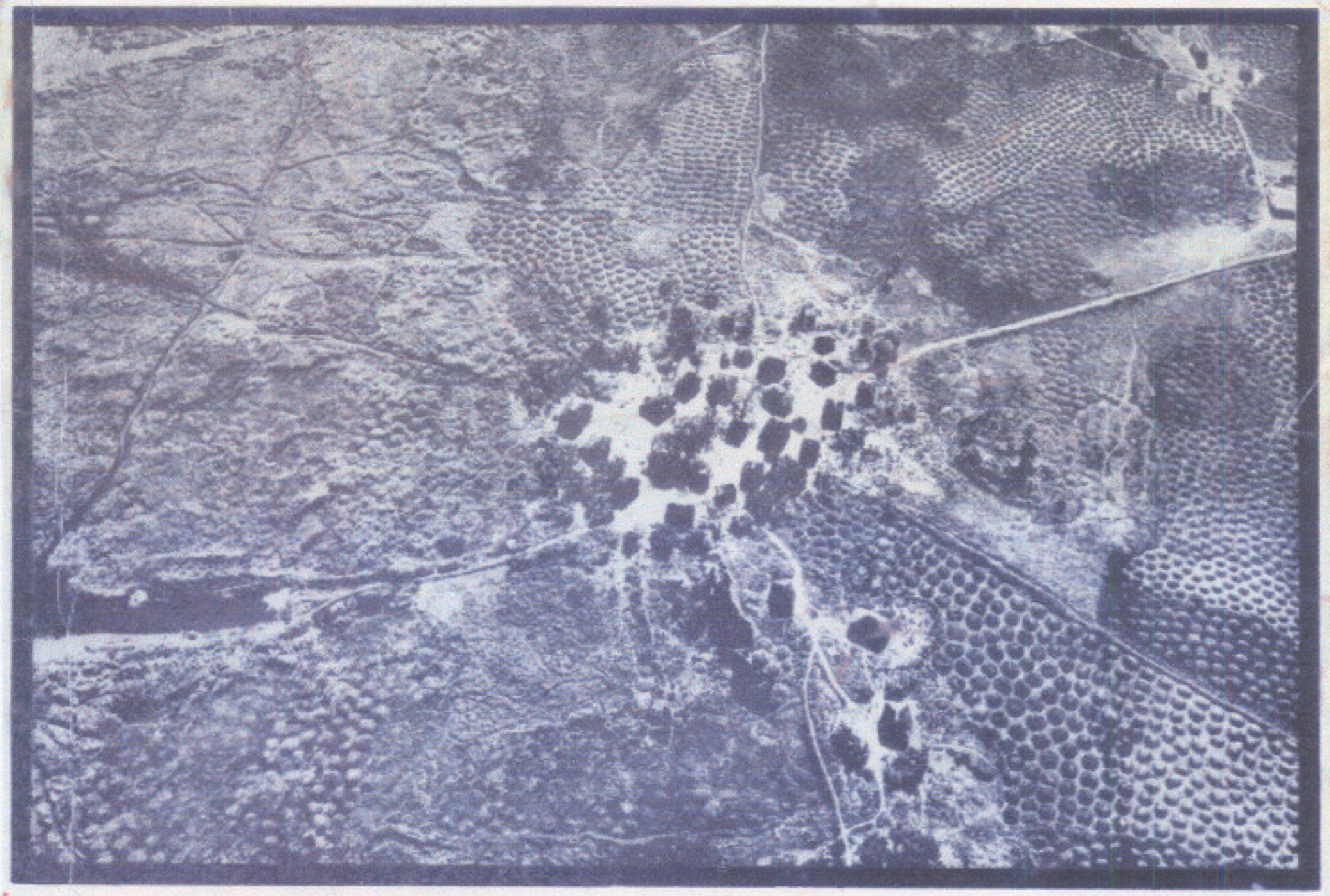
ecological monitoring

by J. J. R. Grimsdell

A series of handbooks on techniques in African wildlife ecology, produced by the African Wildlife Foundation



Handbook number 4

ECOLOGICAL MONITORING

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J.J.R. Grimsdell

Handbook No. 4 in a series of Handbooks on techniques currently used in African wildlife ecology.

SERENGETI ECOLOGICAL MONITORING PROGRAMME

African Wildlife Foundation
P.O. Box 48177, Nairobi, Kenya.

March 1978

Cover : airphoto of a village in the Bangweulu swamps, Zambia; an example of photography used for house counts.

ACKNOWLEDGEMENTS

The following people have cast an eye over earlier drafts of this Handbook and have made many helpful comments : R.H.V. Bell, M.D. Gwynne, M. Norton-Griffiths, D. Western and P.A. Jewell.

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SECTION 1 INTRODUCTION

1.1 The general approach and objectives

The concept of ecological monitoring is relatively new, in Africa and elsewhere, but it is now widely recognised as an important environmental science, being concerned with recording ecological changes as they occur over time and space. The word 'monitor' comes from the Latin, *moneo*, to warn; so monitoring implies a warning system to give notice of changes. This raises the question as to whether a change is considered undesirable or not and some mention of this is made below.

At its broadest, ecological monitoring can be conducted on a global scale, such as the worldwide monitoring system proposed by the United Nations Environment Programme. The object of this programme is to give warning of changes that may reduce the capacity of the earth to support man. This involves monitoring human effects such as the exploitation of natural resources, land development, urban growth and pollution, and how these influences affect the global environment.

Our objectives for ecological monitoring in wildlife parks and reserves are slightly different, however. Before giving some of the reasons for carrying out an ecological monitoring programme, it is worth pointing out how these programmes came into existence in the first place. As it is now beginning to be understood, change is characteristic of most African ecosystems owing to many factors, some of them man-induced. This characteristic has not always been appreciated by wildlife managers, who in some cases have become suddenly alarmed when a change became conspicuous - such as opening up of a woodland or encroachment of settlement. Often, however, that change has been continuing for a long period, perhaps at a steady rate, but then at a certain point becomes strikingly obvious. Situations of this nature prompted the initiation of monitoring programmes in order that rates of environmental change could be accurately documented over time. Given information on rates and probable causes of change, wildlife managers should be in a position to make more rational management decisions, depending on the objectives for the conservation area in question.

Other reasons for ecological monitoring in parks and reserves are as follows :

(1) To measure the stability of ecosystems which experience minimum interference by man - to be called "natural ecosystems" in this handbook. One of the main scientific reasons for keeping natural ecosystems is to use them as ecological reserves, or "base-line stations" [47], to compare with man-influenced systems - such as livestock, agricultural or forestry areas. Active management is not appropriate in such reserves, for this defeats the object of discovering how stable and resilient natural ecosystems really are when left to themselves. Ecological monitoring would aim at documenting changes over time to assess long-term stability in terms of soil, water, plants and animals.

(2) To test the value of predictive models which attempt to simulate the dynamics of the ecosystem, or part of it. If such models prove to be reliable, then they may be used to assess the stability of natural ecosystems and how they are affected by disturbing influences.

(3) To give warning of changes which are considered undesirable in the park or reserve. What is 'undesirable' depends on the management objectives for the conservation area in question. In a strict ecological reserve, no change would be considered undesirable, except when it was heavily influenced by man. However, in other areas where the object is to maintain ecological diversity, the disappearance of a habitat type or an animal species would be considered undesirable. An ecological monitoring programme would give warning of such a change and might be able to suggest the causes. Human developments in or around parks or reserves often conflict with conservation objectives; again, a monitoring programme will give early warning of such things as settlement encroachment and road proliferation.

(4) To provide information for the formulation of management plans for parks and reserves and for land-use plans in areas surrounding a conservation area.

(5) Finally, if active management is undertaken in a conservation area, then a monitoring programme will evaluate how successful the management is in achieving its goals. For instance, whether an early burning programme or an elephant reduction cull is resulting in improvement of certain woody habitats. Another example would be that of an anti-poaching operation designed to allow the increase of a population of animals thought to be kept low in number by excessive hunting; regular monitoring of population size would show how effective the anti-poaching operations were.
Evaluation of management action is perhaps the most important function of a monitoring programme.

Very few parks or reserves in Africa have established monitoring programmes for recording ecological changes, although many areas have survey data (e.g. rainfall records, animal counts) that can be incorporated into a monitoring programme.

For Tanzania's National Parks, it has been recommended that all the Parks should have a monitoring service responsible for keeping a continuous check on ecological changes, and also to conduct research on major ecological problems of each Park. Such a programme was set up in the Serengeti National Park in 1970, called the Serengeti Ecological Monitoring Programme (SEMP)[63]. This was an early attempt to follow changes in an African ecosystem in terms of climate, vegetation, burning, animals and human influences.

Other monitoring programmes have since developed, one of which - the Kenya Rangeland Ecological Monitoring Unit (KREMU) - is attempting to document changes over the whole of Kenya's rangelands. Even larger scale monitoring programmes are planned for West Africa.

The purpose of the following sections is to give an outline of the methods available for recording ecological changes in and around parks and reserves.

1.2 Defining the ecosystem

Preferably, an ecological monitoring programme should cover a complete ecosystem; that is, a reasonably self-contained ecological unit. However, the definition of an ecosystem has to be arbitrary, for any ecosystem smaller than the whole universe is affected by events outside it. In some studies the ecosystem is defined by National Park or Game Reserve boundaries although these are often highly artificial, bearing little relation to the range of large mammals or to land region or system boundaries (see Section 4). Slightly more objective approaches are (a) to define the ecosystem on the basis of the annual range of large migratory species, e.g. elephant, wildebeest, zebra, lechwe, gazelle; or (b) to define the ecosystem on the basis of land regions or systems, i.e. ecological units of land with common landform, geology, climate, soils and vegetation (Section 4). It should be noted that an ecosystem defined in spatial terms only may alter with time, so that the ecosystem may have to be redefined at a later period. For example, a vegetation zone might shift owing to a change in climate; or the range of migratory animals might change for a variety of reasons.

As far as possible, therefore, an ecosystem should be a functional unit designed so that outside influences have minimal effect. Probably a combination of approaches (a) and (b) mentioned above would give the most satisfactory result. Having defined the ecosystem, a regular system of surveys can be begun within it. Time, money and staff availability will then dictate how frequent or intensive these surveys can be.

SECTION 2 OVERALL MONITORING STRATEGY

Anyone starting a monitoring programme will want to know :

- which data to collect and why
- how to collect the data
- how to store and analyse those data
- finally, how to interpret the results in an integrated way.

2.1 The data

Which data to collect will depend on the area in question and the reasons for monitoring in the first place. Monitoring can cover any ecological factor but, clearly, for practical reasons, the field has to be narrowed to what are judged to be the chief factors. At the onset, therefore, one should list the reasons for monitoring in what are considered to be their order of importance. The collection of data then stems from this, the data being ranked according to their supposed importance. To give an example, if one wishes to maintain certain woody habitats within a National Park or Game Reserve which also contains elephants the primary data collections should cover :

(1) rainfall pattern
(2) woodland cover, species composition and population dynamics of the trees
(3) grass height (being related to fire risk)
(4) fire incidence and distribution
(5) elephant distribution and abundance.

This basic monitoring design will show whether there are any significant changes in the woodland. If there are changes, then it may be possible to suggest probable causes. Further monitoring would show whether woodland change is stabilised through management action (e.g. fire control, elephant control, or both).

However, causal relationships are rarely straightforward. Hence the need for more comprehensive monitoring in which many different components are followed. This is the value of research monitoring programmes undertaken to discover the dynamics of an ecosystem as a whole because these programmes may provide insights into the interactions of many components.

Some of the components of ecological monitoring are described in the following sections. For each component it is logical to monitor first the broad, overall changes in the ecosystem; then, second, to narrow the field to more detailed and localised studies. It is important to emphasise that ecological monitoring should be mainly concerned with the overall patterns of the ecosystem, and how these change with time. Detailed localised studies have their place, but there comes a point when attention to too much detail may detract from appreciation of overall changes. For this reason, methods of detailed analysis have largely been omitted from this Handbook.

2.2 Data storage and analysis

Data should be collected and stored in a way that helps analysis. Therefore, one should know in advance how the data are to be analysed, otherwise there is the risk of collecting piles of records without any clear idea of what to do with them. Detailed methods of analysis are referred to in the following sections, but a few general points may be mentioned here.

Firstly, it is sensible to duplicate the raw data and store them in different places so as to reduce the chances of them being lost or damaged. One system is to store a copy of the data on magnetic tape (created from data on computer punch cards) kept, for example at a University Computer Centre or Data Centre of some kind. The magnetic tape can be up-dated periodically; furthermore, the data are then in a convenient form for analysis, which, if many data are involved, is best done by computer anyway.

In many cases the data may be conveniently analysed according to grid-cells on a map, each datum being given co-ordinates for a particular cell. Computer methods are available for ordering the data in this manner, in addition to giving data print-outs in map form. Data for many components may then be analysed together, based on a common grid-cell system. Various multivariate analyses are available to cope with this [23,49,83], but as a preliminary step, simple linear regressions [4] may be plotted of one variable against another, thus showing which variables appear to be correlated and which show no obvious correlation.

2.3 Interpretation

It is highly important to distinguish between a correlation and a causal relationship. A high degree of correlation does not necessarily imply the latter; it can be taken as a strong inference only. More detailed data collections and analysis will probably be needed to confirm the nature, if any, of the causal relationship. Supposing, for instance, that woodland change was strongly correlated with the incidence of fire, but less so with the occurrence of elephants. This could not be interpreted to mean that fire is that much more important than elephants in causing the change. Information on this could only be obtained from study areas in which the detailed effects of both fire and elephants were documented. Therefore, an integrated monitoring programme can suggest probable causal relationships, but these have to be confirmed by detailed work such as using experimental plots (Sections 7 and 9). It may be that other, unmeasured, components are involved; in which case the programme should be modified to include them.

Advanced methods of analysis are available for simulating the dynamics of ecosystems, such as the systems analysis approach [43,93]. Given adequate data on many components it may be possible to simulate the ecosystem in such a way as to predict future changes. African ecology has not reached this stage yet, chiefly because of the complexity of tropical ecosystems. At present, simulation trials should be viewed very critically, as with inadequate information they can give highly misleading results. Commonsense may lead one to overrule the results of a computer simulation trial. This is the basis of interpretation, judging when simulation produces biological nonsense. Continued monitoring will demonstrate how accurate such predictions really are.

SECTION 3 THE USE OF AERIAL PHOTOGRAPHS [44] AND SATELLITE IMAGES [2]

The use of aerial photographs is so fundamental a tool in ecological monitoring that it must be introduced at an early stage in this Handbook. Almost every section in this Handbook leans heavily on aerial photographs in order to obtain raw data. Aerial photographs are used for making base maps, landscape maps, vegetation and soil maps, for measuring woodland change, for counting animals, for determining animal population structure and for assessing human abundance and settlement.

3.1 Government survey aerial photographs

It is nearly always possible to obtain aerial photographic coverage of most African ecosystems via government survey departments. Sometimes it is possible to obtain more than one coverage, spaced by several years. A series of this kind is of considerable value in detecting gross changes within an ecosystem.

The first step, therefore, is to collect all existing aerial photographic cover for a particular area from the government department concerned. The photographs can usually be ordered in several forms :

(1) 10" x 10" individual contact prints
(2) 'uncontrolled mosaics', made up from several prints
(3) 'controlled mosaics'
(4) enlargements of individual prints.

'Uncontrolled mosaics' are pieced together from a number of contact prints to obtain the best possible match up of ground features. However, their scale is usually distorted; this can only be corrected for by measuring distances between known points on the ground, then rearranging the mosaic to render it distortion free - the 'controlled mosaic'. Mosaics are re-photographed so that they appear on one print. Hence, for mapping purposes mosaics are much easier to handle, although since they have been re-photographed their resolution is poorer than the individual contact prints.

The scales of the individual prints usually range from 1 : 20,000 to 1 : 70,000. It is important to know the scale before ordering the prints; it may be too small to be of use in detecting the ground features of interest. Also, the quality of different series may vary considerably. Generally, the more recent aerial photographs give the best resolution at any particular scale. For mapping topographical features, stereo pairs of prints are needed, to be viewed under a stereoscope. But if this is not important, then only half the number of prints need be ordered, i.e. every other print in the photographic runs made by the survey aircraft.

Very often large scale maps (i.e. 1 : 50,000 to 1 : 100,000) will not be available for the ecosystem in question, so one has to make one's own map. For this purpose aerial mosaics, preferably controlled, are essential. But when possible the mapping should be left to a trained cartographer. Base maps may be prepared from one or more mosaics showing major features such as mountains, lakes, rivers, roads, towns, villages, game camps. At the same time, reference can be made to existing, smaller scale maps (e.g. 1 : 250,000). Care should be taken to assess the degree of distortion, as this will affect the accuracy of distances and areas measured on the map. It is convenient to overlay the base map with a grid, the usual ones being 1 x 1 km, 5 x 5 km, or 10 x 10 km. From the original base map, any number of prints can be made by the ammonia process.

Another use of aerial mosaics is to have them mounted on hardboard, overlain with transparent, acetate paper, then to annotate them by chinagraph pencil while flying over the area in a light aircraft. Information is later transferred onto the base map. This is a rapid method of making a preliminary vegetation or land-use map, showing boundaries of major types. However, ground checks should also be made in order to verify the aerial interpretation.

3.2 <u>Aerial photography from a light aircraft</u>

If a light aircraft is available it is possible to make one's own aerial photographs. Oblique or near-vertical photographs taken by hand-held camera are suitable for counting animals, for age and sex structure of animals, and sometimes for photo-ecological plots and for house counts (Sections 7, 9 and 11). For other purposes (e.g. woodland canopy cover indices) a series of vertical photographs is required. In this case it is necessary to fit a vertically mounted camera. It is possible to do this by attaching the camera to a clamp fitted on the lower edge of one of the windows or, alternatively, by fitting a vertical mount on the door frame, with the door removed. A more satisfactory solution is to have the camera mounted through a hole in the floor of the aircraft. This can be an expensive modification, although in a fabric aircraft, such as the Piper Super Cub, a hole can fairly easily be made (with minimum cost) behind the back seat, on the floor of the baggage compartment. Ideally, a gimbal mount should then be fitted over the hole in order that the mount can be adjusted to the horizontal position when the aircraft is in flight. A spirit level is needed to find the horizontal plane; this is important if true vertical photographs are required. It is a good idea to fit a rubber gasket over the hole, leaving only the camera lens protruding, otherwise there is the risk of toxic exhaust fumes entering the cabin.

For serial, vertical photography an electrically powered camer is needed, well-known makes being the motor Nikon (35 mm), Hasselblad (70 mm), Hulcher (70 mm), Vinten (70 mm) and the Williamson F.24 (140 mm). With the exception of the last all take standard film (35 or 70 mm). Some sort of control box is useful, so that the operator can fire off the camera by remote control to avoid going into physical contortions behind the rear seat. Control boxes are often fitted with intervalometers which will take photographs at set intervals of time (e.g. one frame every 2 seconds).

3.3 Films

For most purposes standard black and white photography is perfectly adequate; it has the advantage that it is both simple to use and relatively cheap. Ordinary panchromatic black and white film in the range of 100 to 400 ASA often gives excellent results. Companies such as Kodak and Agfa do, however, make special fine-grain film for aerial black and white photography (e.g. Kodak Aerographic Double-X, Plus-X, or Tri-X; Agfa Aviphot 33, or 30).

Colour photography is technically more difficult and much more expensive but in some cases its use is worthwhile (e.g. for vegetation mapping). High Speed Ektachrome is an adaptable colour film as it is possible to rate it well above its nominal speed of 160 ASA. Nonetheless, fine-grain aerial colour films are available, such as Kodak Ektachrome Aerographic and Agfa Aviphot Color.

Other types of film exist, such as infrared films. Infrared films (black and white, or false colour) are of use, for example, in distinguishing between healthy and dead or dying vegetation; healthy green plants reflect infrared light strongly, whereas dead plants do not. But there is no point in using these special films unless absolutely necessary since they are particularly heat-sensitive and unless they are stored in a deep freeze they rapidly become time-expired.

It should be noted that speed ratings on aerial films are usually not the same as regular ASA ratings. However, conversion tables are available which may be used to find equivalent ASA ratings.

The quality of aerial photographs is often improved by the use of filters on the camera lens (e.g. yellow filter for black and white photography; ultra-violet and haze filters for colour photography).

3.4 Scales

The scale of aerial photographs depends on the height above ground and on the focal length of the camera. Calculation of scale is very simple, being given by the formula :

$$\text{Scale} = \frac{f}{H}$$

where f = the focal length of the camera

and H = the aircraft's height above ground.

Both f and H must be expressed in the same units of measurement. For example, if the focal length of the lens is 6" (0.5 ft), the height above ground 5,000 ft, then the scale of the photograph is :

$$\frac{0.5}{5{,}000} = \frac{1}{10{,}000} \text{ or } 1 : 10{,}000$$

This scale refers to the photographic negative or to a contact print; if the negative is enlarged, then the scale changes accordingly.

Similarly, one can calculate at which height above ground to fly in order to achieve the photographic scale for the job in hand. Knowing the ground speed of the aircraft and the scale of the photographs, one can also calculate the interval between frames to give the extent of photographic cover required (e.g. full cover with 50% overlap of successive negatives). In addition, one can calculate the distance between parallel flight lines in order to give the required photographic cover in a sideways direction.

3.5 Satellite images

Since July 1972 it has been possible to obtain photograph-like images of the earth taken by satellite; namely, the LANDSAT (formerly ERTS) programme. Light reflected off the earth's surface is picked up by a multi-spectral scanner in the satellite; data are stored on magnetic tape, then relayed to a computer storage system in the U.S.A. These data can then be converted into images of the earth's surface. The satellite orbits at about 920 km above the ground; by the end of 18 days it has scanned the whole earth, so that in theory at least it is possible to obtain regular images of a particular area every 18 days. However, regular coverage is not possible because of (a) cloud cover, and (b) the scanning device is not always switched on. Even so, the LANDSAT programme has considerable potential as a monitoring system on a broad synoptic scale.

LANDSAT images may be ordered at cost from the following address :

EROS Data Centre
Sioux Falls, South Dakota 57198
U.S.A.

Images (prints and transparencies) are produced in the following formats :

SIZE	SCALE
Contact (70 mm)	1 : 3,369,000
Enlargment (9" x 9")	1 : 1,000,000
Enlargement (18" x 18")	1 : 500,000
Enlargement (36" x 36")	1 : 250,000

Each frame covers approximately 100 x 100 nautical miles;* for each frame four spectral bands are normally available :

Band 4 (green)	0.5 - 0.6 micrometres
Band 5 (lower red)	0.6 - 0.7 micrometres
Band 6 (upper red - lower infrared)	0.7 - 0.8 micrometres
Band 7 (near infrared)	0.8 - 1.1 micrometres

Any or all of these bands may be ordered for each image frame; band 5 is usually the best selection for a single band. All four bands appear as black and white images; it is only when they are combined,

* 1 nautical mile = 1.85 kilometres.

using appropriate filters, that a colour image, or composite, is produced.

Provided coverage is available for one's particular area it is probably best to order first 9" x 9" black and white prints (band 5) of the frames of interest. If these look promising, then it may be worth ordering a colour composite.

A good quality colour composite can be used, for example, for making a preliminary vegetation or soil map of a little-known area. Satellite images are particularly useful for original mapping or for up-dating old maps. Owing to the fact that the images are taken so far up there is virtually no distortion caused by terrain relief. In addition, one may order precision-processed images in which nearly all other forms of distortion are removed. The resolution of these images is quite good; at a scale of 1 : 250,000 one can often make out major roads, for instance. The smallest object that can be resolved must be at least 80 x 80 metres in area, i.e. about 1½ acres. Satellite images are much cheaper than the cost of obtaining fresh aerial photographic coverage of a particular area. However, they cannot replace standard aerial photographs for detailed work.

SECTION 4 LANDSCAPE AND HABITAT CLASSIFICATION

Classification and mapping of landscape features and habitats is an essential first step in ecological monitoring, or in any ecological survey for that matter. Such classification and mapping will help in the delineation of the ecosystem and will serve as a basis for data collection and analysis.

A system of landscape classification is useful because an attempt is made to combine information on a number of features; that is, geology, topography (i.e. slope), hydrology, soils, climate and vegetation[27].

Early attempts of landscape classification, based on aerial photographs, were first made in Africa in the 1930s [11]. Since that time a number of areas have been classified in this way, mainly as a means of assessing agricultural potential [82]. These classifications attempt to stratify an area into ecologically homogeneous units, stratification being carried out at various levels. One system is as follows :

LAND REGION (the major landscape type)

Land Sub-Regions (landscape sub-type)

Land Systems (major landscape unit)

Land Facets (homogeneous basic unit)

Land Elements (smallest ecological landscape unit)

Very few wildlife areas in Africa have been classified in this manner; but examples are available for the Luangwa Valley in Zambia [3] and the Serengeti National Park in Tanzania [36].

Landscape classification is a specialised subject, requiring as it does an integration of many ecological factors. Because there is a considerable element of subjectivity in defining boundaries, landscape classification is best left to people experienced in this subject. Once produced, however, a landscape map is of long-term value, although it may be necessary to revise it periodically as new data accumulate.

A landscape map should also serve as a habitat map, which can be related to animal distributions for example, but will contain more information than a habitat map alone - which is usually based on vegetation structure. A good landscape map will indicate the range of vegetation types that could exist on a particular landscape unit depending on prevailing environmental conditions; in other words, potential vegetation as well as existing vegetation could be indicated.

Habitat maps, by themselves, describe the existing vegetation types and structure. An example of broad habitat categories is as follows, based on decreasing density of woody species :

(1) Forest
(2) Riverine thicket
(3) Woodland
(4) Busnland
(5) Wooded grassland
(6) Bush grassland
(7) Shrub grassland
(8) Grassland (can be subdivided into long, medium, short, seasonally flooded etc.)
(9) Permanent swamp
(10) Barren land
(11) Open water

(These habitat types are partly based on a classification system of Kenya rangelands [76].)

Broad habitat categories, such as those listed above, can be defined from aerial photographs as described in the previous section. If the necessary computer facilities are available, it is possible to prepare habitat maps from LANDSAT data, as has been done, for example, for grizzly bear habitats in America [29]. This approach is most useful for large, remote areas.

Another method of mapping habitats is to record habitat types during systematic aerial surveys (see Section 10.2). Information is collected on a grid-cell basis and later transferred to map form.

SECTION 5 CLIMATE

Because climate is such a fundamental environmental variable, it is an essential component of any monitoring programme.

In tropical continents, such as Africa, rainfall is the most important climatic element. In these regions, rainfall patterns are largely responsible for determining the nature of whole ecosystems, that is, through their effects on topography, soils, hydrology, vegetation, and both animal and human distributions. Therefore, one of the principal aims of ecological monitoring is to record the rainfall pattern of an ecosystem and how the pattern varies over both time and space.

Variation in rainfall may be considered on various time scales, from long term to short term as follows :

(1) Long-term changes, measured on a geological time scale, which affect the ecology of whole continents. In Africa, it is known that these long term changes have caused the forests and deserts to ebb and flow over the surface of the continent [61].

(2) Medium-term changes of the order of 10 to 100 years, that is, either cyclic or non-cyclic periods of wet and dry years.

(3) Short-term changes from one year to another, or from one season to another, or from one month (or even day) to another. Fluctuations of this kind are characteristic of all areas and not necessarily part of longer term trends in rainfall.

Ecological monitoring can measure changes in the second and third categories, some mention of analysis being given below. Changes in rainfall should be expected as a normal occurrence; stable conditions are perhaps unlikely and this is borne out by recent evidence of changes in world climate [53,54,101]. Change is to some extent influenced by man-induced effects. To give an example, there is some evidence that in dry regions removal of plant cover through unwise land-use will alter local microclimate and increase reflectivity from the land surface; a chain of events of weather conditions then follow resulting in reduced rainfall [41]. Simulation models have been developed to predict such changes in climate. In a recent paper, for instance, the effects of removal of tropical forests on world climate have been simulated in a model of atmospheric circulation [75].

5.1 Design of the data collecting system

A network of rain gauges is necessary in order to discover the rainfall pattern of an ecosystem.

Storage rain gauges, read monthly, are the most practical. The standard type is a steel cylinder of 5" (12.7 cm) diameter, one metre long, set into the ground with concrete. A small quantity of motor oil is put into the gauge to prevent evaporation. Readings are made with a dip stick (to the nearest mm) as cumulative measurements; that is the rainfall for the month is calculated as the difference between that month's reading and the previous month's reading.

When the gauge is nearly full it should be partially emptied with a tin can. It is not advisable to empty the gauge completely, as some of the rain entering the gauge may be lost before it reaches the bottom, i.e. by evaporation off the sides of the gauge. Fresh oil should then be added and a new measurement made. A circle of wire gauze is lodged in the top section of the gauge to prevent entry of insects, small mammals, etc. (See Fig. 1).

Ideally the gauges should be distributed evenly on a hexagonal grid system, within an area somewhat larger than the ecosystem itself in order to give adequate cover. But practical reasons, such as positions of roads and airstrips, may force one to make do with a less ideal design. However, an even design will benefit subsequent analysis, especially if special numerical methods are used. As a rough guide, the density of gauges should be around one per 500 km^2, although greater or lesser densities may be used depending on the locality.

5.2 Analysis of data

(i) Pattern

If the data are stored on magnetic tape they may be programmed to give print-out sheets showing, for example :

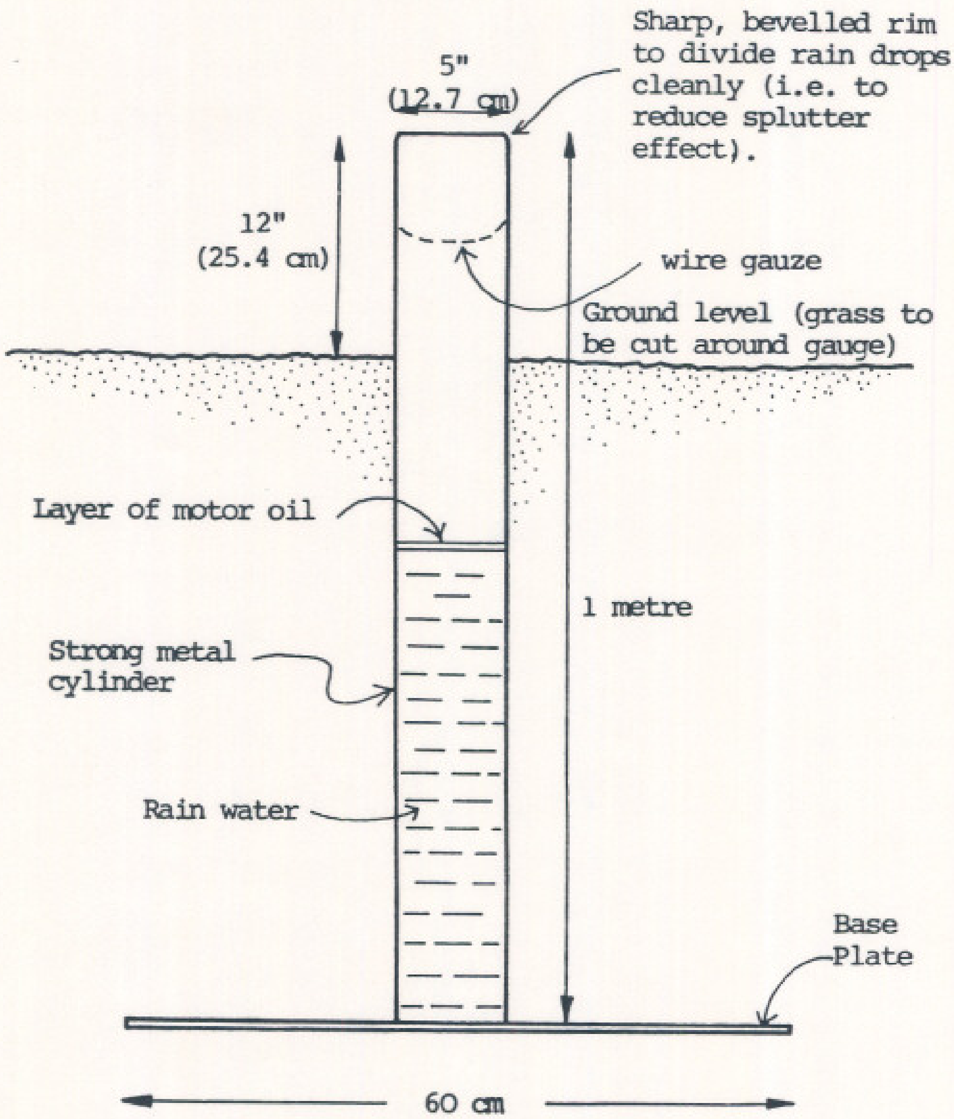
(1) the raw data for each station by years and by months

(2) the mean yearly values for wet and dry seasons, with the standard errors and deviations

(3) the total, and total season, means for all years for which data are available

(4) mean monthly rainfall values (plus standard errors) obtained from the years for which data are available.

FIG. 1 Diagram of storage rain gauge



Even if the data are not stored on magnetic tape (this being likely if relatively few data are involved), they may be analysed as suggested above using a calculator. If this is the case, the data should be filed according to station, year, season and month.

It is more meaningful, ecologically, to order the data according to the climatic, not the calendar, year. For example, in the Serengeti ecosystem there is one mainly wet period (November to May) and one mainly dry period (June to October) each year. These two periods represent one meteorological cycle; so the climatic year in this case runs from November to October, not January to December [66]

Often the rainfall records are not complete, some data being absent. Missing data may be estimated from simple linear regressions [4], calculated between values for some neighbouring gauge and values for the gauge in question. From the regression equation, one may predict an individual monthly reading that was not recorded.

Rainfall data may be analysed in a number of ways. Perhaps the most common analysis is that of deriving contour maps showing lines of identical values (i.e. isohyets) for mean annual or mean seasonal rainfall. Such maps show both the direction and intensity of rainfall gradients across an ecosystem. Contour lines can be drawn by eye or by a linear method; this assumes that any difference in rainfall between two points is directly proportional to the distance separating them. An alternative approach is to use a numerical method such as trend surface analysis [7]. For this, computer techniques are needed. Advanced methods of analysis are also available for clustering rain gauge stations into groups whose members are more similar to each other than they are to members of other groups [66]. This is of use in defining rainfall regions, to be compared with land system and vegetation boundaries.

(ii) Cycles and trends

The analysis and interpretation of fluctuations in rainfall is not easy and should probably be left to specialists in this field. As a guide to the analysis of cycles, a good example is provided by a paper on rainfall of the Serengeti ecosystem [72].

Concerning trends, it is probably best to graph the data - say, annual or seasonal rainfall values - against time. Regression lines can be fitted and tests of significance made using a method such as Spearman's rank correlation coefficient (r_s) [84].

(iii) Climatic indices

It is often useful in ecological surveys to combine various climatic elements in order to obtain an index for the climate as a whole.

One method has been proposed by Thornthwaite [88]. This is basically a book-keeping method, the entries being :

(1) "income (= rainfall)

(2) "expenditure" (= potential evapotranspiration)

(3) "capital reserve" (= soil moisture).

In this manner, it is possible to calculate a water budget for each month of the year (see Table 1). Thornthwaite's Index (I) itself is found from the formula below :

$$I = \frac{(100s - 60d)}{n}$$

where s = the annual water surplus
d = the annual water deficit
n = the annual water need (i.e. the annual potential evapotranspiration).

On the basis of this index a region may be classified according to its climatic type as follows :

arid (less than -40)
semi arid/arid (-30 to -40)
semi arid (-20 to -30)
dry sub-humid (0 to -20)
moist sub-humid (0 and above)

Table 1 shows a worked example using data from the Serengeti ecosystem [66]. In order to calculate the index various data and estimates are needed, namely :

(1) Potential evaporation

The most reliable method of estimating potential evaporation (E_o) is probably that suggested by Penman [69]. The data required for estimating E_o are : radiation, mean air temperature, mean dew-point temperature and wind run. Tables for rapid computation of E_o have been prepared [59], and where

TABLE 1 Calculation of Thornthwaite's Climatic Index for a raingauge site in the Serengeti ecosystem [66]. All values are in mm.

	1	2	3	4	5	6	7
	PO	PET	R	R-PET	SST	WD	WS
January	167	125	108	- 17	0	-14	
February	159	119	83	- 36	0	-36	
March	168	126	161	35	35		
April	148	111	193	82	100		+17
May	145	109	122	13	100		+13
June	148	111	59	- 52	48		
July	155	116	12	-104	0	-56	
August	162	122	60	- 62	0	-62	
September	175	131	52	- 79	0	-79	
October	181	136	60	- 76	0	-76	
November	159	119	125	6	6		
December	162	121	118	- 3	3		
Totals	n = 1446					d = 323	s = 30

PO = potential evaporation; PET = potential evapotranspiration; R = rainfall; SST = soil storage; WD = water deficit; WS = water surplus; n = annual water need; d = annual water deficit; s = annual water surplus. A soil storage of 100 mm is assumed.

Index = (100s-60d)/n = -11 (dry sub-humid) radiation data are lacking, estimates of radiation may be derived from records of cloudiness [102].

An alternative but less precise method is to use Woodhead's regressions of potential evaporation and altitude, these showing a close relationship for stations throughout Kenya and Tanzania [103,104,105]. Similar data for Uganda are also available [77].

(2) Potential evapotranspiration

Potential evapotranspiration from an area covered by vegetation is similar to E_o only when water is abundant. However, when both plant cover and water are limited, actual evapotranspiration drops well below E_o. As an approximation to normal range conditions, potential evapotranspiration may be obtained from E_o by using a multiplication factor of 0.75 [13].

(3) Rainfall data

Mean monthly values should be calculated from as many years' data as available.

(4) Soil storage

Often data on soil storage of water are absent but may be estimated using the methods mentioned in Section 6.

In the absence of actual values, a soil water storage of 100 mm has been assumed for certain sites in East Africa [66].

Having obtained values of Thornthwaite's index, they may be presented in the form of a contour map showing climatic zones and gradients over an ecosystem. This has been done for the Serengeti ecosystem (Fig. 2). A map of this kind is very helpful in explaining the zonation of vegetation types within the ecosystem.

A way of presenting the water budget data given in Table 1 is to plot the results as 'climatograms' that show the extent of soil water deficit or surplus for each month of the year (Fig. 3). If the store of soil moisture declines to unavailable levels during any month of the year, then plant growth will not be possible. Information of this kind may be helpful in explaining animal distributions and movements.

In the absence of any information on soil storage, a simple way of expressing 'rainfall effectiveness' is to use the ratio of rainfall to evapotranspiration. In the Amboseli ecosystem, Kenya, this ratio was found to be more useful than rainfall data alone in explaining animal movement patterns [96].

FIG. 2 Climatic gradients across the Serengeti ecosystem. Isolines show values of Thornthwaite's Index [66].

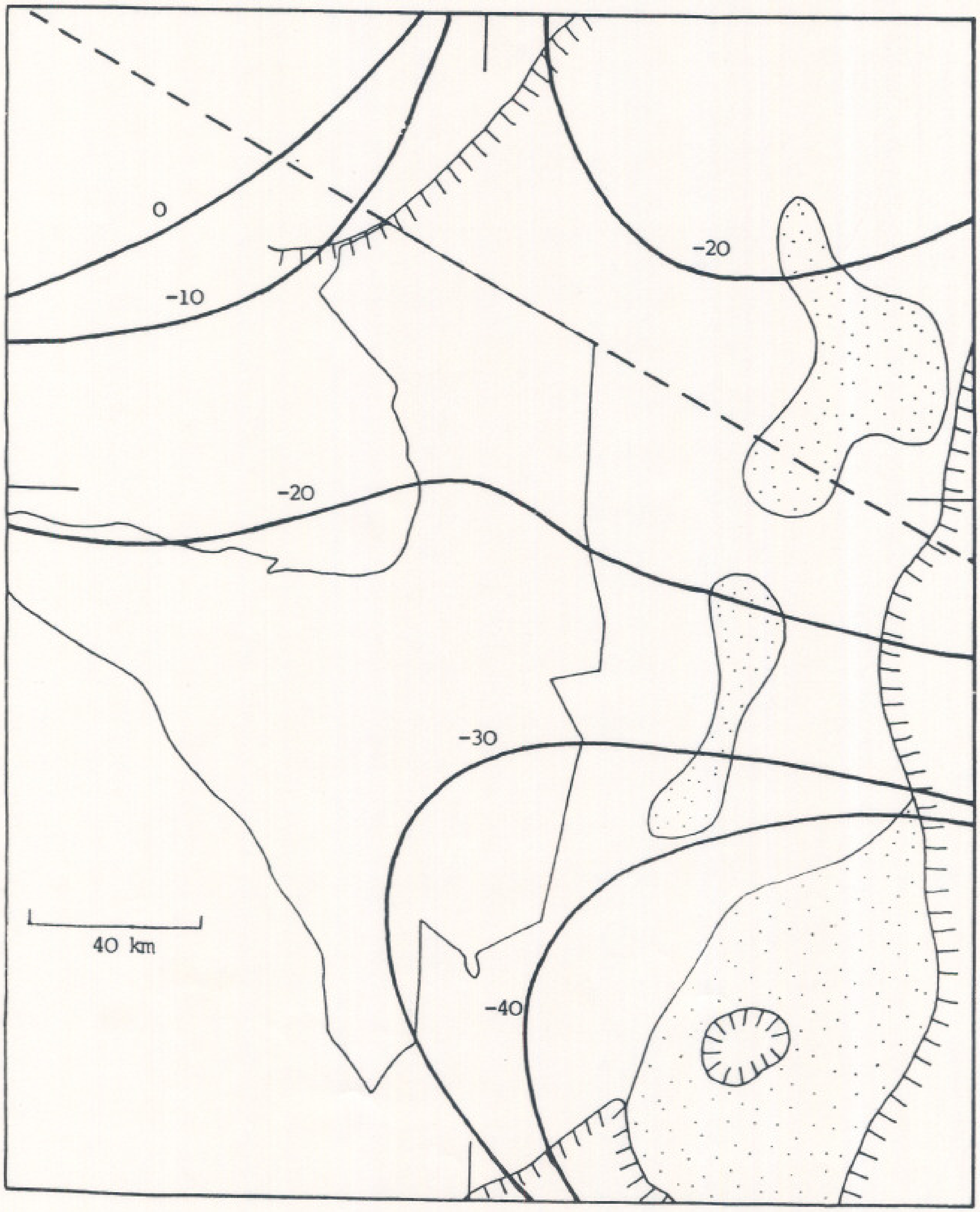
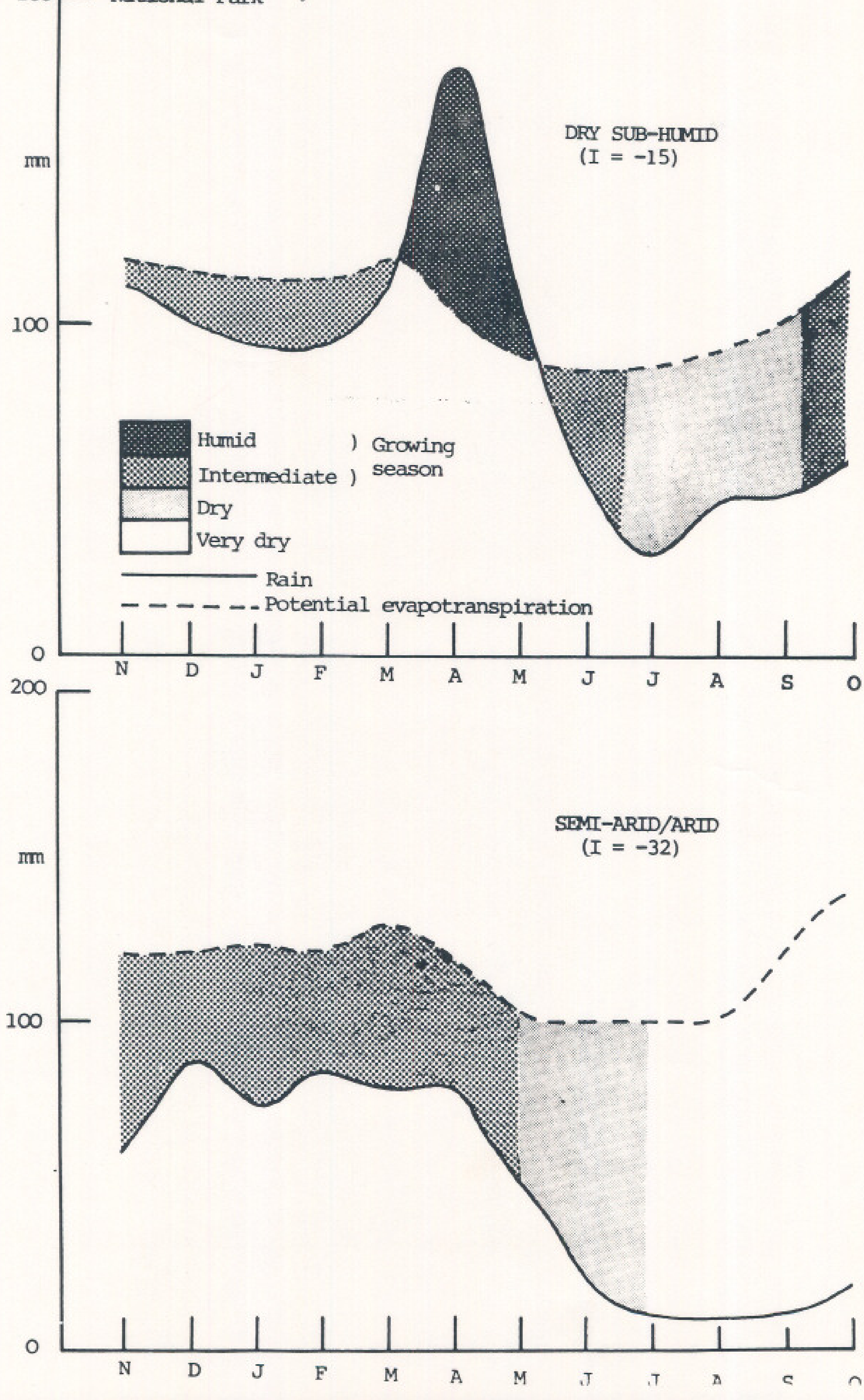


FIG. 3 Climatograms from different regions of the Serengeti National Park [66].



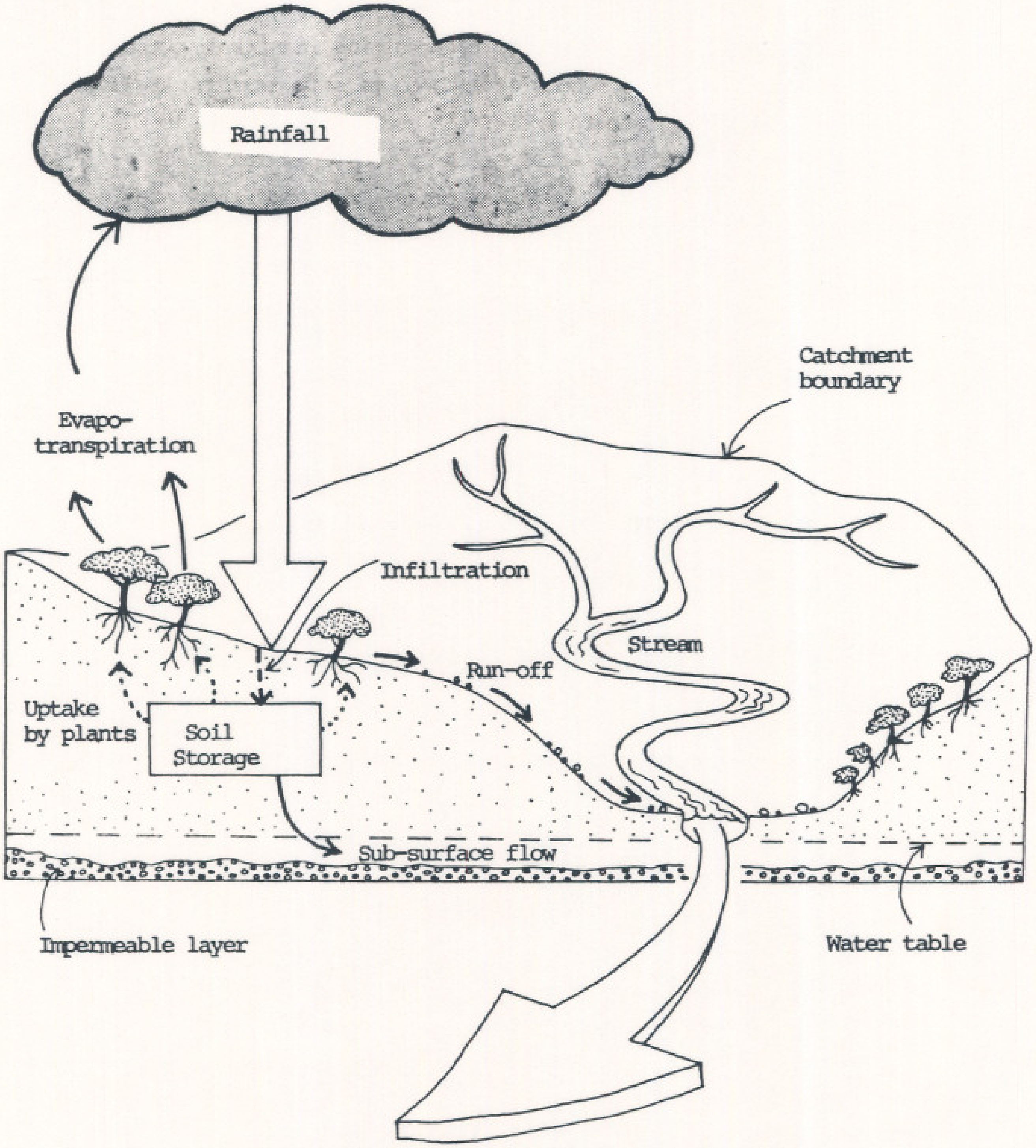
SECTION 6 HYDROLOGY, SOIL EROSION AND NUTRIENT FLOW

6.1 Water run-off and nutrient flow

Rainfall, water run-off, soil water storage, stream flow and nutrient flow are all related (see Fig. 4). Carefully conducted studies [9,10] in an undisturbed North American forest have shown that relatively tight nutrient cycles occur, resulting in minimum output of nutrients and water, with good resistance to soil erosion. However, felling of the forest leads to a chain of events that result in increased rate of water flow accompanied by accelerated loss of nutrients from the ecosystem. Similar processes probably operate in African ecosystems. One function of ecological monitoring is to measure rates of water and nutrient flow in relation to vegetation or land-use changes. Very little work seems to have been done yet on this subject in Africa. Such studies are clearly important in assessing the long-term stability of ecosystems and in determining which types of vegetation (or land-use practices) lead to maximum, long-term stability in terms of essential soil nutrients.

Essentially, the method consists of calculating a water and nutrient budget of a water catchment by measuring the inputs and outputs in meteorological and geological terms. A typical catchment may be selected on the basis of a landscape classification map. In its simplest form, the input of water is rainfall while that of minerals is derived from the weathering of rocks. The losses are evapotranspiration of water, plus both water and minerals flushed out of the catchment by rivers and streams. An important requirement for the study of a catchment is that it should be underlain by an impermeable layer, otherwise the measurements of both water and nutrient outputs may be misleading on account of subsurface water flow. Water and mineral inputs to the catchment can be measured by a network of rain gauges and by estimates of the rate of weathering. Outputs are measured at a weir constructed at the base of the catchment. At this site both the rate of water flow and the flow of nutrients can be determined. Nutrients are measured by sampling the chemical content of the water and by determining the amount of particulate matter trapped by the weir. Evapotranspiration can be estimated by taking the difference between the rainfall input and the

FIG. 4 Diagram of water/nutrient relationships.



water output; that is, knowing the soil storage capacity and assuming no subsurface flow. A diagram of such a catchment is shown in Fig. 5.

6.2 Soil Erosion

Soil erosion is affected by four major variables : rainfall, soil type, slope and vegetation cover. All these should be taken into account when monitoring soil erosion processes.

The subject of monitoring erosion trends has been covered in detail in a recent guide [32], which should be consulted by anyone who wishes to measure soil erosion.

This guide considers two basic approaches to measuring soil erosion, namely :

(1) to monitor sediment transport rates past a point in the river channel at the outlet of a drainage basin

(2) to measure erosion within the catchment to provide information on local rates of erosion.

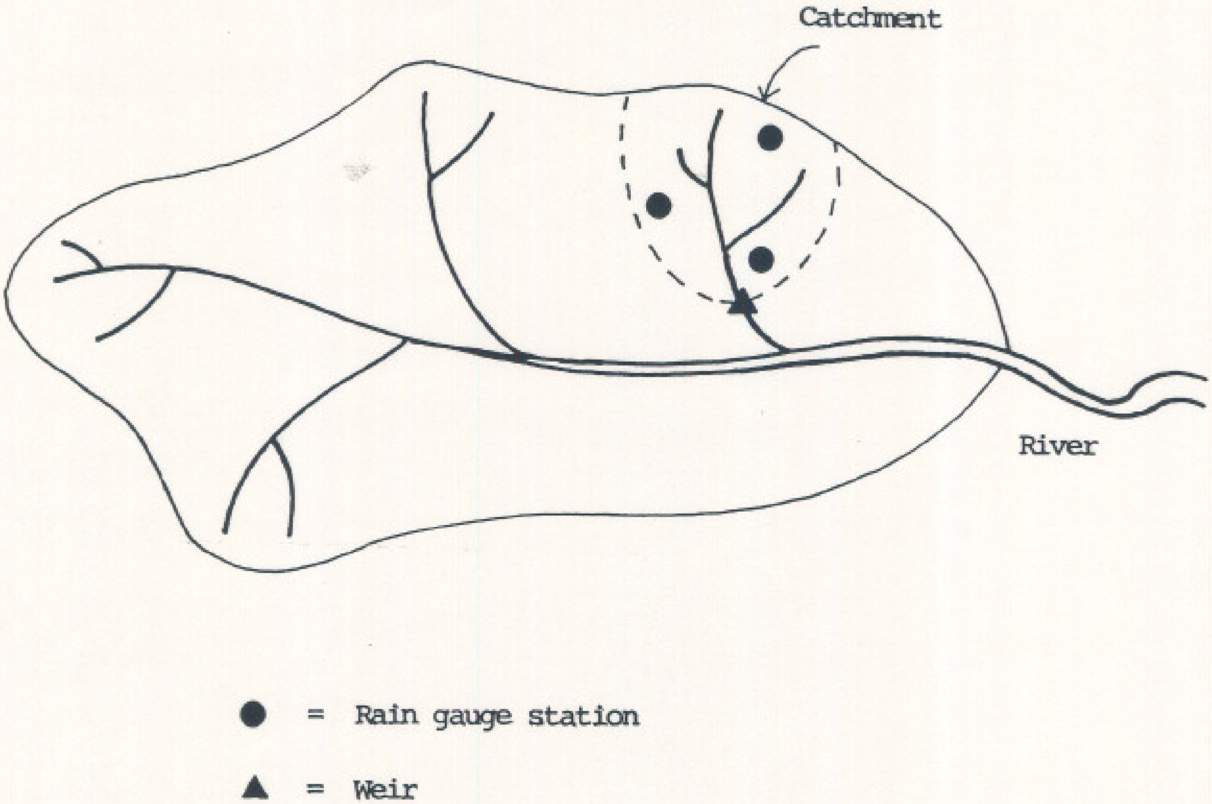
As regards the first approach, some of the methodology has been mentioned in the previous section. Sediment loss via a river channel has two components : suspended load and bed load. The concentration of suspended sediment in the stream or river may be measured with various sampling devices, such as a depth-integrating sampler. The actual transport of suspended sediment may be obtained by multiplying the concentration of sediment in the water measured (say in mg per litre) by the discharge of the stream (say in litres per second).

In small streams, bedload transport may be measured in troughs or catch basins (as described in the last section). However, this method is not feasible in large streams or where transport rates are high. In these situations a bedload sampling device has to be used (e.g. wire collecting basket stabilised with a tail fin).

When measuring sediment yield from a drainage basin, the size of the catchment must be taken into account, for yields from large basins are usually less than from small basins. Therefore, when comparing yields from basins of various sizes, the yields must be corrected to remove the effect of catchment size.

The second approach to monitoring erosion is to measure erosion within a catchment area. This approach can give detailed information

FIG. 5 Catchment study [9]



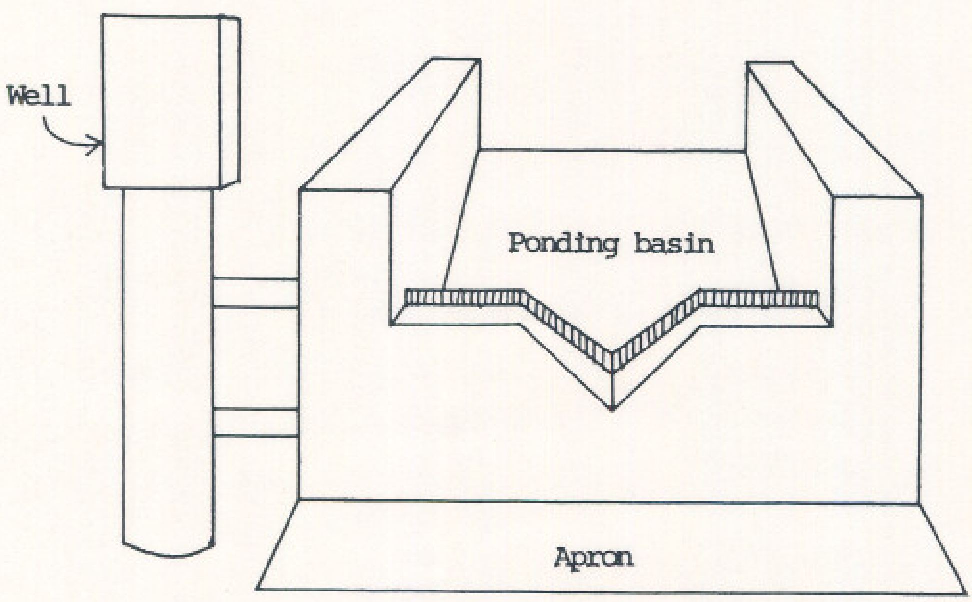


Diagram of weir

on where sidement is coming from. Methods have to be varied according to the erosion processes involved, of which the following are listed below :

Sheetwash erosion

Rilling and gullying

River channel changes

Mass movements

Wind erosion.

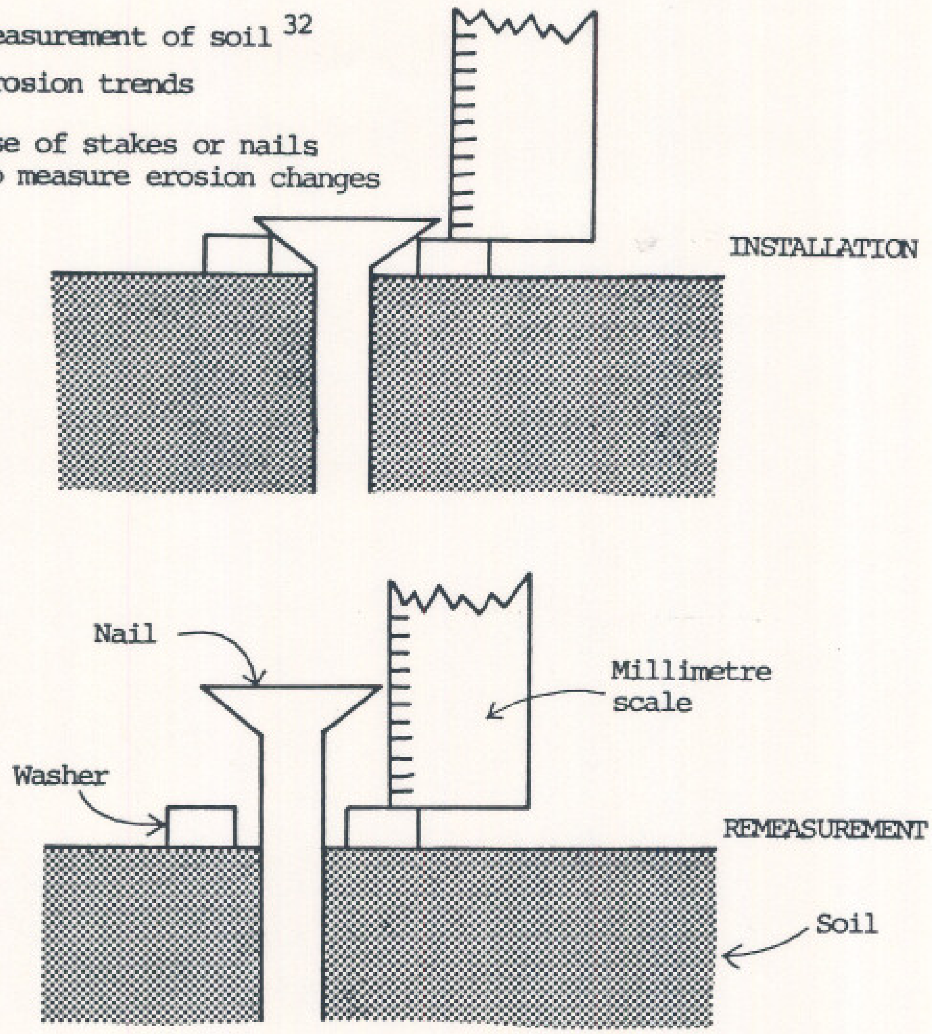
Concerning sheetwash erosion, several methods of measurement can be used. The simplest method is to measure the rate of lowering of the ground surface at stakes or pins (Fig. 6 (a)). Erosion pins should be marked with paint and set in a grid pattern near to a bench mark, which will serve as a reference point when relocating the pins. Groups of pins should be installed in a variety of sites depending on slope, soil type and vegetation cover.

Another technique that has been used in Kenya rangelands is to measure the erosion around tree roots. This is shown in Fig. 6 (b). If the age of the tree can be estimated, then from the mean depth of root exposure a rate of soil erosion can be calculated in cms per year. A reasonably large sample of trees should be measured for root exposure. The PCQ sampling technique may be used (see Section 9.2) with suitable stratification according to slope, soil type and vegetation cover. The age of trees can sometimes be estimated from counts of rings, as seen in cross section of the main stem, or in cores taken with an increment borer. Of course, information is needed on the rate of ring formation; in some parts of Africa two rings are formed a year, in other regions only one is formed. A calibration curve of tree stem diameter against estimated age will provide a rapid method of approximate age determination. Serial measurements of the diameters of known trees will give extra information on growth rates, being especially useful when the tree-ring method cannot be used (as in many tropical areas).

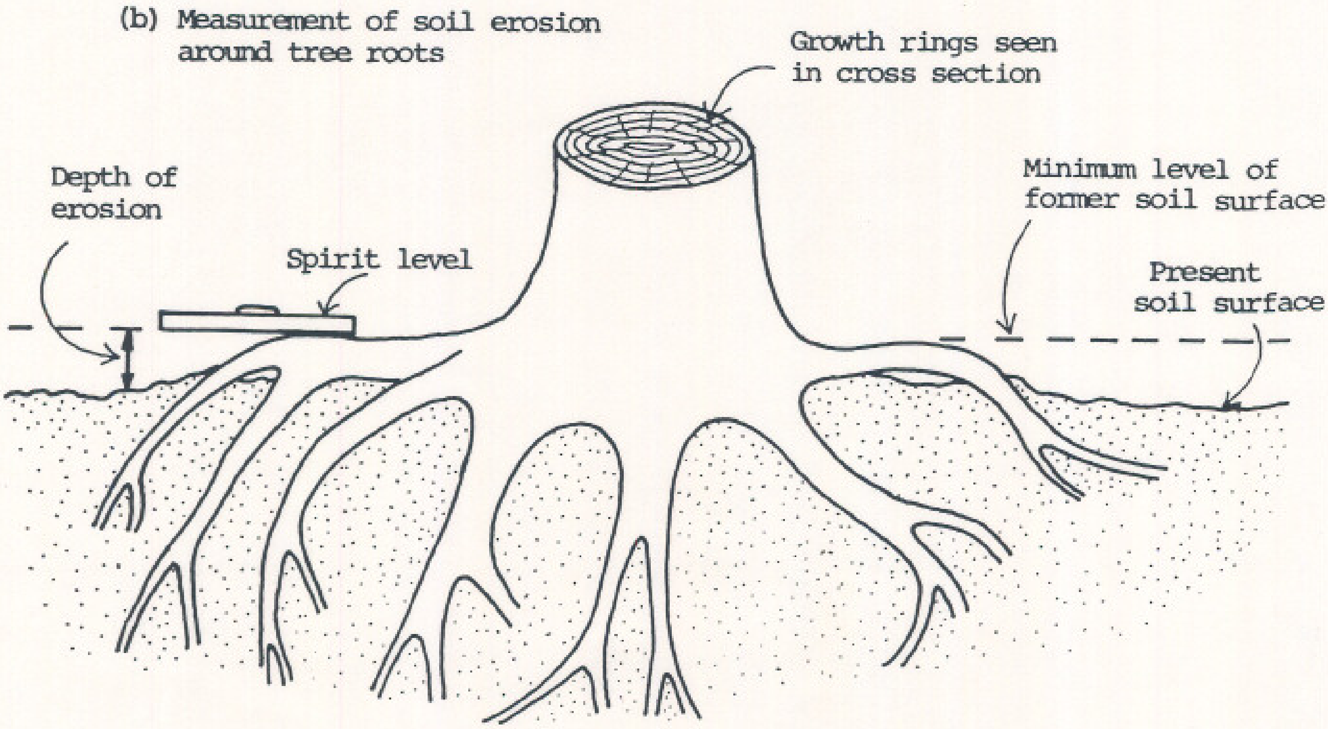
Only brief mention will be made of the other erosion processes. Rilling and gullying, river channel changes and mass movements may all be monitored from a sequence of aerial photographs. Bench marks and iron stakes can be used as reference points for ground measurements of change.

FIG. 6 Measurement of soil erosion trends [32]

(a) Use of stakes or nails to measure erosion changes



(b) Measurement of soil erosion around tree roots



Wind erosion can be measured, like sheetwash erosion, from repeated measurements at stakes, or from depths of exposure with reference to remnants of the former soil surface.

6.3 Soil moisture and water tables

Both soil moisture and water table depth may be measured in a trial catchment as described above. But they may also be measured on a wider scale within the ecosystem. From the standpoint of plant growth, soil moisture is of greater relevance than rainfall, since part of the latter is lost through evapotranspiration and run-off, while different soil types have different water-holding capacities. Subsurface water flow may also contribute to soil moisture, sometimes allowing considerable plant growth even in a low rainfall region; e.g. the ground-water forest in Lake Manyara National Park, Tanzania.

Soil moisture may be measured by extracting standard cores of soil (by soil auger), the moisture content being determined by the weight difference between the fresh and the oven-dried sample. More rapid methods are available, however. One is the use of Plaster-of-Paris blocks, buried in the soil at different depths. Soil moisture is estimated from measurements of electrical conductivity in the blocks [73,74]. Another rapid method is provided by a Neutron Probe, an instrument that can measure the concentration of hydrogen ions in soil, from which water content may be estimated [5]. Once calibrated for the soil type this instrument will give instantaneous readings of soil moisture. Measurements are made at various depths in a metal pipe (preferably of aluminium), which is set tightly into the ground and capped when not in use. A pipe of 1.5 metres in length is probably adequate for most purposes, even though many plants have root systems deeper than this. Recording sites can be placed at the rain gauge stations, thus allowing the relationship between rainfall and soil moisture to be discovered.

Changes in water table (and capillary fringe) can modify a vegetation type, particularly a woodland, through altered water availability, possibly accompanied by a change in hard-pan depth or the rate of salt deposition in the surface soil [98]. Water tables may be measured in boreholes by using a plumb-line [8].

6.4 Water depths in floodplains and swamps

Changes in the flood regime in floodplains or swamps can have important consequences for vegetation and animal life. For example, such changes have, and are at present, affecting various lechwe populations in Zambia [39]. Such alterations in hydrology may be caused by artificial dams, water off-take schemes, changes in flow property (possibly caused by blockage of channels by aquatic vegetation) or even by seismic activity resulting in tilting of the floor of a floodplain basin [39].

As with rain gauges, a system of water depth gauges is needed to monitor these changes. Ideally, the gauges should be spread evenly over the floodplain or swamp. Special emphasis should be given to the principal input and output rivers or channels. An annual water budget may be calculated, knowing the catchment area of the swamp or floodplain, and estimating the annual water input to the catchment via rainfall. Subtracting the estimated annual input from the annual discharge of water at the output source (or sources) will give an estimate of the water lost through evapotranspiration [100].

SECTION 7 GRASSLAND DYNAMICS

Grassland communities are not static but may be changed by a variety of influences including climate, flooding, water tables, fire, grazing by herbivores and human settlement. Depending on the situation, one aim of ecological monitoring is to document grassland changes in relation to these influences.

A distinction must be made here between monitoring designed to document (1) changes in the vegetation itself, and (2) changes in the vegetation as a food supply to herbivores. In the former case, the recording intervals are longer (e.g. a year, or more), the point at issue being the population dynamics of the vegetation. Here measurements are designed to record the distribution and abundance of plants of each species, possibly including information on their age and condition. In the latter case, the recording system should aim at documenting short-term changes (monthly, or seasonally) in standing-crop biomass, productivity, structure, mechanical properties and chemical composition.

These two categories of monitoring are not exclusive, there being overlap between them. In this Handbook only a brief outline is given of the second category since this is a major topic on its own that needs to be related to herbivore feeding ecology.

7.1 The grassland itself

(i) Vegetation map

A first requirement for grassland monitoring is a vegetation map, not necessarily very detailed, showing the major vegetation types including the chief grassland zones or communities [52]. Such a map is best prepared from aerial photographs, annotated on the ground or from the air (Section 3). The vegetation map should be up-dated periodically (say, every 10 years) to see whether there have been broad changes in the distribution of grassland communities.

(ii) Grass species distribution and abundance [37,50]

Updating a vegetation map may show any wide-scale grassland changes but a stratified sampling design* will be needed if detailed changes are to be followed. Some techniques for measuring these more

* Stratified sampling is the technique of subdividing an area into zones or strata, which are reasonably uniform in some respect (e.g. as regards grass community type), and then sampling each stratum individually.

detailed changes are outlined below.

(a) Photo-ecological plots

Permanent ground plots, identified by concrete markers, may be used for monitoring long-term changes in grassland communities. As animals are sometimes attracted to conspicuous markers, the latter should lie outside the actual plots, otherwise there is a risk that the plots will be affected by high animal occupance. Once established, such plots require virtually no maintenance. They can be recorded from the air or from the ground, or both. Their placement is important, however. On the basis of a vegetation map one should decide on representative sites that are typical of a particular community. Alternatively, plots can be located on sites suspected of undergoing change; for example, following removal of hippopotamuses from a stretch of river or lake [1,33,58].

For grasslands, a plot size of 60 x 40 metres is adequate; this may later be analysed according to 10 x 10 metre subsquares. The corners of the plot can be marked with concrete crosses of 40 x 100 cms, with side markers of 40 x 40 cms (see Fig. 7) [35]. The top surfaces of the markers should be covered with a layer of white cement. Such plots must be clearly marked with a number, in addition to being accurately located and recorded on a map.

Plots of this kind may be photographed from the air either with a hand-held camera or, preferably, with a vertically mounted camera. Colour films are best for interpretation purposes. Low-level, large scale photography is needed [15], scales being calculated as outlined in Section 3.4. The prints can be covered with a transparent overlay as an aid to annotation. Aerial photographs are compared at intervals (say of several years) in order to detect what changes, if any, have occurred.

Additionally, ground sampling methods may be carried out within the plots to document, in detail, plant basal cover and species abundance. According to a recent study in southern Africa [92] that evaluated eight methods of botanical analysis, the two most useful methods are :

(1) the line intercept method for estimating basal cover, and

(2) the frequency method for assessing species abundance, using

FIG. 7 Diagram of a photo-ecological plot[35]

a suitable quadrat size. The most suitable quadrat size and shape should be determined by a preliminary survey; the most appropriate quadrat shape is often a rectangle (e.g. 20 x 40 cm), rather than a square.

A combination of these two methods will allow one to monitor changes in basal cover and in species abundance. A stratified sampling design should be aimed at, the data being collected at comparable times in the growing season.

An additional technique that has been used to good effect in the Serengeti and Amboseli ecosystems is the canopy intercept method, using an angled pin (see Section 7.2 (v)). From records on contacts of plant materials with the pin it is possible to obtain data on plant species composition, structure and biomass.

(b) Permanent transects

Permanent, marked transects may be established on the same principles as photo-ecological plots but differ from the latter in that they are designed for ground sampling only [1]. Ground sampling along the transects may be conducted as suggested above.

(c) Sample areas

Provided a good, accurate vegetation map is available then certain defined areas may be both photographed and sampled at intervals without the need for ground markers.

(d) Treated plots

An appropriate design is to establish several large plots, with sub-plots within them, to include the following treatments :

(1) fire plus animal use (unfenced)

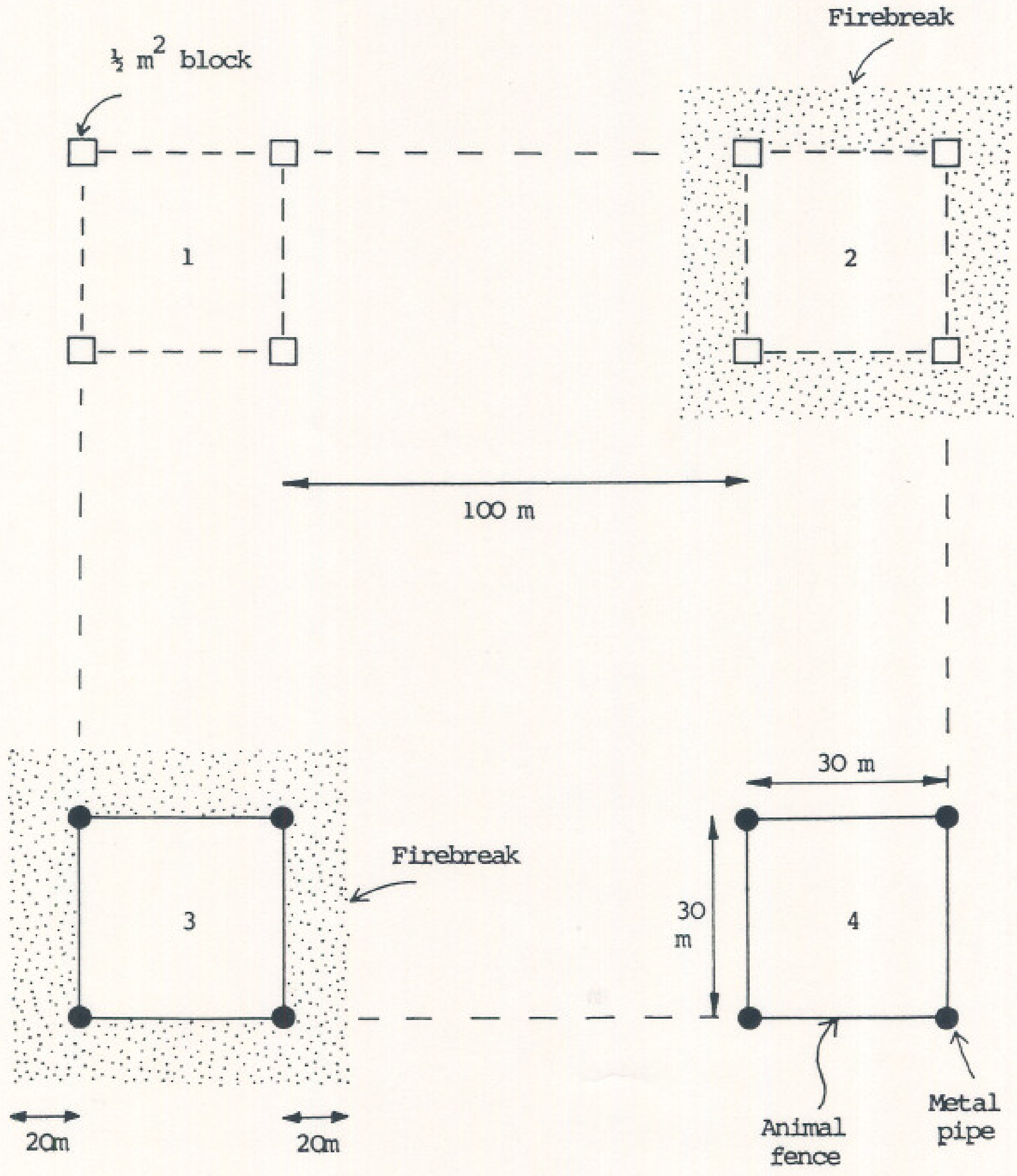
(2) no fire; but animal use allowed (firebreak only)

(3) fire, but no large animal use (fence to exclude large animals; all-metal posts to resist fire)

(4) no fire; no large animal use (firebreak plus fence).

This type of experimental design was set up, for example, in the Serengeti National Park. A plan of one of these plots is shown in Fig. 8. In such plots the animal fences should be about 3 metres high, constructed of diamond mesh and heavy gauge steel wire supported on 10 cms diameter metal pipes. If there is a high density of elephants both a ditch and a fence will be needed. This is the case, for example, in the Ruwenzori National Park where

FIG. 8 Diagram of experimental plot design (after H. Lamprey, unpublished).



enclosed plots were set up to study the effects of hippopotamus grazing [58]

The herb layer within the sub-plots should be recorded at regular intervals (say once a year). Sampling methods have already been mentioned above. As with untreated plots, the sub-plots may also be photographed from the air.

Although this type of experimental plot can yield much interesting information, they are expensive to erect. So great care should be exercised in their placement, priority being given to critical areas where rapid ecological change is suspected. Once set up, a clear set of recording instructions must be put on file for subsequent workers to follow.

If justified, more complicated experimental designs may be used. For instance, those incorporating early and late burning treatments conducted both annually and at longer intervals (e.g. every second year) [87]

7.2 The grassland as a food supply to herbivores

(i) Grass greenness (see also Handbook 2) [97]

Subjective assessments of grass greenness (being related to grass leaf phenology) can be carried out by following a grading system, such as :

Grade 1	0 - 25% green
Grade 2	25 - 50% green
Grade 3	50 - 75% green
Grade 4	75 - 100% green.

These observations can be made from sample points on the ground (e.g. at the rain gauge stations) or from the air, preferably systematically over the ecosystem. 'Greenness' maps can thus be prepared for each month of the year; these can then be matched up with rainfall contour maps or with animal movement maps, for example.

Greenness ratings can also be obtained from colour or infrared aerial photographs. Colour infrared photographs are the most suitable for this purpose as they show the best tonal contrasts that reflect 'greenness'. Problems of infrared photography have already been mentioned (Section 3.3). In addition, there is the problem of calibrating the photographs. The tonal qualities of infrared pictures are modified by light intensity, which is affected by cloud cover, sun angle, and time of day. If infrared photography is used it must be performed under standard lighting conditions (e.g. clear sky; 0900 hrs). Care must also be taken to use fresh film and to develop it under standard conditions.

Infrared aerial photography, therefore, has a number of practical difficulties for monitoring purposes.

An alternative approach for large ecosystems is to order infrared colour composites produced from the LANDSAT data, which refer to a fixed time of day (1000 hrs) (Section 3.5). These composites are developed according to a standard colour spectrum. If a chronological sequence of these images can be obtained covering the ecosystem in question the seasonal greenness patterns can be followed quite well. On these infrared images greenness can be graded as follows :

COLOUR TONE	INTERPRETATION
Grade 0 : blue/brown	no or little green grass
Grade 1 : brown/yellow	mainly dry material, but some green
Grade 2 : yellow/orange	perhaps 50 : 50 dead to green material
Grade 3 : orange/red	mainly green
Grade 4 : bright red	totally green

Ground checks must be made in order to verify, or modify as necessary, the grades assigned on the basis of the satellite images.

(ii) Grass height (see Handbook No. 2) [97]

A crude method is simply to classify grasslands as to whether they are short, medium or long. However, a more quantitative approach is desirable. Grass height has to be measured on the ground, although one can assess grass height roughly from a low-flying aircraft. Each grass community should be sampled, on a systematic or random design, for height of the herb layer. The results for each grass community can then be expressed as a mean height, plus or minus the standard error. A quick way of measuring the height of the herb layer is to 'float' a standard square of polystyrene board (say 25 x 25 x 2 cm thick) on top of the herb layer, then to measure its height above the ground [91]. This helps remove the irregular effects on grass height caused by odd culms standing well above the majority of the herb layer. To make data comparable, the measurements should be made at a particular stage, or stages, in the growing season.

As mentioned in Handbook No. 2, from a combination of measurements of grass height and cover, estimates of grass biomass can be derived (i.e. green and brown biomass) [97].

(iii) Green biomass by spectro-radiometry

A rapid method of measuring the green biomass of plants is now available [89]. The method is based on the reflectance properties of green and non-green plant material. Green, chlorophyll-containing tissues reflect infrared light and absorb red light; conversely, dead, non-green material does not reflect infrared but does reflect red light. Thus the ratio of infrared to red reflected light is related to the quantity of green plant material in a given area. Use of the ratio is important, since the reflectance values of the light bands are affected by several factors (i.e. cloud cover, sun angle, time of day), whereas the ratio stays fairly constant under most conditions, except when heavy cloud cover is present or when soil colour changes.

By using a spectro-radiometer, fitted with suitable probes for receiving infrared and red light, one can obtain instantaneous measurements for any grass community. The measurements then have to be calibrated against actual clip-plot harvest figures for green material, results usually being expressed in gms per square metre. This has been done in the Serengeti National Park where a very close, linear relationship is found between the reflectance ratio and the amount of green plant material actually harvested and weighed. Therefore, once the instrument is calibrated, one may predict with a high degree of certainty the green plant biomass in a defined area. Readings can be made from the ground (at standard height) or from the air (again at standard height). The instrument itself weighs less than one kg.

Very similar data, but on a broad scale, are provided by the LANDSAT programme; that is, the ratio of spectral band 7 over band 5. However, at present it is not straightforward to isolate these data from the magnetic tapes for particular grid cells of a map. It can be done but special computer techniques must be used.

Green biomass values for a particular month may be plotted on a map from which a contour map can be prepared, as with rainfall data. In the Serengeti National Park it has been found that such a contour map can be prepared from a minimum of about 100 aerial sample points spread over the ecosystem (30,000 km^2).

If both green biomass and grass height data are available the former divided by the latter gives an index of 'green biomass concentration', this having particular relevance to grazing herbivores and their distributions at any one time.

(iv) Productivity

Methods of measuring the primary production of grassland are dealt with in a recent handbook [60]. The usual technique is to establish a series of small exclosure plots that are moved at short time intervals, say once a month. This method enables one to measure the effects on grassland productivity of three treatments, namely :

(1) animal grazing (outside exclosure)

(2) artificial clipping (inside exclosure)

(3) no large animal use (inside exclosure).

These treatments may be complicated by grass removal through fire or through small herbivores (e.g. rodents and insects). Plant biomass is weighed by harvesting and then sorting into components (e.g. grass, sedge, dicot; leaf, sheath, stem, inflorescence) [39]. However, use of a spectroradiometer provides a rapid way of estimating green biomass alone.

(v) Structure

The structure of the herb layer is highly dynamic, being affected by seasonal climatic changes, grazing pressure and fire. Since the structure of the herb layer has a major effect on the food available to herbivores [6], it is important to measure it *in situ*, although some information on structure may be obtained from the harvesting data (see above). The structure of an unharvested herb layer may be measured by an inclined point, canopy intercept sampling method [94], or by a vertically-oriented, canopy intercept sampling method [39]. 'Hits' are recorded, at various heights above ground, being classified according to leaf, stem, sheath, or inflorescence. These data may be presented as frequency histograms on a vertical scale.

(vi) Chemical composition

The effect of chemical composition of the plant food on herbivore nutrition and productivity is a complex subject beyond the scope of this Handbook. Chemical composition is linked with plant structure, as the valuable components to herbivores are usually concentrated in the leaves. Standard chemical analyses of the parts of plants only give limited information on the food value to herbivores. The real value can only be gauged by feeding trials on captive animals. This is because chemical analyses alone give no clue as to the availability of plant nutrients to the herbivores. For example, certain plants are known to contain substances that inhibit digestion in the herbivore.

SECTION 8 FIRE

Since fire is one of the principal agents of grassland and woodland change it is important to document its occurrence [22,42,51,55,68,95]. For monitoring purposes, a monthly fire map should be prepared for the whole ecosystem. For large areas this can only be done effectively from the air. One system is to fly systematically over the ecosystem in those months when burning of the grassland is possible; the burnt areas are then shaded in on a map. A master map for each year can be prepared, each month's burning pattern being shown by a different colour shading. These data may then be transferred to a grid map, showing burnt and unburnt cells per year (Fig. 9).

The same data may be obtained from satellite imagery if regular coverage is possible.

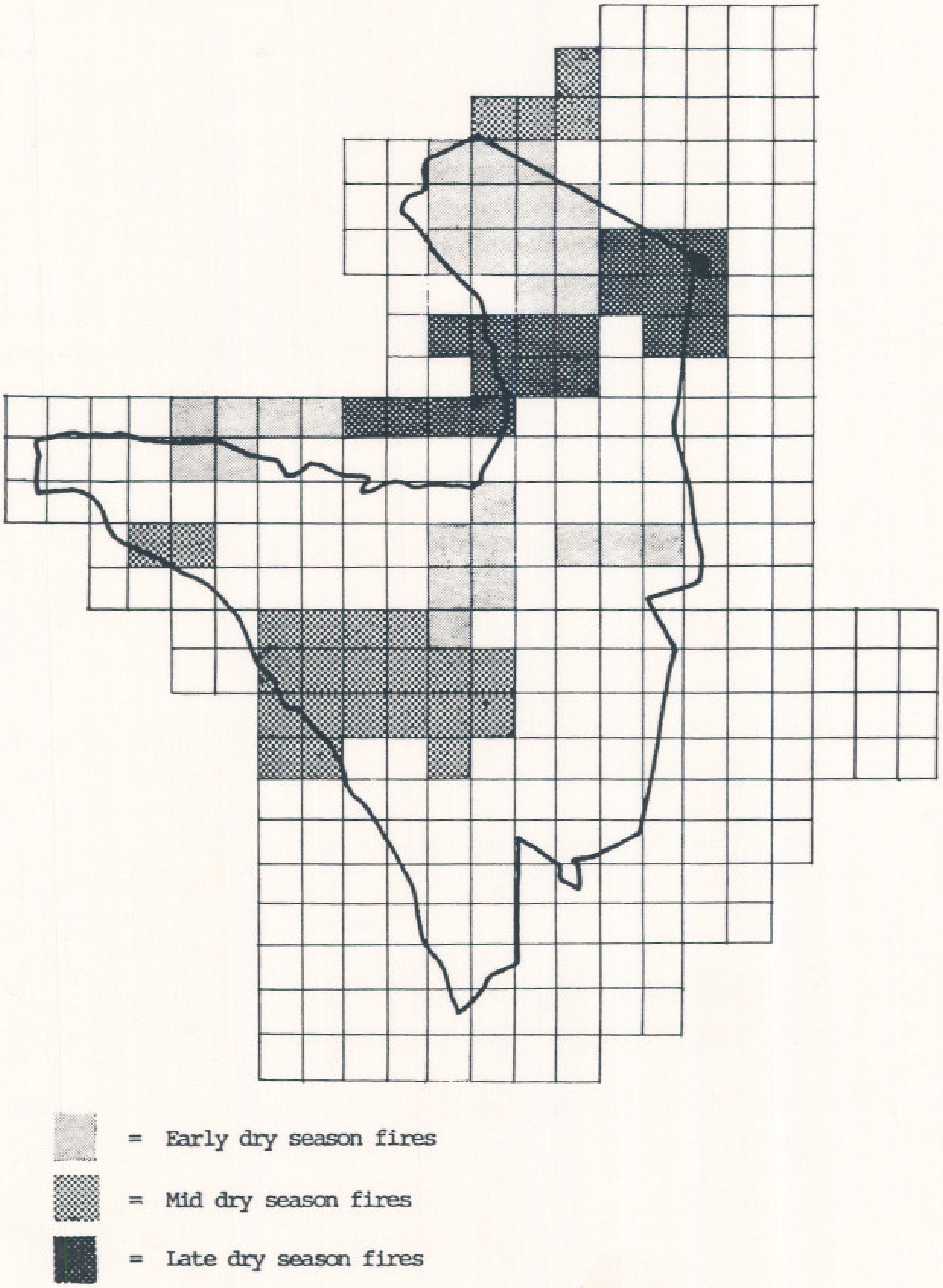
In this way one can follow the extent of burning from one year to another. Also, the proportions of early, medium and late burns may be calculated, as these have different relative impacts on the vegetation.

Trends in the extent of burning can be followed by measuring the areas burnt each year off a map and then plotting the results against time.

A significant positive correlation is often found between wet season rainfall and the extent of burning in the dry season, being due to the fact that with greater rainfall more grass fuel is accumulated. The nature of this relationship will be indicated by plotting annual records of total wet season rainfall against the area burnt. Information of this kind may be useful in planning a controlled burning programme; that is, in high rainfall years extra effort may be needed to control wild fires in the dry season.

Another important factor affecting the extent of grass fires is the density of grazing animals; the greater the density of these, the less grass will be available to burn in the dry seasons. This can be investigated by comparing the annual records of the area burnt with information on trends in herbivore abundance and in grass height.

FIG. 9 Example of a fire map, showing extent of annual burning (10 x 10 km grid)



SECTION 9 WOODLAND DYNAMICS

As with grasslands, woodland communities are characteristically in a state of flux, being chiefly influenced by climate, man, fire and elephants.

Woodlands may be monitored on a broad scale, based on an index of canopy cover but may also be monitored on a more detailed scale, in which tree species composition, density, size structure and population dynamics are documented.

9.1 Measurement of canopy cover change

This can be done from vertical aerial photographs, using two or more sets of photographs of the same area taken at different times. Often it is possible to obtain such a series from a government survey department. This is always the first step. However, it may be that such a series does not exist or, if it does, is of such poor quality as to be unusable. In that case one has to make one's own aerial photographs (see below).

Assuming that two sets of aerial photographs, separated by a few years, are available, then the following procedure may be adopted :

(1) Using a vegetation map, stratify the woodlands into main types; e.g. forest, open woodland, riverine thicket, bushland. Each woodland type can then be sampled separately.

(2) In most cases sampling can be carried out efficiently using a point sampling method. One such system is to use a systematic dot grid printed on transparent (acetate) photographic paper. The dots are arranged in a 10 x 10 square grid, giving a total of 100 sampling points. Such grids are prepared first by drawing out a large scale grid, making sure that the dots are very small; then the grid is photographed using copy film (low ASA rating); finally, the photographic negative is projected onto graphic arts paper to the size required, the end product being a transparent overlay. The advantage of this method is that many grids can easily be produced in a range of convenient sizes.

(3) The next step is to choose a grid size appropriate to the scale of photographs being used, the object being to cover the

central area of a 10 x 10" contact print. For example, 1 : 30,000 scale photographs need an inter-dot spacing of about 2 mm. However, it may well be that the different aerial coverages differ in scale; in this case, the dot grid must cover the same area on the photographs of different scale. If a 2 mm spaced dot grid suits 1 : 30,000 photographs, then for comparison, a 1 mm dot grid is required for 1 : 60,000 photographs.

(4) Having selected a suitable dot grid size (or sizes), one then carries out a photograph-by-photograph comparison of the different time series. If two sets are compared, then the photo-centres of the earlier series (t_0) are compared with the same ground points in the later series (t_1). It is usually quite easy to re-locate matching ground points. Photo-centres are preferred because distortion is minimised.

(5) An index of canopy cover is then measured from the dot grid. One simply counts (preferably using a stereoscope) all those dots in the 10 x 10 grid that hit woody vegetation. A separate score is made for each main vegetation type, care being taken that the dot grid covers only one type at a time.

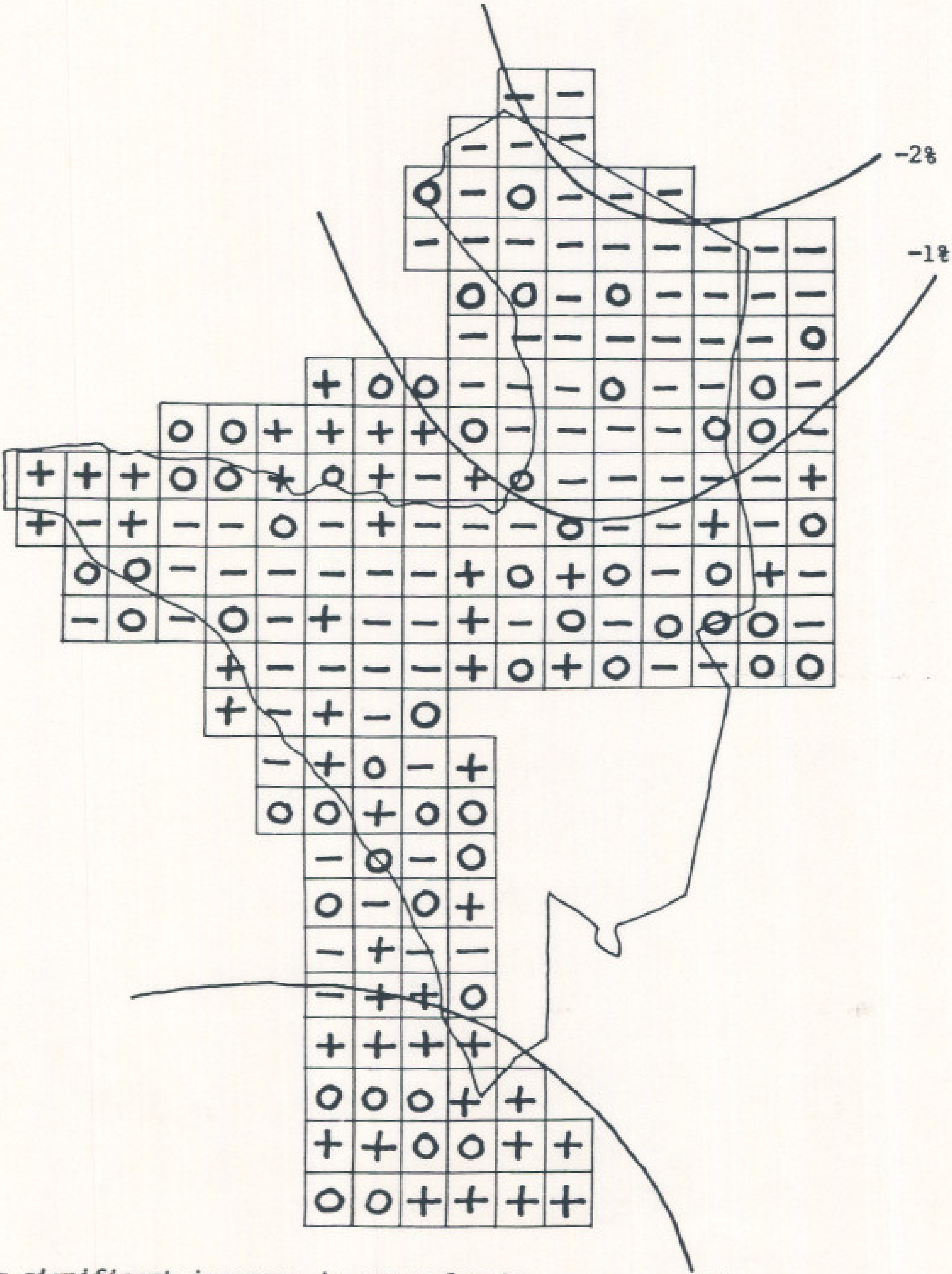
(6) For analysis of possible change, several (e.g. 5) dot counts should be made at each sample point. The dot grid is shifted at random around the photo-centre until the required number of counts have been made. A mean canopy cover index is then obtained for each photograph at t_0 and at t_1. Matching sample points can then be compared using the Student's t-test [4] to see whether there has been a significant change or not.

(7) Finally, the results may be presented in map form, indicating which points show no significant change in the time interval, and which show significant change (positive or negative). Rates of annual change may also be estimated; these can be shown as contour maps. Examples of this type of presentation, for the Serengeti ecosystem, are given in Fig. 10.

If one is to carry out one's own aerial survey for woodland change the following sample design should be effective [62]:

(1) As before, stratify the ecosystem into the main woodland types with the help of a landscape map, if available.

FIG. 10 Woodland canopy cover change in the Serengeti ecosystem, between 1962 and 1972, assessed by comparing percentage cover at photocentres. Isolines show rates of change per year. (10 x 10 km grid) (After M. Norton-Griffiths, unpublished.)



+ = significant increase in cover density

o = no significant change in cover density

− = significant decrease in cover density

(probability = 0.05)

(2) Sample according to woodland (or landscape) regions. Within each region, locate several study areas, typical of the area, which can be located from the air.

(3) Within each study area, fly systematic transects across the area taking vertical photographs at fixed intervals of time. Large scale photography should give good results; that is, at scales of 1 : 3,000 to 1 : 5,000 (e.g. scale of 1 : 4,500 produced by flying at 800 feet above ground, using a 55 mm lens).

(4) At each sample point take 5 overlapping frames; the photo-centres of each of these can later be measured with a dot grid. Thus for each sample point a mean canopy cover index may be calculated for particular woodland types.

(5) From these data, an overall mean canopy cover index may be calculated for each study area and for each woodland type. Changes over time between the same study areas can again be tested with the Student's t-test.

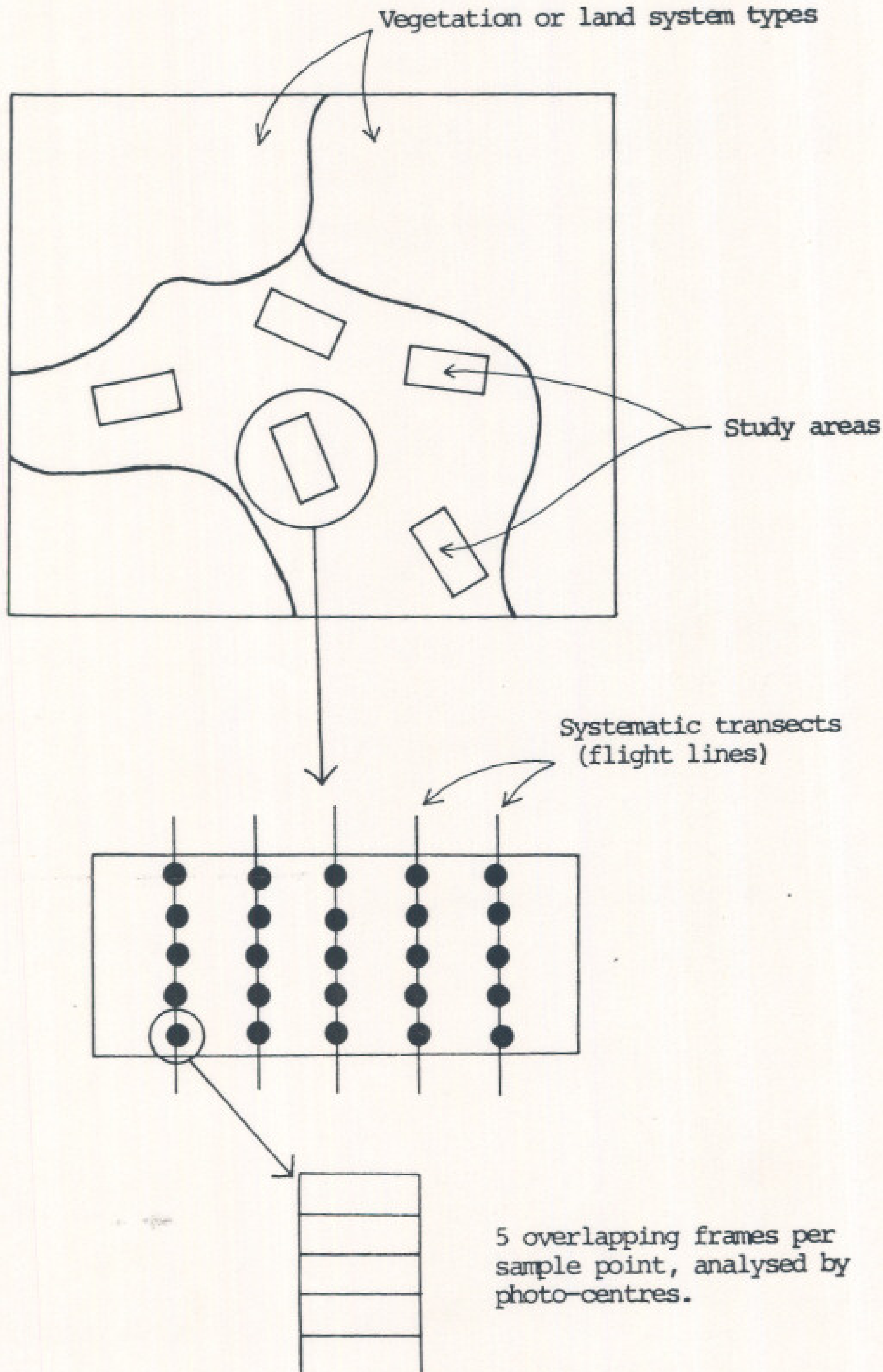
A diagram of this sampling design is shown in Fig. 11. The actual sizes of the study areas and the sampling frequency will depend on the size of the ecosystem, the distribution of woody vegetation and on the amount of aerial photographic cover that can be afforded. However, an advantage of this design is that exact ground points do not have to be re-located, since this is technically difficult to achieve without resorting to total coverage.

Total coverage is practical for small areas but is otherwise very costly, both in time and money. For small areas, sample points may be re-located from large scale, total photographic coverages. At these points actual counts of trees can be made and compared over an interval of time. This method has been used to follow woodland changes in a small part of the Serengeti National Park [30].

9.2 More detailed measurements of woodland change

It may not be enough to know that canopy cover is changing; accompanying changes in species composition and in size (age) structure may also be occurring. For determining these statistics some kind of ground sampling method is needed. However, aerial photographic techniques may still be of use. For instance, vertical colour

FIG. 11 Woodland sampling design [62].



photographs of canopy cover can be used to determine species composition. Different tree species, when in leaf, often show up as distinct colour tones from the air. A striking example of this is *Miombo* woodland at certain times of the year. But, of course, ground checks have to be made in order to calibrate the colour photographs.

A useful ground sampling method for woodland is the Point Centre Quarter (PCQ) technique. Descriptions of this method are given elsewhere [28,30]. It seems to be an efficient and accurate method of sampling provided the trees are not too clumped in their distribution. The PCQ method can be used to give many different kinds of data, some of which are listed below :

(1) tree species composition
(2) data for mapping woody species
(3) tree density (usually per hectare)
(4) relative densities for particular species
(5) tree size (age) structure; both tree heights and diameters
(6) size (age) data for trees in various classes (e.g. < 1 m; > 1 m)
(7) animal impact (e.g. elephant), or fire damage classes
(8) frequency of disease, or parasites
(9) frequency of old, dead, or nearly dead trees
(10) frequency of mature trees with seed
(11) leaf phenology classes
(12) crown diameters
(13) terrain type (e.g. valley bottom, hill slope, hill top) on which tree is growing.

Some kind of stratified sampling design using study areas typical of the stratum should be aimed at, as already mentioned in the previous section.

The PCQ technique may also be used to sample treated or untreated plots such as have already been described in Section 7. However, untreated woodland plots should be larger than grassland plots (e.g. 80 x 120 m). Such plots may also be analysed by low-level, large scale photography but this will yield less information than the potential information available from the PCQ method.

The population dynamics of woodlands in Africa seems to have been little studied. But as with animal populations (Section 10) it is useful to know whether a tree population is stationary, increasing or decreasing. Some observations have been made on tree regeneration, recruitment and replacement [90]; but in *Acacia* woodlands, at least, analysis is complicated by the probable existence of cycles in the growth of tree populations, which result in clumped distributions of even-aged stands. However, if sampling is carried out on a sufficiently wide scale this effect should be minimised. The data should then be analysed according to both the proportions and density of each size (or age) class. If, for example, both the proportion and the density of the age classes stays much the same over several years, then the population is probably stationary. But if some of the age classes then begin to decline in proportion and density, the population may have begun to decrease. The reverse would be true of an increasing population in which one would expect to see a relatively high proportion of young age classes; although such an age structure by itself does not necessarily indicate an increasing population.

9.3 Panoramic photographic views

Long-term woodland changes may be monitored, in a general way, from wide-angle photographs taken from defined sites and directions in the ecosystem. The photographs are simply repeated at intervals. This method cannot be used for quantitative analysis, however, but is useful for showing gross changes.

SECTION 10 MONITORING ANIMAL POPULATIONS

The monitoring of animal populations can be divided into three main components; namely, numbers, distributions, and condition plus dynamics. These are considered separately below :

10.1 Numbers

The question of how many animals there are in a particular area is often asked by wildlife managers. Counts are especially required for :

(i) Endangered species which may be declining in number

(ii) Relatively abundant species that may be causing habitat change (e.g. elephants in some of the African Parks), possibly justifying a management decision such as to cull a certain proportion of the population

(iii) Species that are being hunted, possibly on sustained yield principles. Here the question is how many hunting permits can be issued

(iv) Species of special importance for tourist viewing.

There is now an extensive literature on the subject of counting animals, a full treatment of the subject being given in Handbook No. 1 [65]. Aerial counting has now become common in East and Southern Africa; but although it is the only feasible way of counting animals in large, relatively open areas, it should not be considered as a refined method. Indeed, the technique is subject to many sources of bias and error.

In a number of cases aerial census is impractical either because the terrain is unsuitable (e.g. thick woodland) or because the cost is too high. In such cases, ground counts (e.g. [46]) or estimates of abundance based on indirect evidence (i.e. mark/recapture, pellets, footprints, etc.) must be employed.

In the case of rare or cryptic species (e.g. some of the cat family or the forest antelopes) standard methods of census do not work. For these types of animals it is probably best to develop a system of individual recognition within defined study areas. Radio-collaring techniques may be useful in some situations (e.g. for leopards [40]). After a period of observation it may be possible to determine the number of animals living in a specified area. Population estimates for the ecosystem can be made if data on population density are collected from several study areas representative of the various habitat types.

The ideal census technique is simple, precise and accurate, but these qualities cannot be maximised in the same experimental design. A distinction must be drawn between a precise population estimate and an accurate one [57]; which type of estimate one selects depends on the aim of the survey. A precise estimate has narrow confidence limits yet the estimate itself may be biased; conversely, an accurate estimate is unbiased but may have wide confidence limits. If one is interested in population trends, then precise, rather than accurate estimates are needed to see if the population has increased, remained stable, or decreased. On the other hand, if for example, a population is to be reduced by culling then it is important to have an accurate estimate before taking management action.

Another decision in animal census is whether to use total or sample counts. In general, sample counts are preferable because both errors and biases are more easily measured and controlled than in total counts. Sample counts are ideal for relatively numerous species that show an even distribution, but are much less suitable for highly aggregated species (e.g. buffaloes) because sampling gives large confidence limits, and hence low precision. In the latter case, total counts may be preferable.

Although considerable attention has been paid to perfecting sampling methods so as to improve precision, the pursuit of accuracy has by comparison been somewhat neglected. Lately, however, a few workers have concentrated on methods of correction of bias in order to give more accurate estimates [21,65].

Analysis and interpretation of census data

Particular attention should be paid to the interpretation of changes in animal numbers, as several factors may combine to give a spurious trend. For instance, misleading results would be obtained if any of the following points were true :

(i) Different fractions of the total population (or sub-population) were counted on successive occasions (e.g. due to seasonal movements of the population).

(ii) The method of counting varied between counts, possibly producing different biases (e.g. total or sample counts).

(iii) The accuracy varied between counts even though the same method was used (e.g. different observers were used in different counts).

(iv) There are seasonal changes in population size owing to a peak of births, so unless counts are conducted at the same time of year misleading results will be obtained.

Even if variability due to the above factors can be kept to a minimum, there remains the sampling error of the population estimate, so that any two censuses cannot be shown to differ statistically if the 95% confidence limits of the population estimates overlap.

A good way of analysing population trends is to plot the data on a graph, preferably using the logarithms of population size [99]. There are several advantages in using a logarithmic plot, namely :

(i) It shows relative change in the population.

(ii) It makes the variation symmetrical and almost normal in distribution.

(iii) It is often necessary in order to show all the data on one graph, particularly if data for different species are plotted together.

(iv) It is useful in the analysis of population dynamics.

An example of this type of plot is shown in Fig. 12 for Serengeti wildebeest, and a further example has been published for lechwe population growth in Zambia [38].

In order to support conclusions on population trends, it is very useful to have independent data on say body condition, age at sexual maturity, pregnancy rates and the first year mortality rate (see below). These parameters should parallel the estimated population rate of increase, but if they do not then further investigation is needed.

10.2 Distributions

The distributions of particular animals, over both space and time, show the total annual and seasonal ranges and whether these ranges are changing with time. Detailed surveys of animal distributions also show the relative use of the range or habitat types; such records have been termed occupance data, being expressed in animals numbers (or percentages of the total population) per unit area per unit time

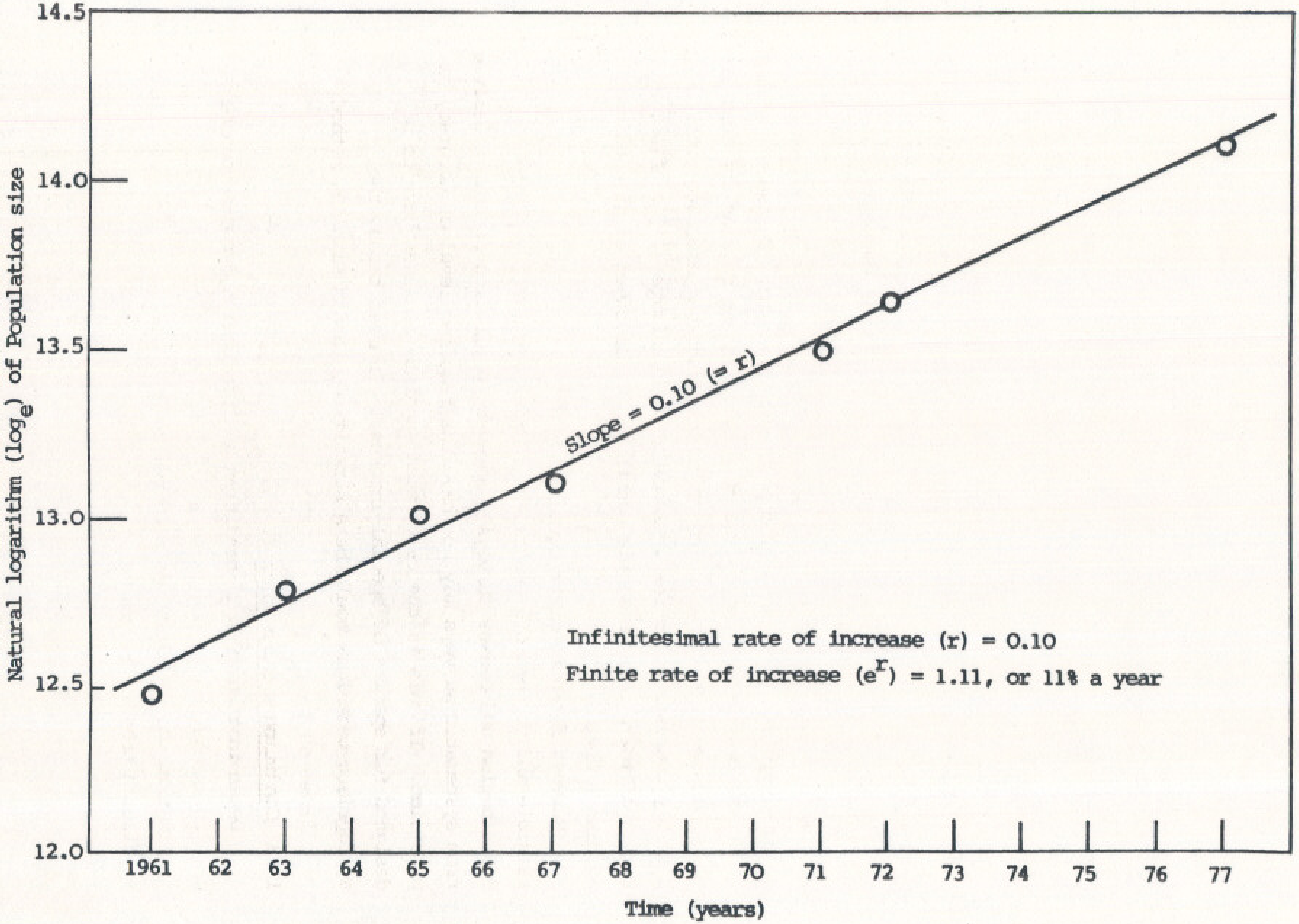


FIG. 12 Population growth of wildebeest in the Serengeti[85] plotted as the natural logarithms of population size against time in years. The average rate of increase is found from the slope of the regression line.

period [34,70].

The object of distribution surveys may be to determine the total annual range of a particular species, or to discover the intensity of use by the species of its range within a wildlife area, or both. Having decided on the survey area, a systematic sample design should be aimed at - except for very small areas where all the animals can be counted. These surveys may be conducted either from the ground or from the air.

Distribution surveys should aim to achieve an unbiased systematic coverage of the area in question. The tendency only to survey areas where one expects to find the animals should be avoided, although if time and money are limited some kind of balance may have to be struck between this approach and the ideal of complete, even coverage.

If possible, data on resources available to animals should be collected at the same time as the animal data. A simplified account of how to carry out such surveys is given in Handbooks No. 1 and No. 2 [65,97]

Records from a systematic sample design may also be used to compute population estimates for particular species. Transects (ground or aerial) may be treated as essentially random as regards the animals being counted, the effect being to give an unbiased estimate while possibly overestimating the variance of the estimate [64,71]. Also, a series of low precision sample counts can be combined to give quite precise estimates [65].

Surveys for both distributions and numbers are therefore quite feasible and may be more economical than carrying out separate distribution and census surveys. However, population estimates derived from systematic surveys may not have the required level of accuracy or precision. If this is the case, then separate censuses have to be designed for species of special interest. In most cases, the appropriate technique would be a stratified, random sampling method.

10.3 Condition and Dynamics

Determination of body condition and population dynamics can be used to assess the potential of a population to increase. Such information should not be used to replace censuses in order to follow population trends, but rather as an adjunct to census data.

For instance, a population that is heavily hunted may be low in number but have a high capacity for increase if the hunting pressure is relaxed. An example of this situation is the black lechwe antelope in Zambia [39]. Conversely, another population may be relatively abundant but in poor condition and declining, perhaps because of adverse habitat change. Examples of this case are red lechwe in Botswana [24] and elephants in Kabalega Falls National Park, Uganda [56]

Body condition of ungulates can be used as a rough measure of the potential rate of increase of a population. For example, in Himalayan thar it was found that the kidney fat index was highest in increasing populations, lower in stable populations, and lower still in declining populations [18]. But of course the use of such a body fat index depends, initially at least, on census data to show the actual rate of population increase.

Some methods of assessing body condition are as follows :

(a) Live animals : The field technique developed by Riney [78,79] has been used by several workers in East Africa. Animals can be classified visually into three or four grades depending on the characteristics of the lumbar region.

(b) Captured animals : The visual method above has the disadvantage that it is subjective, but this disadvantage can be overcome somewhat if a sample of animals can be caught and examined by hand. A condition scoring system can be used based on the criteria given for sheep [80] These criteria (slightly modified) have been used for lechwe antelope [39] The scoring system is based on manual palpation of the anterior lumbar vertebrae.

(c) Shot animals : A common method used for dead animals is the kidney fat index, being calculated as a hundred times the weight of fat surrounding the kidney, divided by the weight of the kidney. However, other indices of condition may be used; for example, those based on bone marrow [86], on mesenteric fat (the omentum), or on muscle weights. Muscle weights standardised against a skeletal measurement (e.g. the length or weight of a limb bone), give a good indication of an animal's condition at the time of death [31]

As regards monitoring the condition of populations, it is essential to compare the same sex at the same period of the year [19]. For instance, it has been found that comparison in Himalayan thar is best made with females of all ages, excluding age one, in the period December to February [18].

Other criteria may be used to assess the condition of the population; for example, mean body weight of one sex at a particular time of year; mean age at sexual maturity; and the pregnancy rate.

As has been suggested, the pregnancy rate in the first mature age group seems to be a sensitive indicator of the condition of the population [48]. As an example, I will quote some figures for lechwe populations in Zambia. The following mean pregnancy rates were recorded in the first mature age-group (yearlings in this case) :

	Pregnancy Rate
1. Stable population (Kafue Flats)[81]	0.36
2. Increasing population (Bangweulu) [39]	0.67
3. Rapidly increasing population (small captive herd) [39]	1.00

The subject of population dynamics will be covered in a subsequent Handbook, so I propose to limit this section to a few aspects that seem relevant to monitoring.

(a) Age Ratios : Age ratios (such as the ratio of juveniles to adults) are sometimes used to judge the 'health' of a population. But it has been shown that age ratios can give ambiguous information without a knowledge of the population rate of increase; and if the latter is available, then age ratios are largely redundant [20].

(b) Age Distributions : As with age ratios, age distributions are often difficult to interpret without information on the population rate of increase [17,22]. They cannot be used to estimate mortality rates between age classes unless the population is known to be stationary and to have a stable age distribution. A change in age distribution over time may indicate a change in population rate of increase, but other alternatives are possible. For instance, if survival rates were to change proportionately in all age classes then the age distribution would not change, but the population rate of increase would [26]. However, an age distribution showing a high proportion of old age classes is suggestive of a declining population - as for example in the elephants of Kabalega Falls National Park, Uganda [56].

(c) Estimates of Mortality : Mortality rates are difficult to measure accurately in wild populations, except perhaps in very small restricted populations where all the individuals are known and can be accounted for.

Adult mortality is particularly difficult to measure. Estimates can be made from life tables based on the age distribution of deaths or survivors, but as mentioned above, the population must be stationary. There are direct methods of measuring mortality - such as recording the number of animals of an original cohort born at the same time still alive at various ages. But this method is rarely practical for long-lived animals in the wild.

In ungulates, a measure of first year mortality often gives an index of the condition of the population. A growing population will probably have a low mortality rate in the first year, while a declining population may have a high mortality in the first year.

A rough way of measuring first year mortality is to sample the population when the young are approximately a year old, expressing the number of young as a proportion of the adult female population. The method is dependent on three conditions, namely :

(i) the season of births is restricted
(ii) the birth rate of adult females is known (e.g. from the pregnancy rate in shot or captive animals)
(iii) the death rate of adult females is known, approximately at least.

This method has been used to estimate first year mortality rates in lechwe [39].

For example, supposing we obtain the following results from an unbiased sample of the population :

500 adult females : 250 young (of about 12 months old).

If we know that each adult female is capable of producing 0.7 young per year, on average, then the recruitment potential is $500 \times 0.7 = 350$ births.

However, an allowance should be made for female mortality over the year; if this is 10% p.a. then the original female population was larger when the young were born, i.e. 10% larger, or 550 in this example.

From an original 550 females we would expect $550 \times 0.7 = 385$ births.

But of those 385 births, 250 have survived the first year; therefore, the first year mortality rate is $\frac{385 - 250}{385} = 35\%$.

Alternatively, the survival rate is 65%, this being the recruitment into the yearling age class.

SECTION 11 HUMAN SETTLEMENT AND DEMOGRAPHY

A study of the human population trends and influences in or around National Parks, Game Reserves or land-use units is fundamental to any monitoring programme. Man-induced effects pervade every aspect of wildlife ecology in Africa through settlement, cultivation, cutting and burning of vegetation, hunting, fishing, grazing and browsing of livestock, and through the parasites and diseases that accompany man and his livestock. Recent human population increase in Africa has greatly exaggerated these long-standing effects.

11.1 National Census data

National Census data will normally be available from the relevant government offices; often summaries, with some analysis of the data can be obtained. If two or more recent censuses have been carried out the data may be analysed for trends. The data can first be analysed according to (a) the population trends for the whole country and (b) for population trends for the district or districts of special interest. It should be noted that National Census data are never completely accurate, being subject to several kinds of errors and biases, depending on the method of enumeration. If the efficiency of enumeration varied between two censuses misleading results could be obtained unless corrected for.

(a) National trends

Trends in population size are normally shown as percentage change per year. Currently, most African countries are showing positive rates of increase, often in the range of 2 - 4% per year [14]. The maximum rate of human population increase is about 5% per year[16], that is of internal growth alone. However, the factors of emigration and immigration have large, local effects on human populations [25,67]. For example, in Zambia there have been high rates of urban growth, chiefly through immigration, while in certain rural areas there has been a decrease of population owing to emigration mainly to urban centers. The overall national trend, however, has been an increase of population, at about 3% per year [45].

(b) Local trends

These changes may be analysed by districts and by enumeration areas. When comparing two or more censuses, care should be taken to see whether the enumeration areas for the censuses match up. Sometimes they do not. In which case several enumeration areas may have to be lumped together in order to analyse changes between censuses. For wildlife areas these local changes are of great importance, so it is necessary that they should be determined as accurately as possible.

11.2 Aerial photographic interpretation

For various reasons the National Census data may be inadequate for monitoring local changes in human population, in which case aerial photographic techniques may be used to estimate the number of dwellings and their distribution, from which population size may be estimated. In addition, one may use aerial photographs to monitor patterns of settlement and cultivation.

(i) Dwellings

In some cases it is possible to photograph all the villages in an area and to plot their distribution accurately on a map. For example, this was possible in the Bangweulu flood plains of northern Zambia where the population is restricted to island and river bank areas [39]. In that case it was a relatively simple matter to photograph all the dwellings in the area from the air, even though the area itself was quite large (13,000 km^2). Photographs were taken with a hand-held camera, fitted with an 80 mm lens, at about 500 feet above ground.

But in other cases it may not be feasible to carry out total photographic counts. For instance, dwellings might be thinly scattered over a very large area. If this was the case, some kind of stratified sampling design would be used. One method would be to fly transects of known strip width and to count the number of dwellings seen. Both method and analysis would be as described in Handbook No. 1 [65]. Alternatively one could define and sample study areas on the same principles as outlined in Section 9.1, on woodland dynamics. In other cases a combination of total counts and sampling might give the best results. Total photographic counts could be used for large villages, while sampling could be used for the more thinly populated areas.

(ii) Population size

Having estimated or counted the number of dwellings in an area one is in a position to estimate the population size provided the mean number of people per dwelling is known (this is often around 4 persons per house). It is important to distinguish dwellings in which people actually live, from other buildings such as shops, schools, offices, clinics, grain stores, churches, etc.

The estimate of mean number of persons per dwelling must be derived from ground sampling. Sometimes these data are available from the National Census. Otherwise one's own sampling has to be done, care being taken that the sampling is carried out randomly. If such a sampling programme is undertaken, permission must first be granted by the chief district officer and secondly by the various village headmen concerned. As inherent in National Censuses, one should beware of false or inaccurate information.

At the same time, data may be collected on the sex and age structure of the population for demographic analysis [12].

(iii) Land-use patterns

By using the same method of dot grid sampling as used for woodlands (Section 9.1), various estimates of land-use may be made. Government survey photographs can be analysed by photo-centres or a sampling area design can be used [7], preferably stratified according to land regions or systems. If pairs of photographs are examined stereoscopically it is possible to classify land-use patterns according to terrain relief. The categories of land-use that can be recognised will depend on the quality of the aerial photographs. However, some of the categories could be as follows :

(1) proportion of settled (houses plus cultivation) to unsettled land, per land region or system;
(2) of the cultivated land, how much falls on the various terrain types (e.g. valley bottom, hill slope, hill top)?
(3) of the cultivated areas, how much is being utilised, and how much is fallow (e.g. the ratio of fallow to utilised area may be an index of soil fertility in a particular region)?
(4) of the unsettled areas, how much land is available for settlement, i.e. excluding rocky, mountainous, swampy, or otherwise unsuitable terrain?

(5) of the available unsettled areas, how much is divided between the usable terrain types?
(6) availability of water.

Ground checks should be made to verify the aerial interpretation. Knowing the rate of change of these land-use patterns (both in time and in space) together with the trends in population size will allow one to forecast the future impact of settlement on particular conservation areas. This should be of use in land-use planning and in the placement, or adjustment, of National Park or Game Reserve boundaries.

These land-use assessments may also make it possible to indicate where land may be more intensively utilised, thus delaying the conflict of intense competition for land in or near a wildlife area.

SECTION 12 CONCLUDING REMARKS

During this century the study of African wildlife has evolved through several stages. Early naturalists were chiefly concerned with naming and describing the fauna and flora, clearly an essential first step. However, by the 1960s this descriptive phase had given way to a more quantitative approach, and a great burst of scientific activity began. University departments expanded and research institutes were established, notably the Uganda Institute of Ecology (formerly the Nuffield Unit of Tropical Animal Ecology), the Serengeti Research Institute in Tanzania, and the Tsavo Research Project in Kenya.

The result of this activity is that we now know quite a lot about the biology of many African species, particularly the large mammals. During the last 20 years the emphasis of research has been directed, and probably still is, towards the study of single species. There has been a tendency for the studies to become more ecological in nature, that is, by attempting to relate the biology and behaviour of a species to its environment.

This process has been carried a stage further by attempts by certain workers to study the interrelationships of several animal species and their environment.

The final step is the study of the entire community of animals and plants in relation to the physical environment of the ecosystem. Such a synthesis would attempt to understand the dynamics of the whole system, as well as the interaction and balance between individual species. If the complete system can be understood in this manner, it would perhaps be possible to predict future changes, and how the system would be affected by management actions and other disturbing influences in or around a conservation area. However, the study of African ecosystems has yet to reach this level of sophistication.

In the absence of reliable prediction, we shall have to depend on ecological monitoring programmes to inform us of the nature and direction of ecological changes. And even if satisfactory predictive models were available, a monitoring programme would still be needed in order to confirm the outcome of events.

This Handbook has given an outline of some of the techniques that are currently available for following ecological changes. Ideally, all the important components of an ecosystem would be monitored. However, a start can always be made by monitoring one or a few major components, such as rainfall, and then incorporating further components into the programme when feasible.

In conclusion, ecological monitoring programmes are necessary for all conservation areas if we are to understand how they are changing over time. Given such knowledge, it has then to be decided what action, if any, to undertake. This will depend on objectives and management plans for the particular conservation area.

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Printed by Afropress Ltd., Lusaka Close, off Lusaka Road, P. O. Box 30502, Nairobi, Kenya