measuring the distribution of animals in relation to the environment

D. Western and J. J. R. Grimsdell

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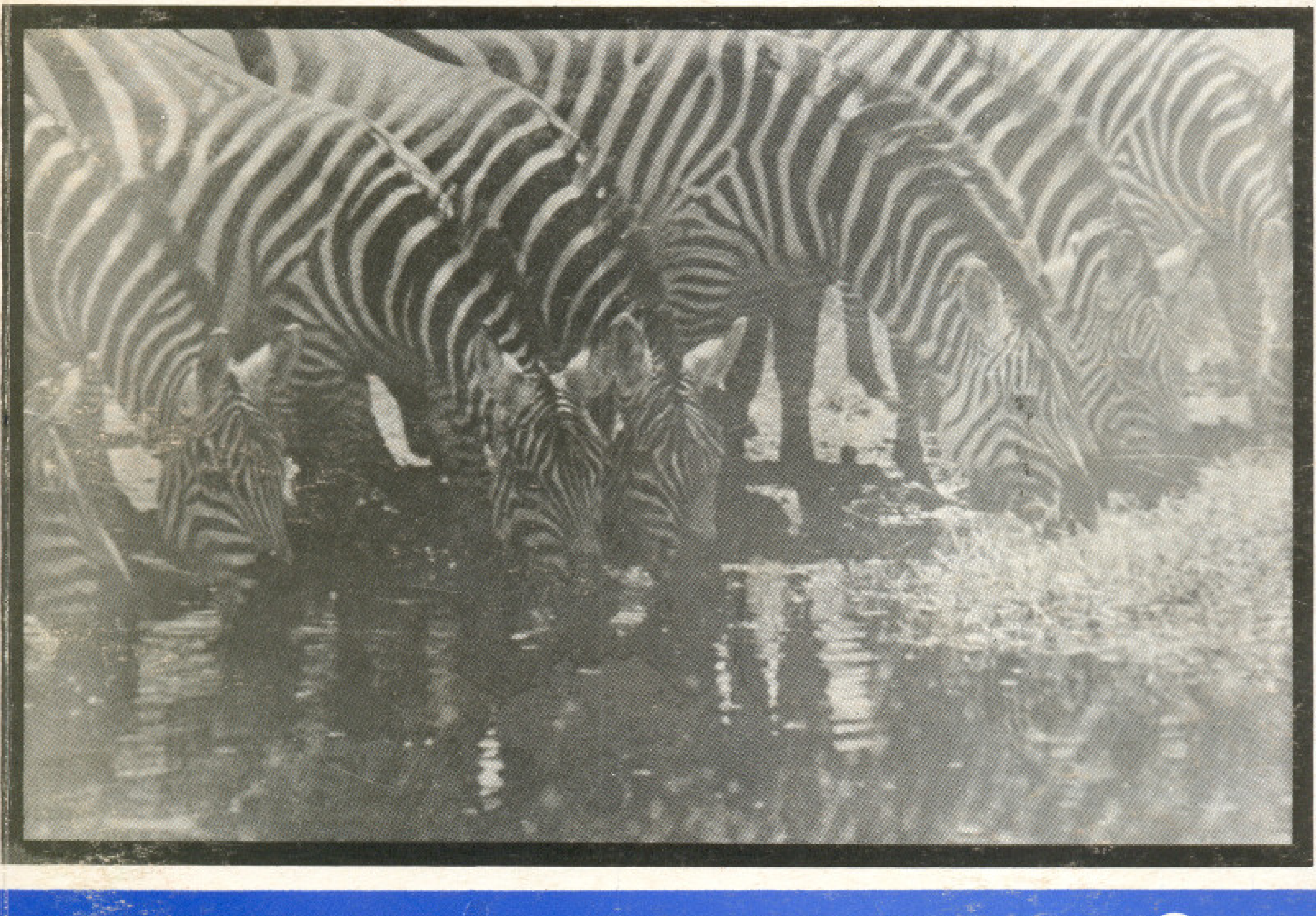

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MEASURING THE DISTRIBUTION OF ANIMALS IN RELATION TO THE ENVIRONMENT

by

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SECTION 1 PREFACE

Why do we need to know how animals distribute themselves in relation to the environment ?

If our objectives are to use wildlife in some way, then we need to know something about its distribution of numbers, how these vary with time or season and what causes such variations. In time, as we build up better information on what controls distributions, it is increasingly possible to predict what will happen to the distributions and numbers of animals under a variety of conditions. Prediction is the basis of good management.

Being in a position to predict makes it possible, for example, to plan the optimum boundaries of a national park or reserve, or to determine which areas to include if we are presented with some constraint on the area available, as is usually the case. This, of course, has relevance both to the conservation and management of individual species and of ecosystems.

Another reason why we need to know why animals distribute themselves the way they do is in order to predict what will happen to a species if we alter some aspect of its environment. This may entail reducing a part of its range, putting in extra water supplies, or starting a livestock development programme.

There are two main aspects of predicting the distribution of animal numbers. The first is resources: what resources are needed for an animal's growth and reproduction (e.g. food, water, cover). The second is what may be termed negative influences; that is, those environmental factors that limit or reduce the growth of populations. Such factors would include lack of forage or water, stressful temperatures, areas of human settlement, and so on; in other words, factors which the animals will try to avoid.

Both the positive and negative environmental influences change over time. Animal distributions will therefore tend to shift too, either to improve access to resources or to avoid increasing hazards. Not all animals can have access to the best resources at the same time, so some are distributed in less favourable areas; but here their density declines until, where conditions are quite unfavourable, there are no animals at all.

We need to know how to measure the distribution of animals in time and space and how these distributions relate to the environment. Ultimately the object is to predict the distribution of animal numbers from a knowledge of environmental factors.

Clearly, these measurements can be made as simple or complex as we have the time and means to achieve. But as neither are unlimited, the level of prediction needs to be related to the purpose for which it will be used.

In the following sections an outline is given of the general principles to be followed in planning distribution surveys; then accounts are given of methods of collecting and analysing data; and finally there is a section on the use of results. It is in this final section that the practical value of distribution surveys can be seen, be it in deciding on the boundaries of a wildlife reserve or in the implementation of a livestock development programme.

SECTION 2 PLANNING A SURVEY

2.1 Introduction

Both the distribution of animal numbers and of resources must be recorded at the same time if the two are to be related. This is the basic requirement, whichever method is used. One could in fact measure animal distributions and then immediately record the availability of resources within different density strata of their range, but this is only possible if the interval is so short that no change occurs between measurements.

Sampling animal distributions and resource availability can be conducted from aircraft, vehicle or on foot and each of these methods have advantages and disadvantages. Some of the possible techniques of each will be examined in due course. For the moment, however, the general principles of sampling for animal and resource distribution will be examined without reference to the method of data collection.

2.2 Animal Distribution

Having made the point that data on animals and resources must be collected more or less simultaneously we can consider how best to measure animal distribution and then look at ways and means of collecting resource data. This is one way of tackling the problem so that the animal information can be used as a basis for recording the availability of resources rather than vice versa, although, as we shall see, both can be useful.

Methods of measuring animal numbers have been outlined in the first Handbook in this series.[30] Both sample and total counts can be used, but here we are less interested in an accurate population estimate than an accurate description of their density distribution in space. It is the variation in density that has to be related to variation in resource distribution. This is not to imply that animal counts and distribution surveys need be independent exercises. In most cases they will be combined in a single count because of the dictates of time and costs, so we must necessarily consider both aspects in such situations.

2.3 Resource Distribution

One method of sampling resources is to use the distribution of animal densities as a basis for defining strata or zones, then recording resource values within each stratum.

An alternative is to select some important aspect of the environment, usually habitat types, and then sample for animal densities within each. This method has been used quite often,[5,22] and is invariably employed where the study area is much smaller than the population or ecosystem range. Since, however, knowledge of the population or ecosystem as a whole is often of particular interest, this approach can be very misleading and should be avoided where possible. At the very least some attempt must be made to assess how representative a so-called cross-section really is.

2.4 Area of Study and Duration

In order to determine the relationship between the distribution of animals and resources both must be studied over a reasonably long period. In large mammals the minimum study of any value is one seasonal cycle, i.e. one wet and one dry season. But to understand more about what governs distributions it is necessary to continue the study through several seasons. If the results are required so urgently that there is only time for a single season of study, then it is essential to try to relate that season to others on the basis of rainfall records and decide how more, or less, extreme seasons would alter the observed pattern.

As with time, so with area; usually the larger the area studied the better. If it is only possible to study a small part of the total area of the population of interest then, once again, some effort should be devoted to deciding which is most representative, or alternatively how the area studied relates to the whole range. Nothing is more wasteful and misleading than a detailed study which is totally atypical of the situation on a larger scale.

2.5 Frequency and resolution of surveys

Both of the above qualities - one relating to time, the other to space - determine the level of detail of the data collection. The intervals between distribution surveys determine the degree of accuracy on a time scale. For example, if only two distribution surveys were carried out in a year, one in the wet season and one in the dry, we could discover something about the wet and dry season ranges of particular species, but could say very little about the timing of the animal movements. If these surveys had been carried out each month it would then be possible to give a fairly accurate account of the timing of the animal movements. At the same time it would be possible to get a much better idea of the average density distribution over the wet and dry seasons.

The question of resolution arises when data are collected according to a sampling system, for example, the grid sampling system (p. 19). If the latter method is used then the accuracy of the distribution data will only be as good as the grid size used. For instance, if a 20 x 20 km grid is used then the animal data are only accurate to the nearest 20 km and therefore can only be correlated with major vegetation zones. Data collected in this way are useful for showing the broad distribution of a species on a large scale. An example of this type of low resolution distribution map is given in Fig. 1, which shows the distribution of Burchel's zebra in the whole of Kenya.

If the animal data are collected at a finer level then it is possible to match the density distributions with particular habitat types, as has been done in Amboseli with a 5 x 5 km. grid (Fig. 2). It would be extremely costly and time-consuming to cover the whole of Kenya at this degree of resolution - so a grid of this size is only practical for relatively small areas (e.g. 1,000 - 10,000 $km.^2$).

At even greater levels of resolution animal distribution data can be correlated with particular plant communities and topography (i.e. the slope of the land). For this level of resolution, 400 x 400 metre and 800 x 800 metre grids have been used.[5, 13] Of course, this type of study is only practical for small areas (e.g. $<$ 500 $km.^2$).

All these levels of resolution give different types of information; the coarsest showing distributions on a broad, geographical scale; the intermediate at the scale of major habitat types; and the finer at the level of the dominant plant species or the local topography.

2.6 Selection of environmental variables

The biggest problem comes in deciding which resources to measure. It is sensible to start off with the obvious variables in the first instance, such as condition of the vegetation and the availability of water. The type of terrain or habitat will often have a great bearing on animal distributions; they will tend to avoid difficult terrain such as rocky and steep hill slopes, deep gulleys, barren expanses or habitats that offer dense cover for predators. So habitat and terrain are other important factors to take into account.

Fig. 1 The distribution of Burchel's zebra in Kenya, based on a 20 x 20 km grid.
Source : Kenya Rangeland Ecological Monitoring Unit; 1977 survey data.

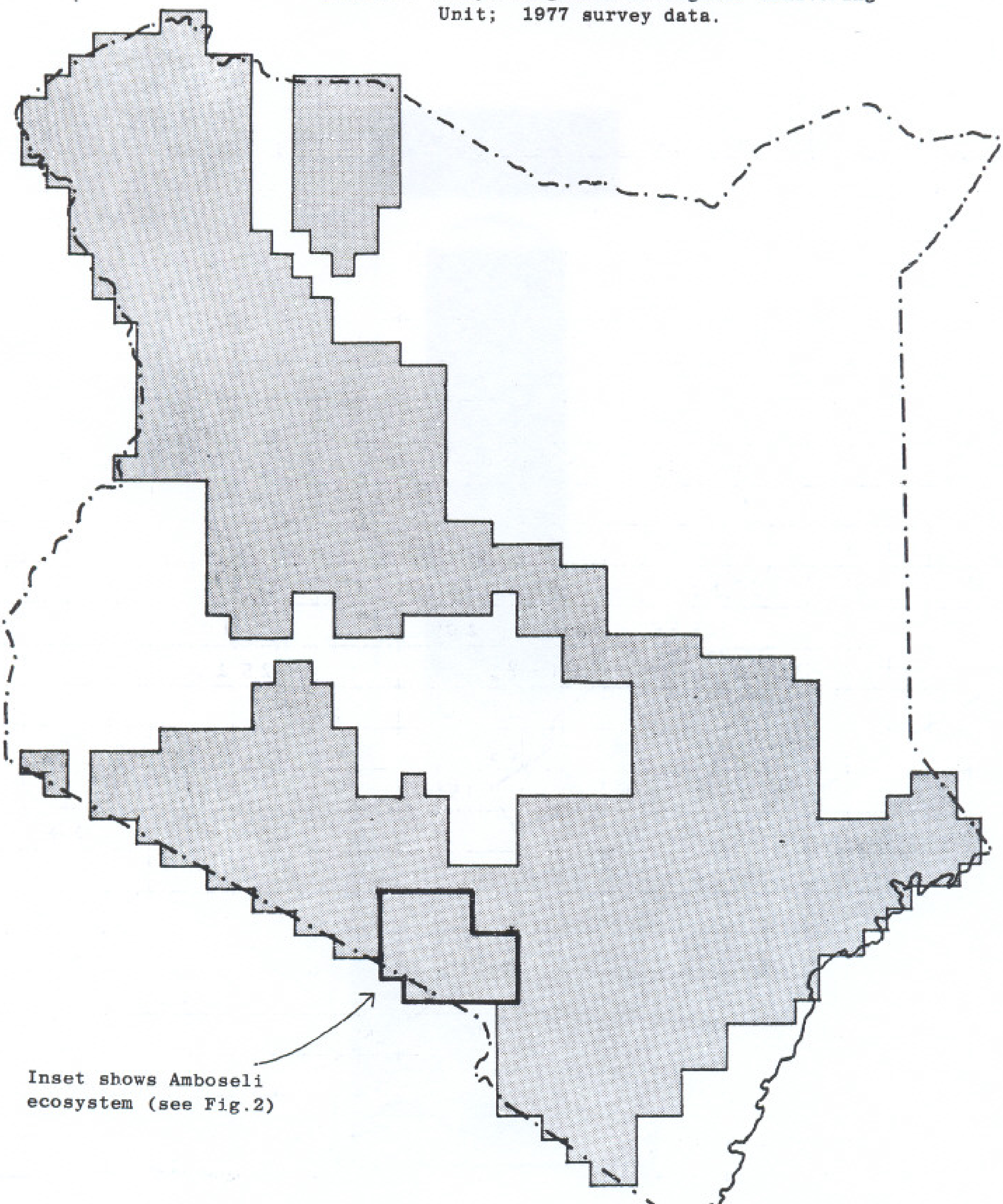
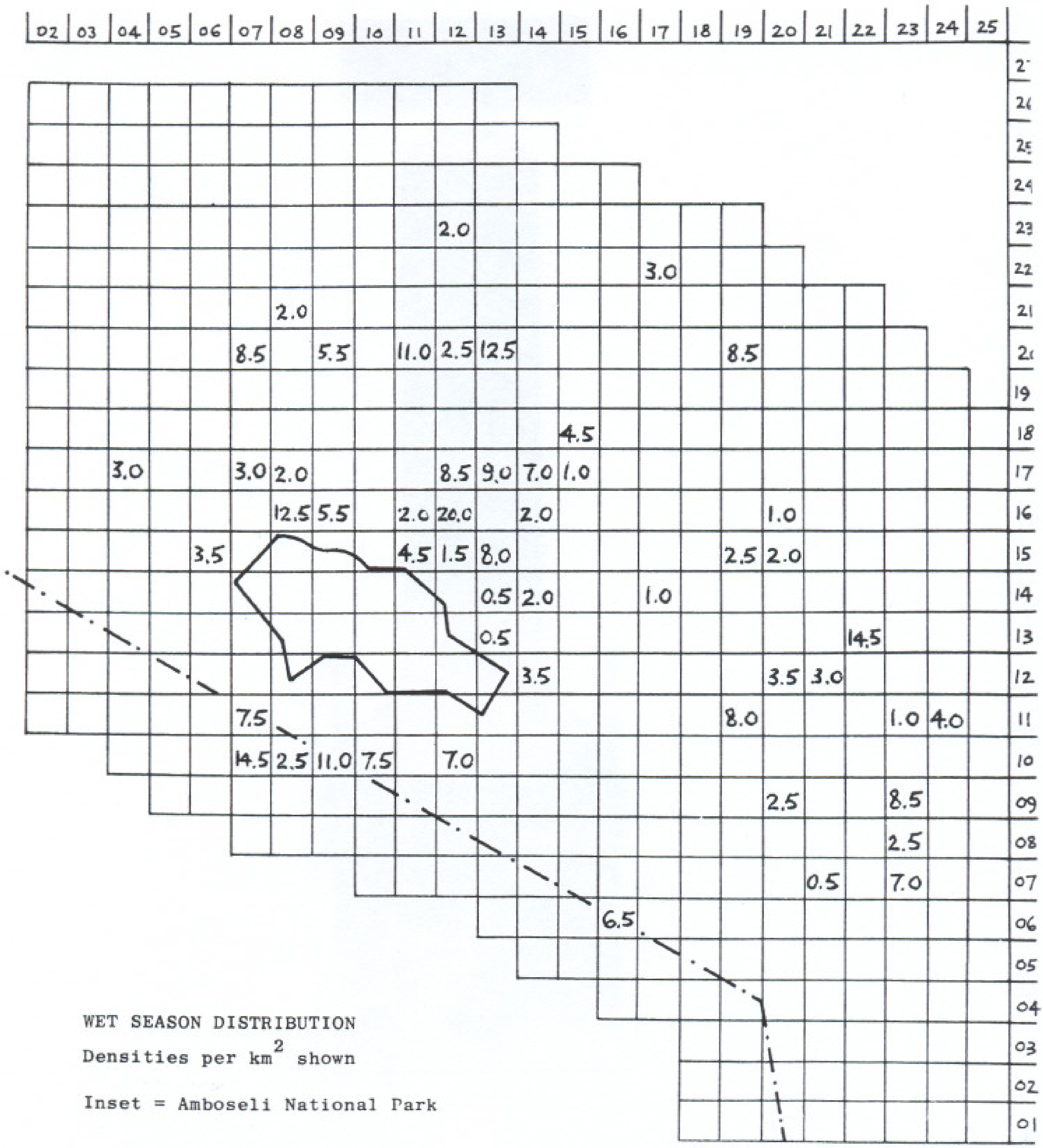


Fig. 2 The distribution of Burchel's zebra in the Amboseli ecosystem, based on a 5 x 5 km grid.



Particularly important are the animal data themselves. Knowledge is required not only on how the animals distribute themselves, but why, and how they respond to varying conditions in the environment. Data on animal activity are therefore very valuable if collected at the same time as the distribution and environmental data are recorded. This will enable us to say whether a species is entering a particular habitat to, for example, feed, drink, or use shade, or all three. Also, by recording age classes birth periods can be determined to see whether these coincide with a specific season or habitat. Animal condition is also useful to record as it tells us whether a species is doing well or poorly under specified conditions.

There are many other variables which will have a greater or lesser influence on animal distributions; salt, shade, presence of human activity and so on. But for the time being the more important variables can be selected and then related to animal distribution. Subsequently, it is possible to find out how much of the distribution can be predicted from these variables. By gradually increasing the number of factors recorded a progressively greater amount of the observed distribution changes can be accounted for.

2.7 Construction of Categories

If animals are to be related to pasture conditions (for example, grass greenness and grass quantity) a suitable description of pasture conditions is needed. Grass can be ranked from newly sprouting to dried out. The number of categories should not be more than can accurately be recorded. At the simplest level only green and dry grass could be recorded, but in practice a larger number of categories can be distinguished. A manageable breakdown is :-

Grass Growth Stage

1) New Shoots
2) Shoots grown, pre-flower
3) Flowering, unripe
4) Flowering, ripe
5) Flower dead/leaves green
6) Leaves 0 - 25% dry
7) Leaves 25 - 50% dry
8) Leaves 50 - 75% dry
9) Leaves 75 - 100% dry

Grass height is more easily evaluated since it can be measured with a rod or ruler. It might be necessary to distinguish between the height of leaves or stems, and the height of flowers, the former usually being more useful.

Height can be divided into an infinite number of measurements but usually the centimetre interval is adequate. Often it is found convenient to construct height classes as follows:-

Category	Grass Height
1	0 - 2 cm
2	2 - 4 cm
3	4 - 8 cm
4	8 - 16 cm
5	16 - 32 cm
6	32 - 66 cm
7	66 + cm

It is usually found that small differences in length are more important in short than long grass, hence the larger units with increasing length. However, it is a good policy to have more units initially and only group these into larger units once the data are available for doing so.

Two further examples can be given of categorising resources. Water should be mapped as completely as possible just before, during, or immediately after an animal count. Unlike grass, even a small pool can make a difference to whether or not animals can survive in an area. But water is not necessarily always available to wildlife, either because the banks of the pool are too steep, or the well has been fenced off. At the other extreme, too much water (for example, flooding) can cause animals to abandon an area. Categories might therefore be constructed as follows:-

Category	Description
1	No water present
2	Present but not available to species x, y.
3	Water available
4	Water-logging
5	Flooding

We would then want to know how far from the nearest available water each animal was since this will tell a great deal about its water dependence.

The final example is habitat. Ideally, the whole area should be mapped and split into habitats. This may be a vegetation map or may include more information, e.g. descriptions of terrain and human settlement. It should be borne in mind that a map giving infinite detail is not necessarily any more useful than a less descriptive one. A habitat covering 1 km^2 in a study area of 2,000 km^2 is fairly meaningless, since even if we sampled monthly at a 20% level, the chances are that we would only sample this habitat one in five times. Habitats should be large enough to ensure that they have a chance of being sampled on each occasion. A typical habitat breakdown might be :-

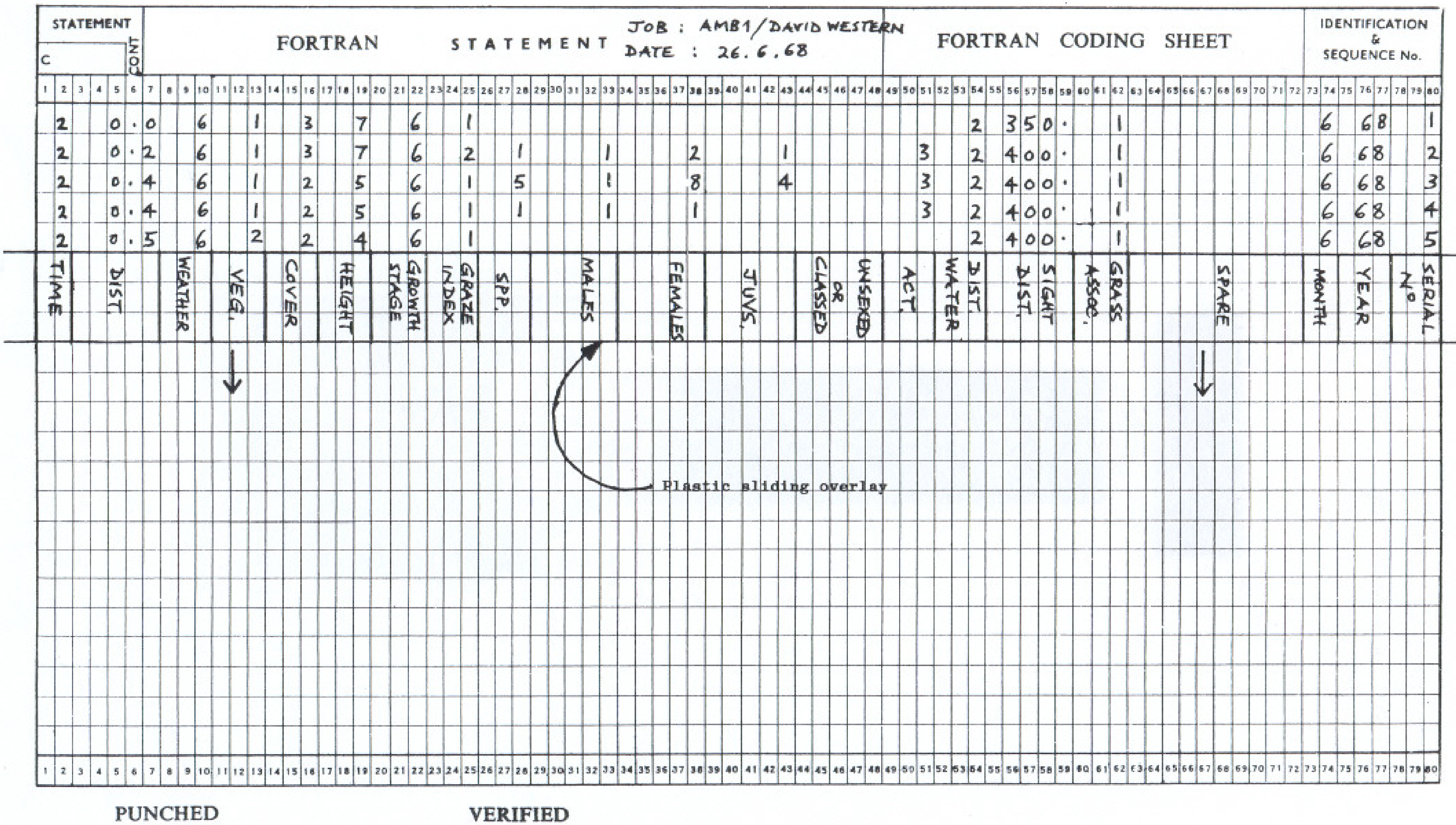
Category	Description
1	Short grass plains
2	Medium grass plains
3	Long grass plains
4	Open woodland
5	Denser woodland
6	Riverine woodland
7	Thicket
8	Forest

2.8 Recording of Data

Data must be recorded conscientiously and systematically and this is why the subject of categories has been mentioned.

A data form must be drawn up so that information can routinely be recorded in the appropriate columns. A typical data form is shown in Figure 3. It will be noted that animal numbers and environmental conditions are recorded for each sample point. An index of the categories used should be available so that the appropriate data can be entered as numbers rather than as a description each time. The real value of categorisation lies in time saving and consistency.

Fig. 3 Records entered on a computer data form



TIME	DIST.	WEATHER	VEG.	COVER	HEIGHT	GROWTH STAGE	GRAZE INDEX	SPP.	MALES	FEMALES	JUVS.	UNSEXED OR CLASSED	ACT.	WATER DIST.	SIGHT DIST.	GRASS ASSOC.	SPARE	MONTH	YEAR	SERIAL No
2	0.0	6	1	3	7	6	1							2	350.	1		6	68	1
2	0.2	6	1	3	7	6	2	1	1	2	1		3	2	400.	1		6	68	2
2	0.4	6	1	2	5	6	1	5	1	8	4		3	2	400.	1		6	68	3
2	0.4	6	1	2	5	6	1	1	1	1			3	2	400.	1		6	68	4
2	0.5	6	2	2	4	6	1							2	400.	1		6	68	5

With a well thought out programme, data can be entered onto computer forms rather than data forms as in Figure 3, a procedure which simplifies the ensuing stage, analysis. But this should not be attempted without first consulting those familiar with computer techniques

SECTION 3 METHODS OF COLLECTING DATA

3.1 General

The main methods that have been used to collect data for relating animal distribution to environmental conditions are from vehicle, aircraft and foot. Each of these has advantages and disadvantages and they are in many respects complementary techniques. Obviously far less ground can be sampled on foot than by aircraft in a given period of time, and therefore aerial techniques are widely employed for large study areas. However, although an aircraft can cover a large area at high speeds, it is only useful for a fairly coarse level of analysis, in that, for example, grazing conditions cannot be recorded at such a fine scale as sampling on foot. Provided the terrain is suitable, a vehicle offers an ideal compromise, since not only can a large area be covered fairly rapidly, but detailed vegetation sampling can be undertaken simultaneously. But, it is not always possible to traverse dense bush or broken terrain with a vehicle and the method is therefore of limited value.

The size of the study area, the type of terrain, the frequency of sampling, and the mobility of animals will all influence the choice of sampling procedures and technique. These aspects are discussed in the first Handbook[30] and need not be expanded here. Instead, some of the uses of aerial and ground counts can be briefly described.

3.2 Ground Counts

In principle there is no difference between the capabilities of vehicle and foot sampling. In both the same sorts of data can be collected with the same resolution. A vehicle is simply used as a mobile platform between sampling points, at which the observer can lean out, or get out, and sample. A vehicle is a useful tool for speeding up the sampling. In situations where a vehicle is not available, foot sampling is the only alternative. In this event the sampling fraction is likely to be much lower and therefore representative habitats may have to be sampled. This method was most successfully used for daily sampling along foot paths across a section of the Tarangire Game Reserve.[22] It has already been pointed out, that where such methods are used, independent checks on the representativeness of the selected sampling units should be undertaken.

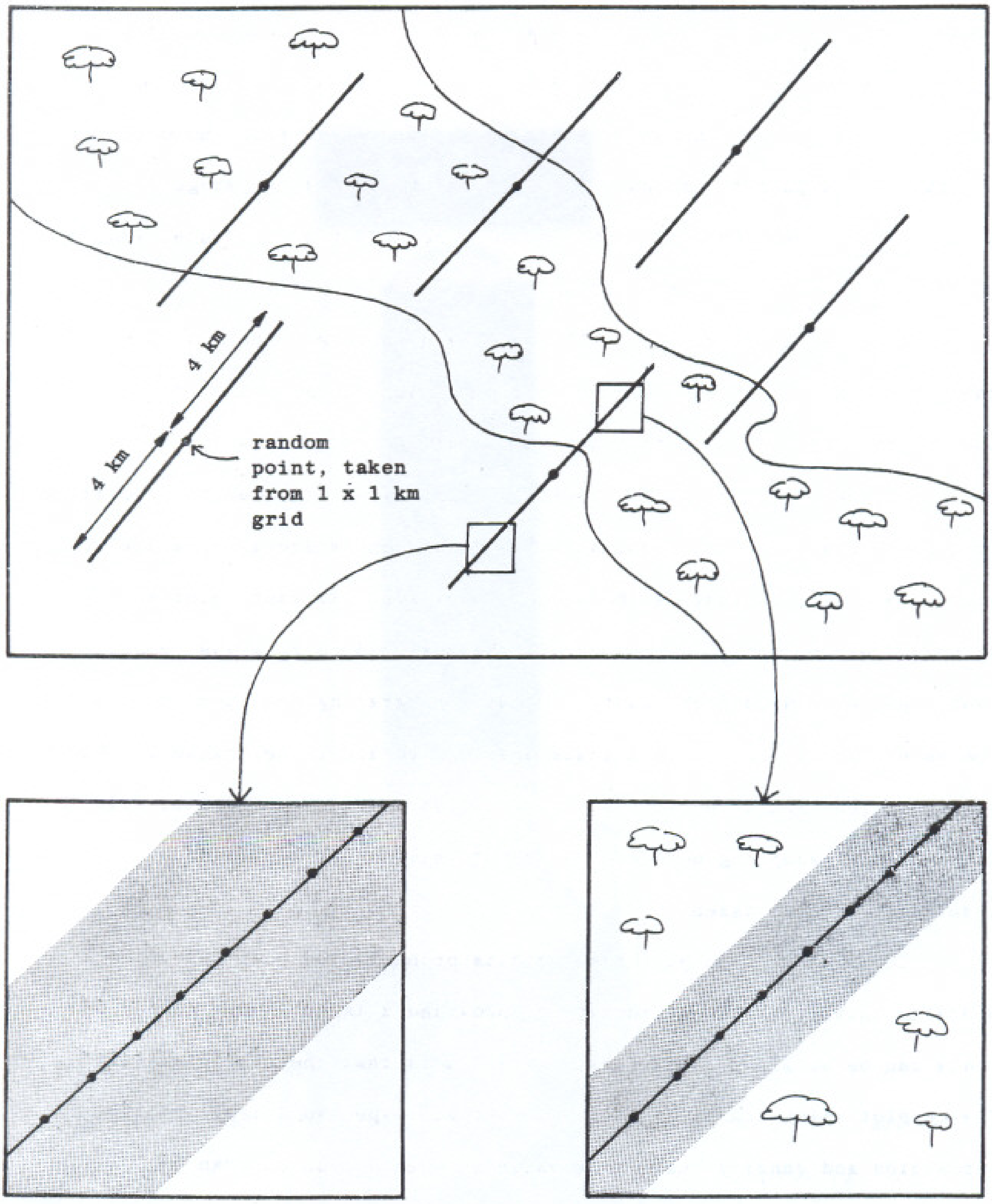
Where vehicles are unable to traverse the terrain, a method frequently adopted is road transecting. Here the roads are used as transects and are taken to be samples of the various habitats they cover. This method has frequently been used [4, 8, 18]. The method does, however, suffer from lack of randomness, although this can be corrected for, provided there is a good road coverage.[30] Once again, independent checks will be needed to test the validity of extrapolating from road count data to the whole area. Other biases may be present, such as the tendency of animals to concentrate near to or away from roads. On the resource side, it is almost inevitable that the road must alter the local drainage patterns and therefore soil moisture balance and plant production, composition and quality.

The basis of relating animals to resources lies in the selection of an appropriate sampling unit. In areas of heterogenous vegetation it may prove extremely difficult to relate animals to the forage that they are actually feeding on. In any event the sampling unit must be small enough to discriminate a range of values for a given variable. For example, if each block sampled includes the range of grass heights being sampled, there is no point in trying to relate animals to grass height, at least at this scale; much smaller blocks would have to be used. For example, blocks of 200 m length and a maximum of 800 m wide have been used [44] in the Amboseli basin where pasture types are fairly uniform (Fig.4). In other areas of diverse pasture type, plots little bigger than the herd size of the animal may have to be used. In this situation it is preferable to relate animals to habitat type or other major resources, and then sample specifically for those which need to be sampled at a much finer scale. In effect, this is a two-stage sampling procedure; that is, sampling for one resource influence, and subsampling within it for the influence of other resources.

Whatever block size is selected, the principle is basically the same. At points along the transect, or plot, samples are taken for resource availability and other environmental factors. These points should be independent of animal locations since when it comes to accounting for density distribution of animals, the conditions where animals are not recorded are as important as those where they are. At each point a variety of environmental variables will be measured, e.g. grass height, cover, species composition, pasture condition, grazing pressure, distance from water, and so on. When animals are located along the transects, their exact position should be recorded. Their distribution can then be related to the nearest sampling point, or alternatively, a new series of measurements can be taken.

The use of fixed plot transects is probably the best method of recording animal/resource information, provided a large enough number of points can be obtained. The reason for this is that the characteristics of each plot which change little, e.g. terrain type, soil type, habitat composition and density, permanent water sources and so on, can be recorded independently of when the animal counts are made. This allows not only greater accuracy in plot description, but means that such data can be handled as constants; that is, if they do not vary appreciably over the study period, then they can be taken as fixed properties. Then,

Fig. 4 Random ground transects, as used in Amboseli.[44]



Wider transect in open country, e.g. 400 m on each side of vehicle; sampling points every 200 m.

Narrower transect in wooded country, e.g. 200 m on each side of vehicle; sampling points every 200 m.

on each sampling occasion, only the variables, those which vary from time to time, need be recorded; e.g. vegetation greenness, cover, height and ephemeral water availability. Furthermore, the variance between sampling occasions can be assessed accurately as the fixed plot provides a series of repetitive samples. But once again, checks must be made to determine whether the plots represent the whole area.

Randomised monthly transects were used to relate animal distributions to environmental factors in the Amboseli basin (see Fig.4)[44] Along each of 25 transects, 8 km long, the observer stopped every 200 m to record a range of environmental variables (Table 1) and in addition stopped each time animals were noted. The activity of the herd and the sex and age composition were also recorded. This particular sampling system proved extremely useful in recording a wide variety of variables simultaneously and exemplifies the usefulness of ground transects under the best conditions - a small ecological unit with open terrain and distinct habitat and pasture types, running unidirectionally across the study area.

3.3 Aerial Counts

Aerial counts used in the same Amboseli study area show the limitations of aerial compared with ground counts. Detailed data on pasture conditions which largely dictated animal distributions could obviously not be measured. Ideally, aerial monitoring programmes are suited to large and inaccessible areas and are useful in giving first indications of what variables to look at in detail on the ground.

The Serengeti Ecological Monitoring Programme relied initially on systematic aerial flights to locate animal distributions within an area of some 30,000 km^2, and to indicate the sorts of conditions that they were associated with, e.g. grass greenness, water availability and burning[33].

TABLE 1

Computer codes for ground counts used in Amboseli ecosystem survey

TIME

1)		- 07.59
2)	08.00	- 08.59
3)	09.00	- 09.59
4)	10.00	- 10.59
5)	11.00	- 11.59
6)	12.00	- 12.59
7)	13.00	- 13.59
8)	14.00	- 14.59
9)	15.00	- 15.59
10)	16.00	- 16.59
11)	17.00	- 17.59
12)	18.00	- 18.59

WEATHER

1)	$> 30^{\circ}C$	cloud cover	$0 - 1/3$
2)	"	" "	$1/3 - 2/3$
3)	"	" "	$2/3$ - full
4)	$21 - 30^{\circ}C$	" "	$0 - 1/3$
5)	"	" "	$1/3 - 2/3$
6)	"	" "	$2/3$ - full
7)	$< 21^{\circ}C$	" "	$0 - 1/3$
8)	"	" "	$1/3 - 2/3$
9)	"	" "	$2/3$ - full
10)	Rain		

DISTANCE (along transect)

Direct from trip speedo

Vegetation Zone

1) plains
2) lakebed
3) bushland
4) swamp
5) open bushland
6) open woodland
7) denser woodland

DISTANCE FROM WATER

1)	0 - 2 km
2)	2 - 4 km
3)	4 - 6 km
4)	6 - 8 km
5)	8 - 10 km
6)	10 - 12 km
7)	12 - 14 km
8)	14 - 16 km
9)	16 - 18 km
10)	18 - 20 km

Grass Height

1)	< 10 mm
2)	10 - 20 mm
3)	20 - 30 mm
4)	30 - 50 mm
5)	50 - 70 mm
6)	70 - 100 mm
7)	100 - 150 mm
8)	150 - 200 mm
9)	200 - 250 mm
10)	300 - 500 mm
11)	> 500 mm

Grass Growth Stage

1) New shoots
2) Shoots grown, pre-flower
3) Flowering, unripe
4) Flowering, ripe
5) Flower dead/ leaves green
6) Leaves 0 - 25% dry
7) Leaves 25 - 50% dry
8) Leaves 50 - 75% dry
9) Leaves 75 - 100% dry

Level Grazed

1) No graze
2) Top of leaves/ flower
3) Middle leaf
4) Lower leaf
5) Stem

Grass Cover

1) > 75%
2) 50 - 75%
3) 25 - 50%
4) 1 - 25%
5) 0%

Animal Species

1) Zebra
2) Wildebeest
3) Kongoni
4) Thomson's gazelle
5) Grant's gazelle
6) Impala
7) Oryx
8) Eland
9) Buffalo
10) Elephant
11) Giraffe
12) Cattle
13) Sheep
14) Goat
15) Ostrich
16) Donkey
17) Rhino
18) Warthog
19) Waterbuck
20) Lesser Kudu
21) Reedbuck
22) Gerenuk
23) Baboon

Animal Activity

1) Drinking
2) Feeding
3) Grazing
4) Lying
5) Shading
6) Standing
7) Running
8) Walking
9) Social interaction
10) Browsing

However, because of the large numbers of animals involved it was necessary to use animal density classes rather than actual animal densities, but this was quite adequate for mapping movements and range conditions on an index basis. The monitoring flights could then be used for the basis of planning more detailed flights and ground monitoring, demonstrating an efficient co-ordination of large scale aerial and detailed ground methods.

A more refined aerial monitoring technique[47] is used in Amboseli over an area of 8,000 km^2. A series of systematic transects is flown through the centre of 5 x 5 km blocks; the aircraft used, a Cessna 180, carries a pilot/navigator and three observers. The pilot calls out the beginning of each square, and the two observers in the rear seat count animals falling within strut markers that define a set strip width (see Handbook No. 1).[30] Any animals too densely packed to count immediately are photographed and counted later. In other words the observers are concerned simply with the animal counts, the end result being a distribution map for each species giving approximate density values. Population estimates and variances can be derived as for random transects, although the variance may be exaggerated.[29,32] The front observer is concerned with environmental data, or specific data, such as elephants observed outside the strip. The data recorded are listed in Table 2. The smallest unit is normally a 5 x 5 km cell, but this can be subdivided into smaller lengths for analytical purposes, in which case the pilot would need to call out the subdivision so that the observers can record subunits.

It is worth pointing out that the same system can be applied to set-block aerial transects as to set-block or set-transect ground counts, namely the possibility of separating constant data from variable data. For example, each block can be assigned a vegetation category, and this can be conducted as a separate exercise, say by a botanical ground survey. A similar situation applies to other constants such as soils, permanent water,

TABLE 2. Environmental variables recorded on the Amboseli aerial monitoring flights

1) Grass greenness
2) Grass cover
3) Herb greenness
4) Canopy greenness
5) Burned area
6) Cultivated land
7) Crop greenness

Categories 1) - 7) are recorded on a scale of 0 - 100%

8) Grass height - 5 categories
9) Ephemeral water - 1 = No water
   2 = Water available to livestock only
   3 = Very limited supply - all species
   4 = Unlimited supply - all species
   5 = Water-logging
   6 = Flooding
10) Spectrometer readings of wavelengths 6700 and 8000 Å
11) Time of day

Other factors that do not change between flights e.g. canopy cover, permanent water sources, soil type, habitat type, are recorded separately and only need recording once, or periodically.

terrain, drainage basin morphology, and permanent human settlement. The data that would then need to be collected specifically on each count would be those which vary from time to time; for example, grass greenness, grass height, ephemeral water - in other words the same variables as we noted for ground counts.

The great value of the systematic counts is that both animal number and distribution data can be derived simultaneously. This approach is far more powerful than random transects in deriving distribution maps. It is also ideally suited to a large number of statistical analyses - trend surface, multiple regression, analysis of variance and so on (see Section 4) - because the data are already assembled as a data matrix, the starting point of many statistical treatments.

3.4 Recording environmental variables from the air

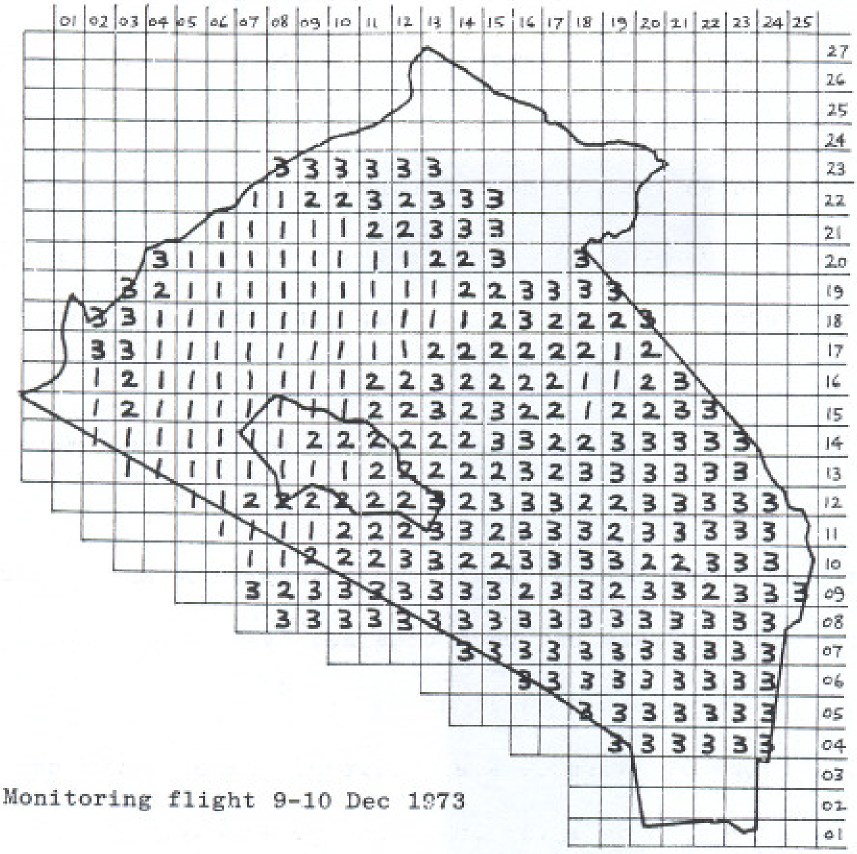
One of the difficulties of recording data from aerial counts is that the categories are subjective; for instance, it is difficult to obtain objective measures of grass greenness and cover from the air.

However, there are some techniques for improving the accuracy of data. Spectrophotometers have now been used in several study areas (e.g. Serengeti and Amboseli) for measuring the biomass of green matter in vegetation.[28,47] Green chlorophyll-containing material reflects infrared light and absorbs red light; the opposite is true of non-green material. The ratio of vegetation reflectances at 8000 Å (infrared) and 6750 Å (red) is related to the amount of green material in a specified area. By calibration with ground plots, accurate estimates of the standing crop of green matter can be obtained. By and large, the method is most useful for open grasslands; complications arise when measurements are made of woodlands.

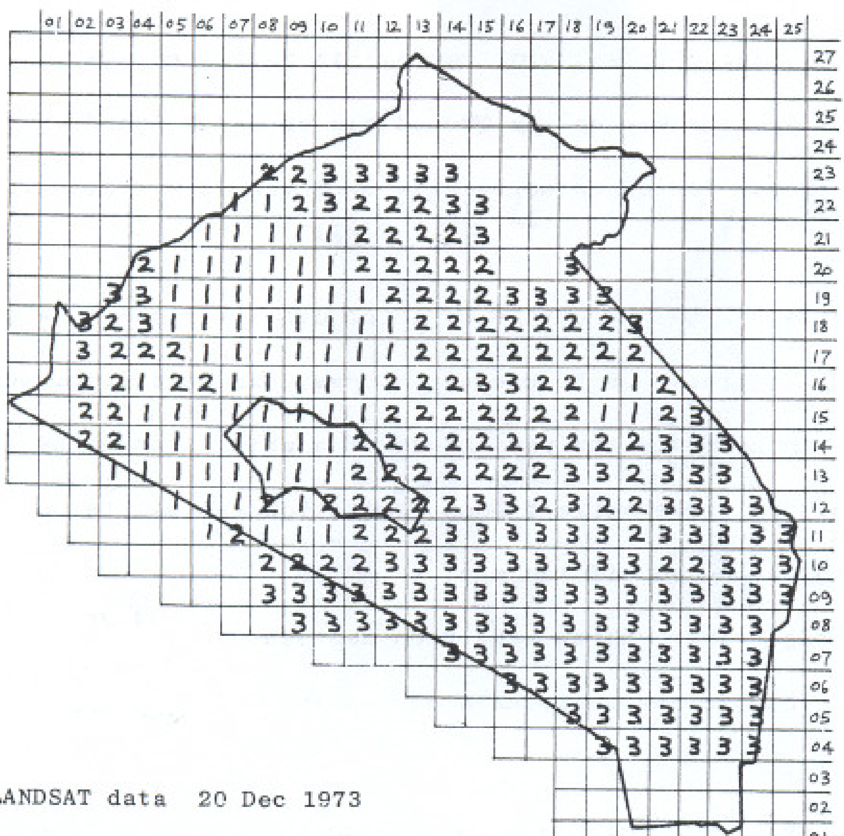
A similar objective method can be provided by satellite imagery. In Amboseli, simultaneous coverage by LANDSAT satellite imagery and a standard aerial monitoring flight were compared. The ratio of spectral band 7 (infrared) to band 5 (red) can be used in the same way as described above to obtain an estimate of green biomass. The agreement between the two methods was very close (Fig.5) and so it appears that regular satellite coverage could provide a good way of recording green biomass over large areas.

Another method of improving the quality of environmental data is to take at least one colour photograph of each grid square. The colour slides can be kept for reference purposes and can be used as a check on estimates of grass greenness, grass cover, woodland cover, etc.

Fig. 5 Comparison of monitoring flight (low-level) classification of grass greenness with data from LANDSAT. Outline of Amboseli ecosystem is shown; the inset is Amboseli National Park



Monitoring flight 9-10 Dec 1973



LANDSAT data 20 Dec 1973

1 = Dry < 10% green

2 = Slight green 10 - 20% green

3 = Very green >20% green

3.5 Training and calibration of environmental observers

The most important requirement of any subjective assessment of range conditions is consistency. Once consistency is achieved, regional and seasonal differences tend to be sufficiently large that they can be detected by such techniques. A well trained eye can in fact pick out very subtle differences in range conditions; the problem is to standardise the estimates.

Extensive pre-flight training is needed to produce a moderately useful observer. The approach that has been used in Amboseli was first to calibrate the observer against measureable variables on the ground. Once consistency and accuracy had been obtained, aerial estimates could be tested against information from ground plots.[47]

Two main types of estimate are required; namely, the percentage of the grid square covered by a variable, and greenness.

(i) Percentage cover:

Cover estimates of grass or canopy can be tested against plots on the ground. Grass cover on the ground can be established with a pin-frame;[16] and canopy can be established with a variable plot sampling method.[1]

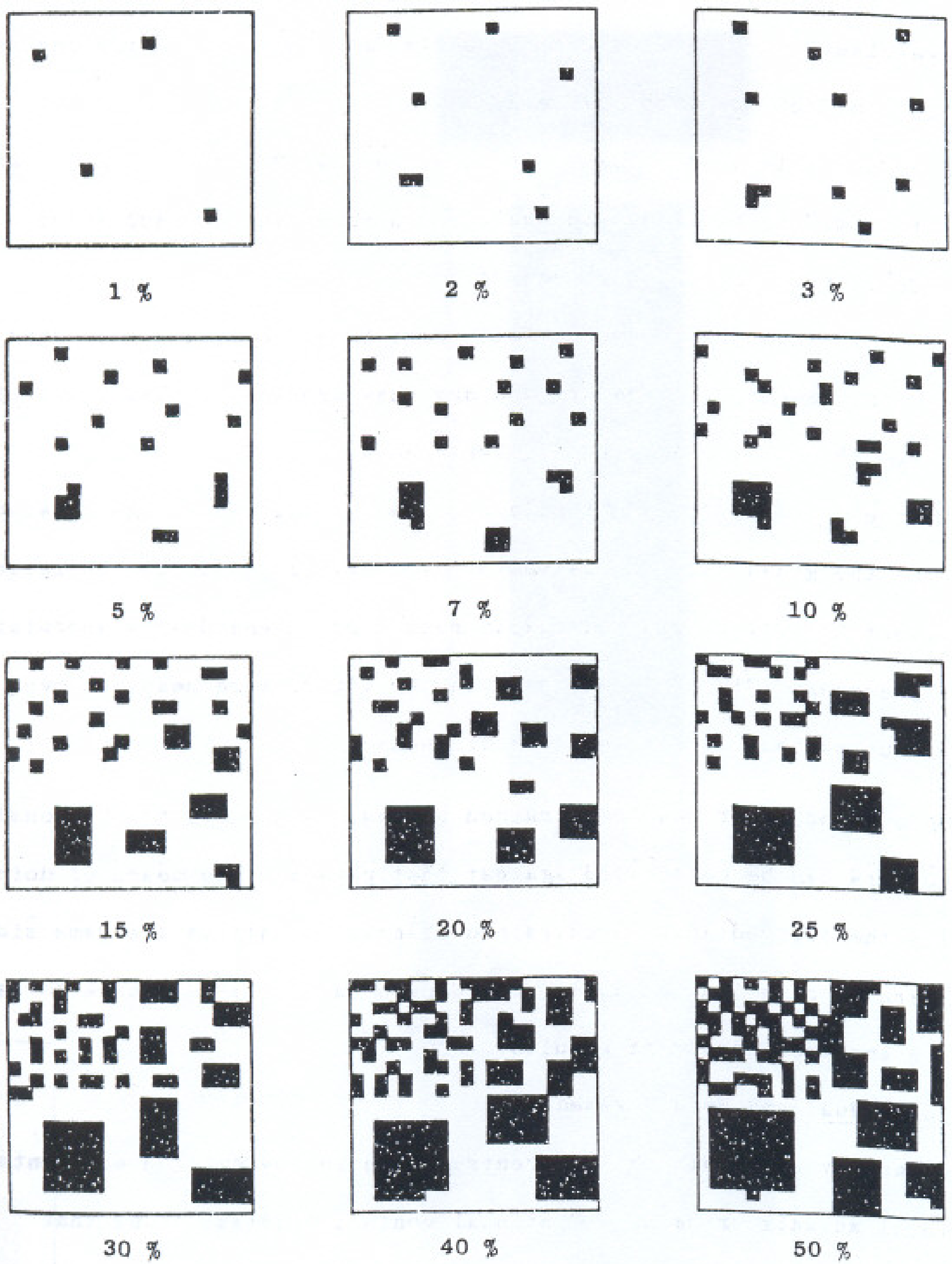
Estimates of the percentage cover of other variables (e.g. cultivation, burnt areas, or a vegetation type) can be calibrated. An easy method is to estimate the percentage of a grid taken up by different vegetation types in areas where a good vegetation map exists. The actual area can then be measured off the map.

Percentage cover charts have been published [14,34,35] which will provide some guide to the environmental observer (Fig. 6).

(ii) Greenness:

Greenness can be rated as a percentage from 0% (no green at all) to 100% (totally green). One way of checking the consistency of an

Fig. 6 Chart for estimating percentage cover.[14]



environmental observer is to use a series of colour slides of a rangeland area. A set of numbered slides can be randomly sorted and each given an estimate. On randomly re-sorting, consistency is checked by re-rating each slide again and comparing the first and second estimates. In flight, a similar exercise can be carried out by re-flying a series of grids the next day, but in a different flight pattern.

Some possible ways of calibrating estimates of grass greenness are:

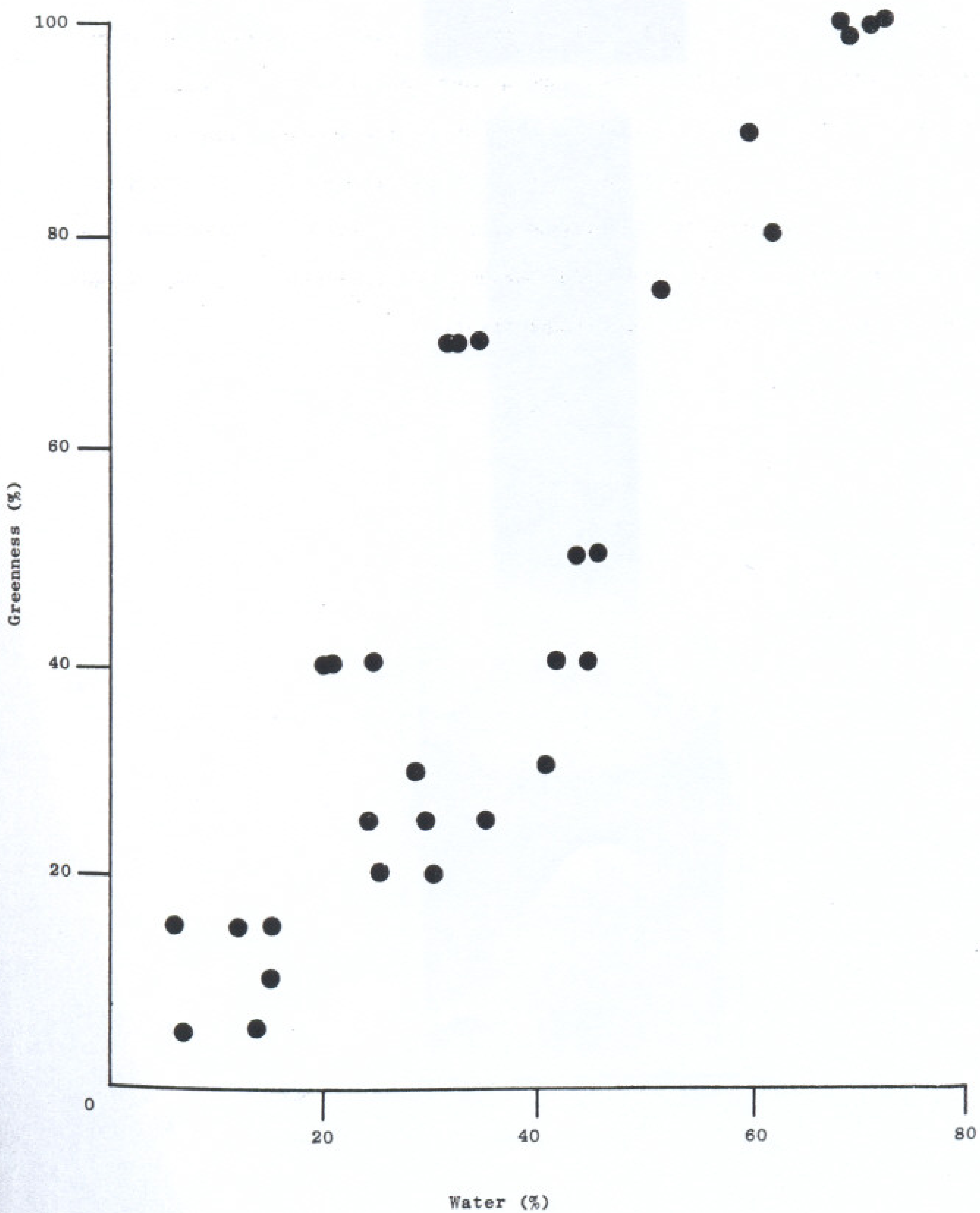
- To estimate greenness in small plots where the dry and green fractions can be separated out.
- To estimate greenness in plots where both green mass, measured with a spectrophotometer, and dry mass are known. The ratio of the two should give a measure of greenness.
- To estimate greenness in plots for which the percentage moisture in the grass can be measured by oven-drying a sample. Moisture content will give a reasonable method of independently appraising greenness (Fig. 7). The data in the figure were measured over four months, from a wet to a dry season.

Once an observer has been trained and has been shown to be consistent, other observers can be calibrated against that person. One means of doing this is for the trained and the untrained observer to sit on the same side of the aircraft, both independently recording a particular variable for each grid square and then comparing results.

3.6 Individual and Herd Movements

A variety of studies has concentrated on following the movements of individual animals or herds. Continual contact studies, those that follow a group or individual around continuously, or perhaps intermittently, suffer from a problem of sampling bias. It is often difficult to show that the individual or group is representative of what the majority of the population is doing. However, a large amount of extremely useful data

Fig. 7 Relationship between estimated grass greenness and measured water content of grass (Amboseli data).



can be derived in this way, data that are often at a much finer scale than that obtained in population sampling.

Radio tracking has become particularly popular in tracking the movements of animals that are difficult to keep up with and which move considerable distances, e.g. wildebeest [19]. Where a few discrete groups occur, this is an ideal method of using the radio beacon as a mobile sampling point and speeding up the process of data collection.

Both the above techniques provide useful complementary data to larger scale monitoring of animal movements in relation to the environment. At least two studies provide useful examples of continuous group contact and radio tracking techniques respectively [2,23].

SECTION 4 ANALYSIS OF DATA

4.1 Preliminary Sampling

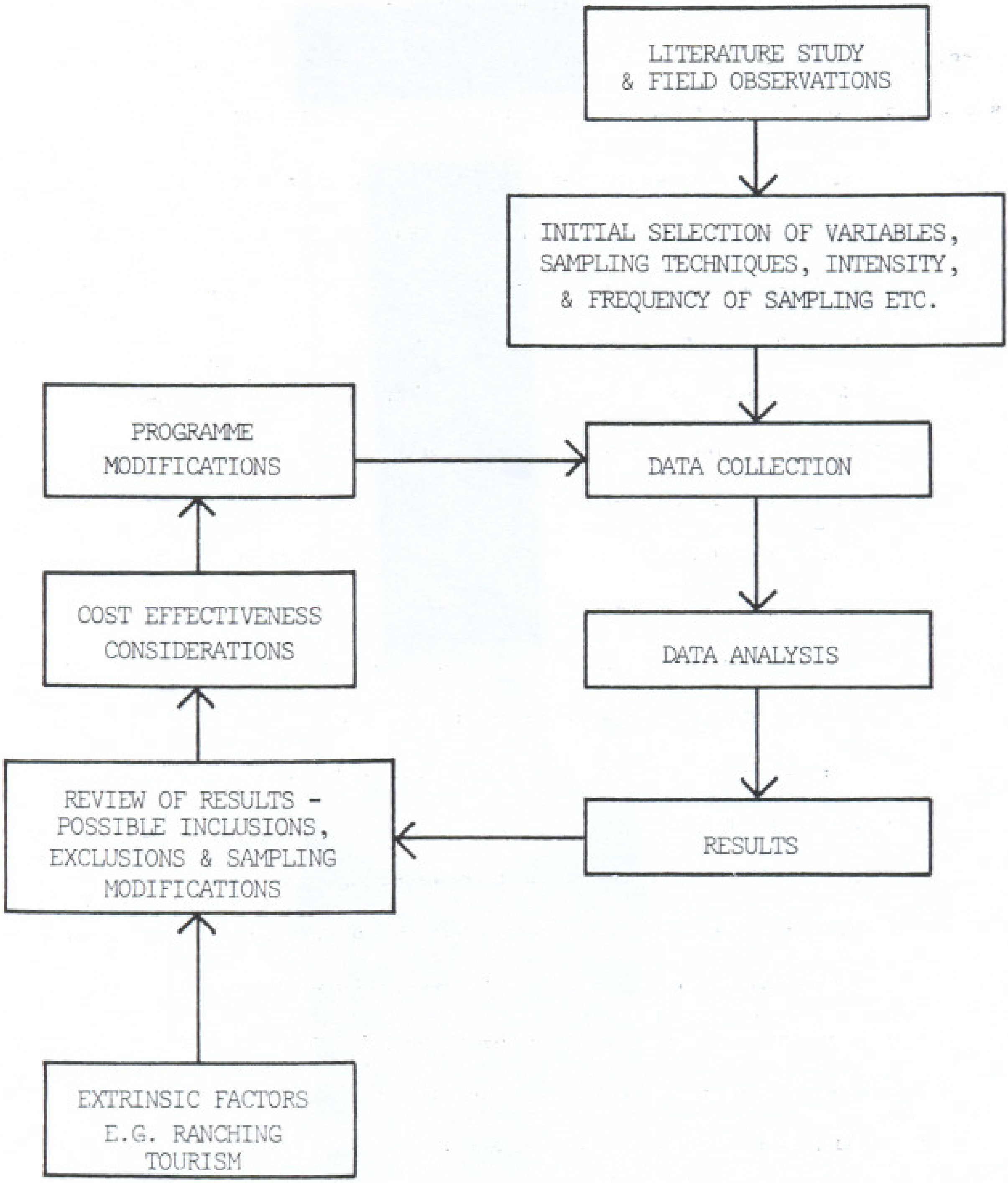
The most important first step is preliminary sampling. It is essential to ensure that the sampling procedure is providing the amount and quality of information needed. Two stages can be considered :-

(1) Is the selected method of sampling suitable for the level of accuracy required ? Whether the method used is line transects, blocks or total counts, a preliminary count is essential. On the basis of such a count it will then be possible to increase or decrease the intensity of the count, the strip widths and so on. It is also essential to determine whether the categories recorded are fine enough to provide suitable animal and resources data for correlation. Finally, there is a need to ensure that the frequency of sampling is adequate to detect major changes of animal distribution or resource variation, but not so frequent that no change is detected and great expense is incurred.

(2) If resources and their categories are to be useful, then every effort should be made to test that the most suitable are recorded. It might be found that during the early samples, animals were found to be consistently associated with some factor not recorded, e.g. salt. That variable would need inclusion. Similarly, categories should be tested for suitability. After constructing habitat categories, for example, it might be found appropriate to revise them in the light of early sampling.

A simplified scheme of preliminary sampling is given in Figure 8.

Fig. 8 A flow diagram of the sampling design used in Amboseli.



4.2 Level of analysis

The analysis of data can be as simple or as complex as the researcher is competent to handle. But two considerations should be borne in mind:-

(1) Data will ultimately be expected for Parks and wildlife management. Therefore, the information must at some point be interpretable to planners and wardens. A complex mathematical model means nothing to a warden who simply wants to know roughly where his animals are at different times, and why. Whatever analysis is used, it is worth remembering that it must be amenable to simple presentation as this is more inclined to gain a positive response from planners than obscure flow diagrams and jargon.

(2) An oversimple analysis wastes data and belies the complexity of the real world.

So it is recommended that a realistic attempt is made to use and integrate all the data collected in the analysis, but that for management purposes a simplified version should be drawn up.

4.3 Detection of Pattern

The basic analysis will centre around detecting patterns. This involves two stages, although in certain analyses both can be performed simultaneously:-

(1) Dėtection of animal distribution patterns and the changing patterns through time.

(2) A correlation of animal distribution patterns to resource distribution patterns.

The important point to emphasise is that animal numbers, densities or biomass, whichever is used, is the dependent variable while resources are the independent variables, at least initially. This simply means that we are trying to predict animals on the basis of resources and not *vice versa*.

4.4 Sequence of analysis

It will become apparent in dealing with a range of species, a number of different resources, and their changing patterns of distribution through time, that the integrating analysis can become complex. The only reasonable solution to this is to employ multivariate statistical analyses (see below) which are designed to handle a large volume of interacting variables. For the use of these techniques statistical advice should be sought, but before that stage a series of specific questions should have been formulated, since even using these techniques on high speed computers the data have to be interpreted meaningfully. These techniques should be used to speed up the process of analysis and to answer specific questions, not to do the thinking for you.

To begin with, it is important to order the analysis in such a way that the large scale data are handled first, the fine scale data afterwards. This usually entails detecting seasonal trends on the basis of rainfall, then possibly distribution in relation to water, habitats and features within habitats such as grazing conditions.

At a finer level of analysis it might be possible to show daily changes in activity, for example a concentration on the plains in the morning, woodlands during the middle part of the day and plains again in the evening. In looking at the activity state of animals it might then be possible to show why they move, such as feeding on the plains but periodically moving into the woodlands to drink, or maybe to seek shade during the hotter hours.

There are enormous analytical possibilities, but a scale of events from large scale to small scale is a wise procedure. Most of the important relationships should become obvious long before the final analysis and these will act a valuable guide at that stage.

In the following sections the chief methods of analysis are discussed.

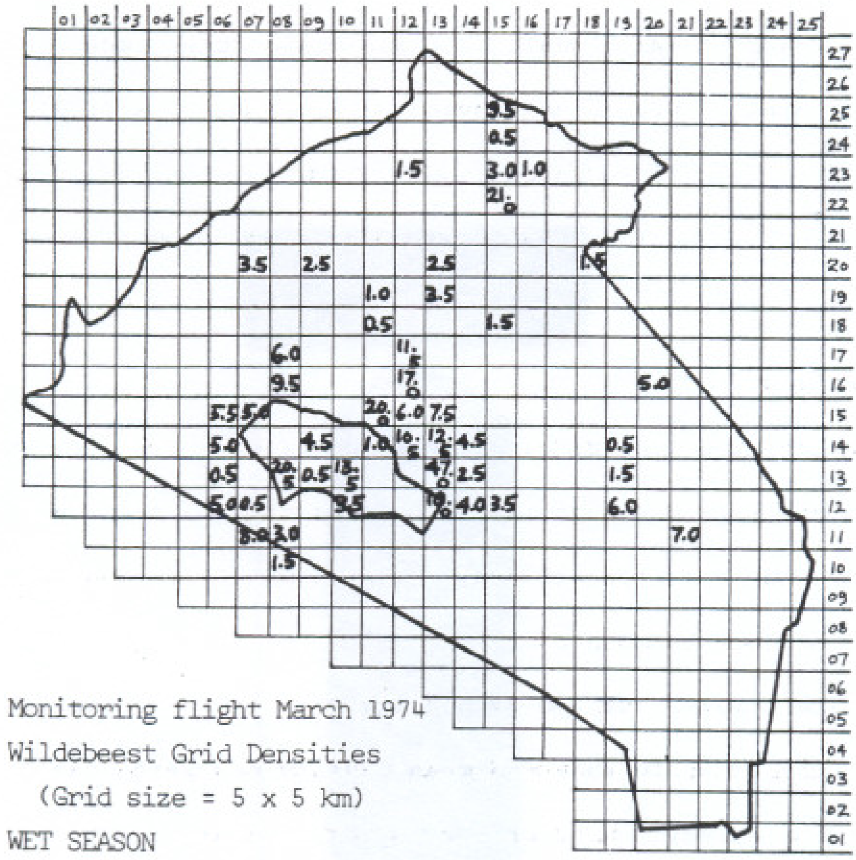
4.5 Occupance Maps

Occupance maps are a means of presenting the density distribution of the animal species recorded. It is most useful to plot the density distribution according to a grid pattern, which is often how the data are collected anyway (see Section 3.3).

The maps are simply obtained by pooling data from a number of systematic surveys in order to show the mean density per grid square, either over the total survey period or for any particular year or season. Given sufficient data, these maps are useful because they show exactly how an area is used and which grid cells support the highest occupance values. The occupance values can be calculated for individual species, or on the basis of total biomass or livestock units per grid square. Several examples of the use of occupance maps are available[6,33,43].

Examples of single occupance maps for wildebeest and Grant's gazelle in Amboseli are given in Fig. 9. These data were obtained by systematic aerial sampling. What can be determined from these maps is that wildebeest are highly localised in their distribution and show a marked seasonal shift, while Grant's gazelle show quite the opposite characteristics. Continued over time, such counts will give a progressively better idea of how animals use the area. Already it is apparent that the Amboseli National Park does cover most of the wildebeest dry season distribution, but little of the wet season range. For Grant's

Fig. 9a Wet and dry season grid densities of wildebeest in the Amboseli ecosystem; the location of Amboseli National Park is shown.



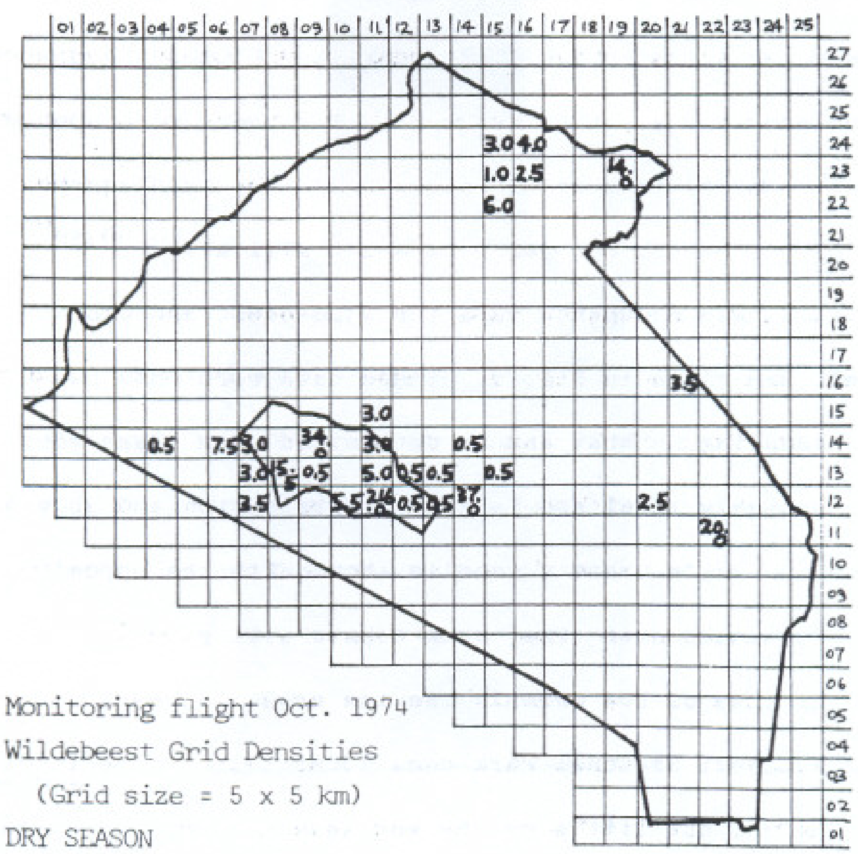
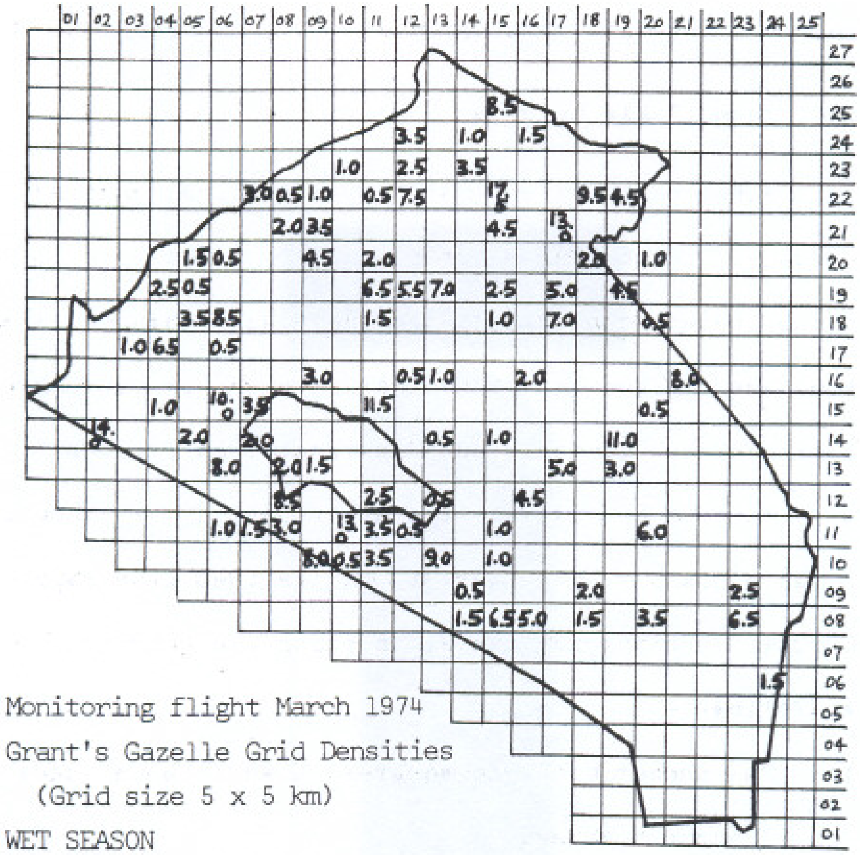
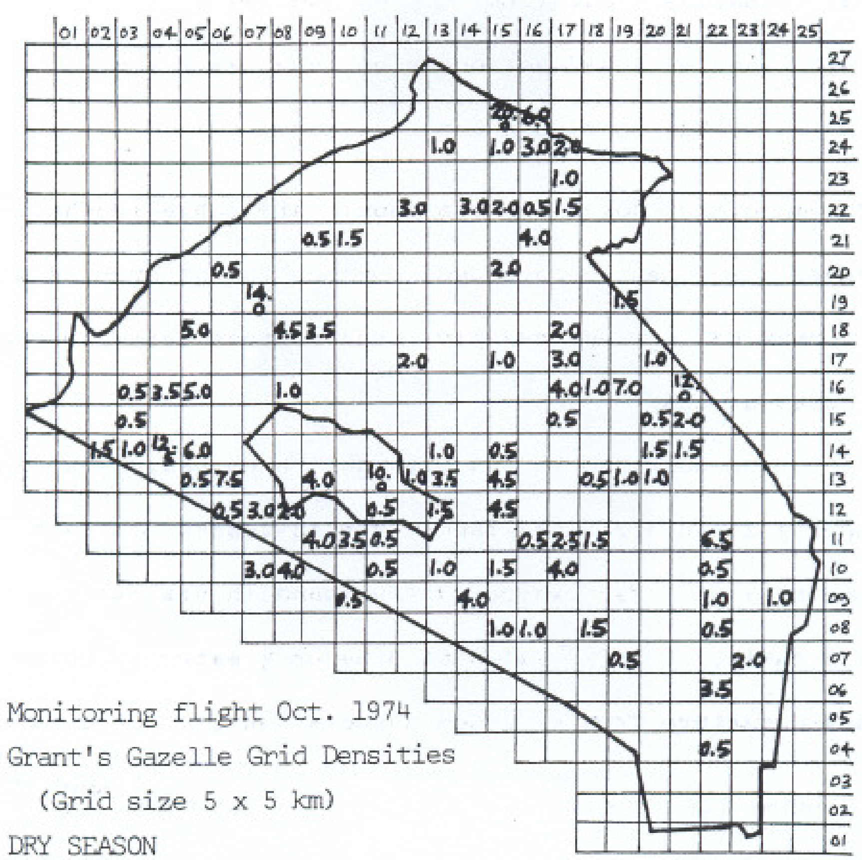


Fig. 9b Wet and dry season grid densities of Grant's gazelle in the Amboseli ecosystem; the location of the Amboseli National Park is shown.





gazelle the Park only forms a small part of their total range, the reason being that they are less dependent on water than wildebeest (Fig.14).

4.5 Contingency Table Methods

Contingency tables are used for testing frequencies; that is, the degree of association between discrete categories of observations[3].

In the present context, contingency tables may be used to test the degree of association between animal species, or between a species and some environmental factor - such as vegetation type or burnt areas.

For this type of analysis the distribution data should be plotted on a grid square basis. The observations can then be arranged according to a simple 2 x 2 contingency table, in which the four cells are, for example, as follows:-

(1) The number of grid squares in which both species A and B occur together,

(2) species A occurred but not species B,

(3) species A did not occur but species B did,

(4) neither species A nor B occurred.

The important point to note about this table is that only presence or absence of a species is recorded; but on the other hand all the grid square information is used, negative observations being as important as positive observations.

It is now possible to test the null hypothesis that the two animal species are distributed randomly with respect to each other. This can be done by an X^2 test, which can be found in statistical textbooks[3]. For a 2 x 2 table, if an X^2 value of 3.84 or greater is obtained then a significant departure from a random association is indicated.

4.7 Coefficients of Association

Having drawn up a contingency table and discovered a significant association, it is then possible to calculate a coefficient of association. The most useful is Cole's coefficient of association, which gives values from +1 (complete positive association) to -1 (complete negative association), zero indicating random association[7,39]. The formulae involved for the calculation of the coefficient and its standard error are shown in Table 3, and a worked example is given in Table 4.

An important point to bear in mind about Cole's coefficient of association is that the value of the coefficient will vary according to the grid size selected. If the grid squares are too large then the important associations may be obscured. For example, a 10 x 10 km grid is too large to show the phenomenon of the grazing succession in the Serengeti[26]. However, the method is useful for making relative comparisons, either at a point in time or over a series of similar surveys.

Two examples of the use of Cole's coefficient come from studies in the Serengeti. In one case the coefficient was used to assess the interaction between grazing ungulates, using an 800 x 800 metre grid[5]; and in another case, it was used to show seasonal selection of habitats by buffalo, this time with a 500 x 500 metre grid[37].

Although Cole's method is based only on presence or absence, the number of animals per grid square can be used to obtain an index of association of individuals. A formula has been proposed[39] and is given below :

$$I = 2\left[\frac{Ji}{A+B} - 0.5\right]$$

Where Ji = no. of individuals of species A and B in squares where both are found

A + B = no. of individuals of A and B in all squares

Table 3

The 2 x 2 contingency table and Cole's coefficient of interspecific association

(1) 2 x 2 contingency table :

		Species A: Present	Species A: Absent	
Species B	Present	a	b	a + b
	Absent	c	d	c + d
		a + c	b + d	n = a+b+c+d

Note : (i) Such a table should always be drawn up so that A is more abundant than B, i.e. $(a+b) < (a+c)$

(ii) A corrected chi-square (X^2) test should be used to see whether the association is significant or due to chance[3]. If a chance association is indicated then further analysis should not be carried out[39].

(2) Cole's coefficient of interspecific association :

Different formulae must be used depending on the sizes of the figures in the table; that is :

(i) When $ad \geq bc$: $C_{AB} = \frac{ad-bc}{(a+b)\ (b+d)} \pm \sqrt{\frac{(a+c)\ (c+d)}{n(a+b)\ (b+d)}}$

(ii) When $bc > ad$ and $d \geq a$:

$$C_{AB} = \frac{ad-bc}{(a+b)(a+c)} \pm \sqrt{\frac{(b+d)\ (c+d)}{n(a+b)\ (b+d)}}$$

(iii) When $bc > ad$ and $a > d$:

$$C_{AB} = \frac{ad-bc}{(b+d)(c+d)} \pm \sqrt{\frac{(a+b)(a+d)}{n(b+d)(c+d)}}$$

Table 4

Cole's Coefficient of interspecific association

Example : Association between the huts of a nomadic pastoral tribe and their livestock. Data from an aerial systematic survey. Both associations are significant (X^2 test).

1.

		Sheep & Goats +	Sheep & Goats -
Huts	+	a 59	b 19
	-	c 39	d 61

$n = 178$

2.

		Huts +	Huts -
Camels	+	a 39	b 27
	-	c 39	d 73

$n = 178$

As in both cases ad $>$ bc, then the appropriate formula is :

$$C_{AB} = \frac{ad - bc}{(a+b)\ (b+d)} \pm \sqrt{\frac{(a+c)(c+d)}{n(a+b)(b+d)}}$$

Results :

$C_{\text{sheep/goats and huts}} = + 0.46 \pm 0.09$ (standard error)

$C_{\text{huts \& camels}} = + 0.27 \pm 0.09$ (standard error)

Conclusion : Both associations are positive but sheep and goats appear to be more strongly associated with huts than are camels.

4.8 Further examples of X^2 methods

X^2 tests can be used to show selection or avoidance of habitat or vegetation types using the number of animals observed in each type[20]. The observed numbers in each habitat/vegetation type are compared with the expected numbers if all the animals had been distributed at random with respect to habitat types. A worked example of this method as applied to a road count is given in Handbook No. 1[30].

This method should only be used when it is not possible to calculate the mean density and variance of animals in each vegetation type. If the latter can be done then it is better to use analysis of variance or t-test methods (see below).

4.9 Analysis of Variance and t-test methods

These methods allow one to test the significance of differences in animal density between one vegetation type and another.

Grid square data from an occupancy map may be used for this purpose. The grid can be superimposed over a vegetation or habitat map and each square allocated to a particular type. If more than half a square is occupied by one vegetation type, then the whole square should be allocated to that type.

Alternatively, if the animal data have been collected on the basis of the vegetation types (i.e. stratified sampling), then the density is calculated from the portions of transects in each type, as described in Handbook No. 1[30].

The mean densities of animals in the different vegetation types can now be calculated. A one-way analysis of variance, or a series of t- or d-tests[3], may then be used to see if there are any significant differences in animal density between the types.

4.10 Simple regression methods

In this type of analysis one variable is graphed against another to see which show obvious correlations. This is very easy to carry out and can quickly show how the animal densities appear to be correlated with the various environmental factors.

For example, if grid square densities of wildebeest were plotted against values of grass greenness we might expect to find a positive correlation. On the other, if the densities were plotted against grass height a negative correlation would be expected (see Fig.10). However, care must be taken in interpreting correlations of this kind, as a casual relationship is not necessarily implied; the underlying, causal agent governing the animal distribution could be a different factor (e.g. soil type or water). For instance, the distribution of wildebeest on the Serengeti Plains may be more strongly related to the availability of calcium than to grass greenness or grass height[21].

4.11 Multivariate analysis

The various types of multivariate analysis make it possible to compare the animal density values with all the environmental factors at once. In this way the chief factors correlated with animal distribution can be isolated and their relative importance determined.

As this type of analysis is often complex it is necessary to seek expert statistical advice beforehand. It is important to remember that the animal data are the dependent variables and that the environmental data are the independent variables. This is because predictions can then be made on animal distribution, based on a knowledge of environmental factors.

Transformation of the original data is sometimes necessary in order that they should approximate to a normal distribution, a basic

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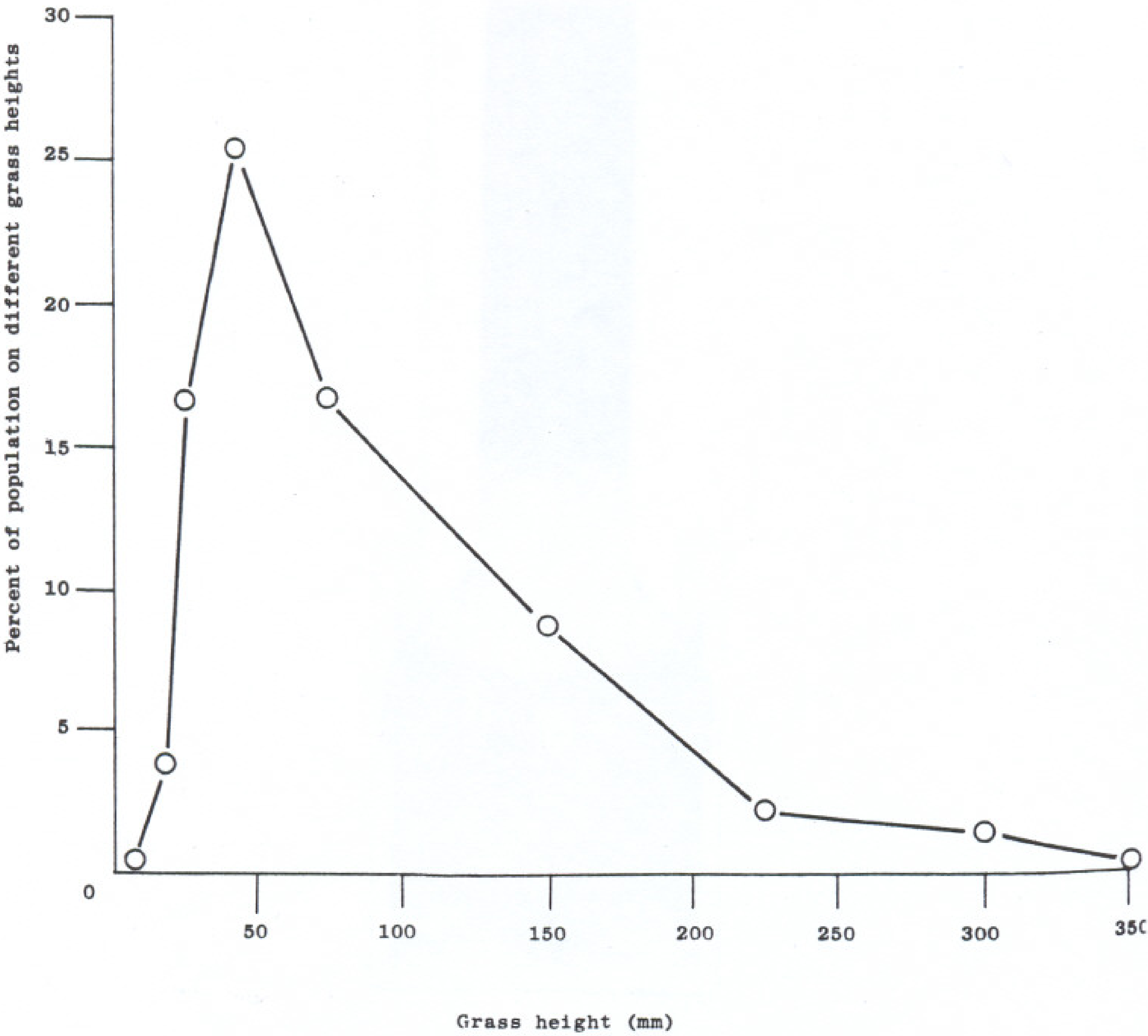
Transformation of the original data is sometimes necessary in order that they should approximate to a normal distribution, a basic

Fig. 10 The dry season distribution of wildebeest in Amboseli in relation to grass height. Note peak of curve at 40 mm, followed by a negative relationship with grass height.



assumption of many statistical tests. Again, advice is needed on what type of transformation to use (e.g. log, square root, arcsin)[38].

A detailed description of the various methods is beyond the scope of this handbook. Some examples of the various methods that have been used by ecologists in Africa are as follows:-

- Multiple regression analysis (Serengeti, Tsavo)[6,31]
- Principal components analysis (Serengeti)[11]
- Discriminant function analysis (Zimbabwe/Rhodesia)[12]

The results of the multivariate analysis have then to be scrutinised to see how much ecological sense they make; a rigorous statistical interpretation is usually not possible because the original data are either incomplete or inadequate in some way. Useful results are likely to be those that explain most of the variation in animal density on the basis of the environmental data collected.

An example of multiple regression analysis is given in Table 5.

4.12 Reducing the numbers of variables

In order to simplify analysis some of the environmental variables can sometimes be discarded, either because they are highly correlated with another variable, or because they appear to contribute little to the prediction of animal distribution. In addition, by subdividing the study area into different ecological zones, it may be possible to stratify out certain variables, which then become redundant.[31]

In other cases, variables can be combined. For example, the product of grass height and grass cover can be used to determine the standing crop of grass, or in other words, a rough estimate of the quantity of available food (Fig.11).

Table 5

An example of multiple regression analysis: variables associated with the wet season distribution of zebra in Tsavo East National Park, Kenya[6]. Variables estimated according to 10 x 10 km grid squares.

Significant variables	r	% variance accounted for
Aridity index	- 0.37	13.5 %
Rain month 2	+ 0.35	13.5 %
Rain month 1	- 0.26	24.7 %
Grass height	- 0.28	11.6 %
Grass cover	+ 0.18	6.1 %
Rain 1973-74	- 0.05	5.3 %
Shrub cover	- 0.01	2.8 %
Tree canopy	- 0.30	3.2 %
Topography	- 0.15	3.1 %
Distance from water	- 0.15	2.5 %
Multiple r = 0.93		Total = 86.2 %

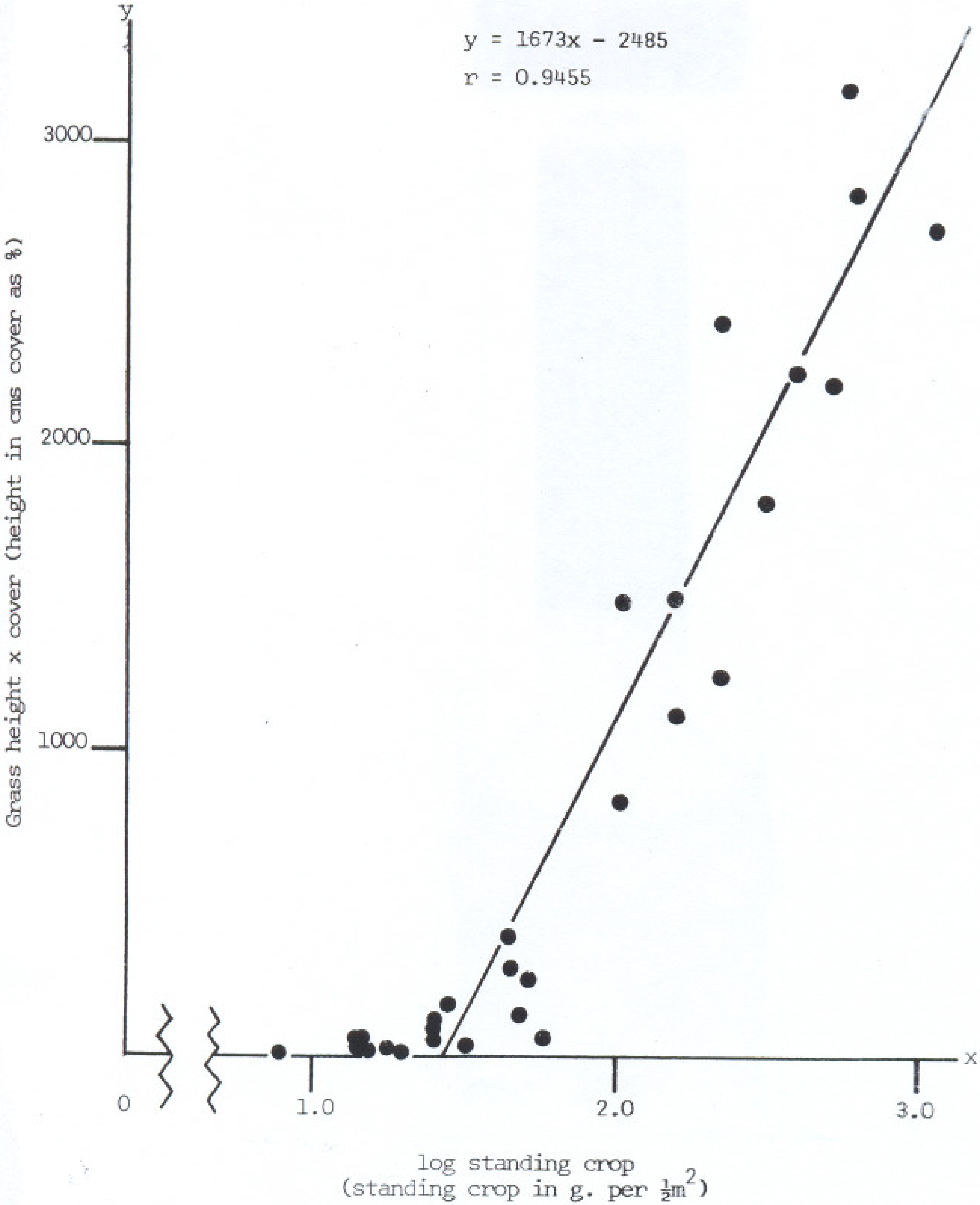
n = 37 (= number of grid squares)

r = correlation coefficient

Dependent variable (Y) = zebra density distribution

Independent variables (X) = environmental factors

Fig. 11 Relationship between the height times cover of grass and the measured standing crop biomass of the same plot (Amboseli data).



4.13 Analysis of gradients

Gradients in animal density or in environmental factors will be evident in any ecological survey. If the data are organized according to a grid pattern (e.g. the occupance map) any major gradients will be fairly obvious.

If a more objective treatment is needed, then a trend surface analysis may be used[15,29]. Trend surface analysis is a three dimensional multiple regression which is used to fit surfaces of increasing complexity to the grid square data. The surface of best fit is found by analysis of variance. Essentially, the method provides an objective means of smoothing the original distribution data.

SECTION 5 HOW DISTRIBUTION DATA CAN BE USED

The following examples give an indication of how distribution data may be used for solving various practical problems.

Example 1 : Designing reserve boundaries

The results of distribution surveys are of particular value in designing the size and shape of wildlife reserves. It is now widely recognised that a fauna that is isolated geographically in space represents an "island" community[25]. Lacking continuity with other populations the natural process of immigration is curtailed [9,24]. In consequence, local extinctions are not replaced through immigration, and over time the community loses a proportion of the species it had at the time of its isolation. The number of species an "island" community loses is roughly a function of its geographic size and distance from potential colonising sources[10]. The smaller the area and the further it is from potential colonising sources the greater will be the proportion of species which go extinct in time.

The results of studies from island biogeography have been widely discussed in terms of the principles they offer for the design of faunal reserves[10,27,36]. These can be broadly summarised as follows:-

(1) In general, one large reserve is more viable than several small areas because it has more species at faunal equilibrium and therefore a lower extinction rate.

(2) Where it is not possible to have one large reserve, the smaller reserves should be designed so that their proximity is sufficiently close to allow movement between them. A series of corridors or stepping stones will also permit some degree of migration.

(3) Reserves should be designed to maximize the area to perimeter ratio so as to avoid a peninsular effect. Long narrow reserves will have a higher emigration rate (and therefore probability of extinction) than circular reserves.

In practice, the principles are seldom of direct benefit in designing reserves, especially in the savannah ecosystems. The reason is that for areas small enough to consider setting aside as reserves (less than 30,000 km^2), the simple relationship between the number of species and the size of an area is largely masked by habitat diversity[49]. An area of uniform habitat will contain fewer large mammal species than a similar sized area with diverse landforms and habitats[17,40]. The density distribution of species in space and time is therefore the best guide to the design of reserves, and this is precisely the data which are recorded on monitoring programmes.

Reserve boundaries should ideally encompass the ecosystem, but constraints on area rarely permit the ideal. It is in this context that long term data can be most useful. What fraction of the ecosystem, species, animal numbers or habitats can be included by reference to the data available ? Or, if the reserve is to be established for specific species, what proportion of their annual range can be included ? By reference to the animal distribution and resource maps the optimum boundary can be established for the reserve. In most areas the dry season range of herbivores is more important to their future survival than the wet season range, as this is where resources are limiting either in terms of permanent water or forage. Such areas are readily identified from monitoring data and can therefore be given special emphasis in designing reserve boundaries. Amboseli National Park was designed on the basis of existing monitoring data, and though only 390 km^2 includes

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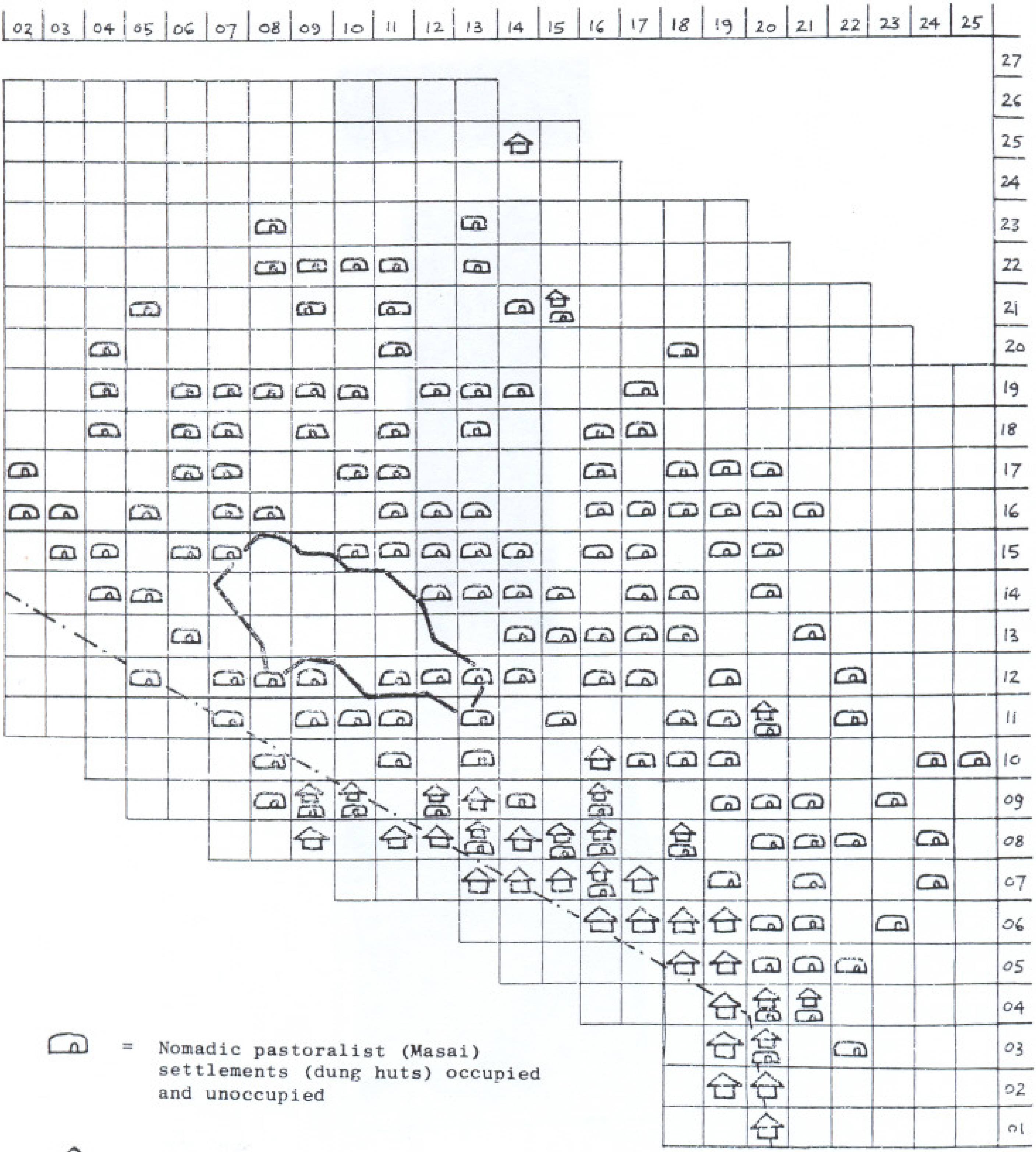
Suitable monitoring data are therefore the best guide to the design of a specific faunal reserve for a given sized area and avoids the need to fall back on general ecological principles, which while evident on a sufficiently large scale and which serve as a generality for all situations, are not always appropriate for specific cases. We could accurately arrive at the mean foot length of men in Kenya but would hardly use this information as the basis of having shoes made for a given individual.

Example 2 : Following changes in human settlement

Aerial monitoring is increasingly widely used as a method of following changes in human distribution and activity, particularly in the arid and semi-arid rangelands. Though a number of individual studies and surveys have been conducted in the past to look at human activity it was only as late as 1976 that the first national unit was established for this purpose. This, the Kenya Rangeland Ecological Monitoring Unit is, amongst other functions, involved in recording livestock and agricultural usage of Kenya's rangeland through time. The United Nations Environmental Program is currently initiating similar projects elsewhere in Africa, as well as in S.E. Asia and South America, to monitor human and environmental changes in arid lands.

A typical example of data currently derived from aerial monitoring programs is given in Fig. 12. It demonstrates the spatial distribution of various patterns of land use in Eastern Kajiado District in Kenya. Continued over time, the results have shown the progressive encroachment of agriculture into the pastoral areas, the size and mobility of the pastoral population, and changes in livestock wealth[48].

Fig. 12 Distribution of human settlement in the Amboseli ecosystem (5 x 5 km grid), according to 1973 survey data. Amboseli National Park is shown.



= Nomadic pastoralist (Masai) settlements (dung huts) occupied and unoccupied

= Cultivator settlements, thatched houses

By recording the number of huts of different categories such as pastoral dung huts, agricultural huts, stone buildings, etc. estimates of the human population involved in various sectors of the economy can be made; that is, once the mean number of occupants for the various hut types is established from ground surveys. Other surveys have collected more detailed data on agricultural activity which includes the area of land under various crops[42].

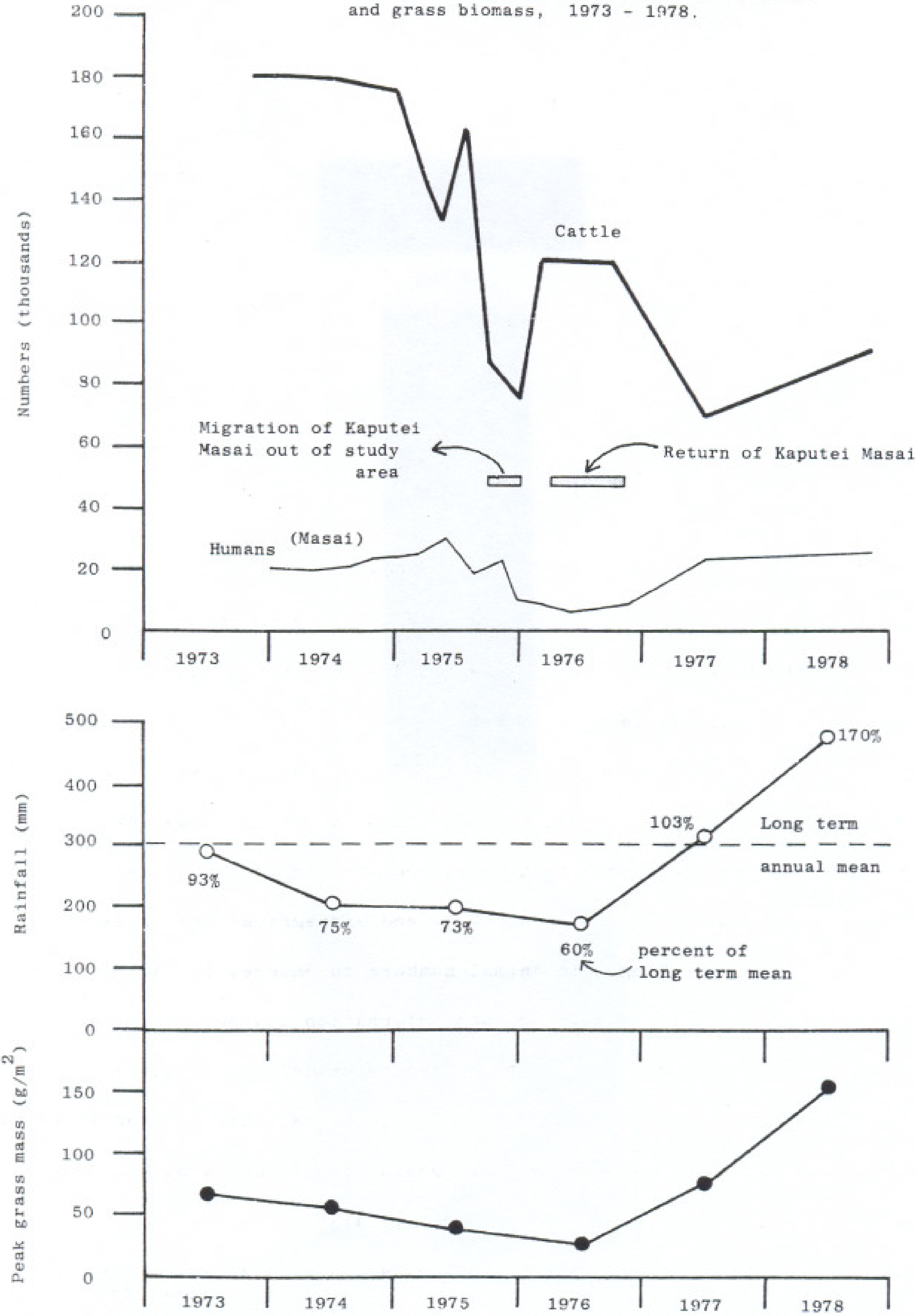
Example 3 : Animal and resource change over time

Repeated over time monitoring programmes can give valuable information on how animals, people and resources are changing numerically and spatially.

An example of such changes in the Amboseli ecosystem is given in Fig. 13. A large reduction in livestock numbers occurred during the recent drought years, which began in 1973 and ended in late 1976. Most of the reduction in numbers was due to mortality, with cattle showing much higher losses than sheep and goats. Some of the reduction was, however, temporary and due to movement out of the ecosystem. This temporary emigration phase is seen amongst the human population at that time, when some of the pastoral Masai moved into highland and agricultural areas.

We can relate changes in animal numbers to changes in the availability of resources, provided such information has been recorded in the monitoring programme. Returning to the example of livestock in the Amboseli ecosystem, it can be shown, for instance, that the mortality in cattle was clearly associated with a prolonged drought and a marked and sustained fall in pasture production. This is also shown in Fig. 13 for comparison with the livestock and human population estimates. Carcass counts of livestock were made in the course of the routine monitoring flights and were complemented by more detailed ground counts. From both

Fig. 13 Changes in cattle and human numbers in the Amboseli ecosystem in relation to rainfall and grass biomass, 1973 - 1978.



data sources both the spatial distribution of livestock deaths and estimates of the levels of mortality were obtained.

Such examples serve to show that surveys designed to demonstrate the relationships between animals and their resources over a long time span can tell us a great deal about the changes of both in response to climate, and ultimately perhaps give us a better understanding of long-term oscillations in ecosystems.

Example 4 : Animal distribution in relation to water

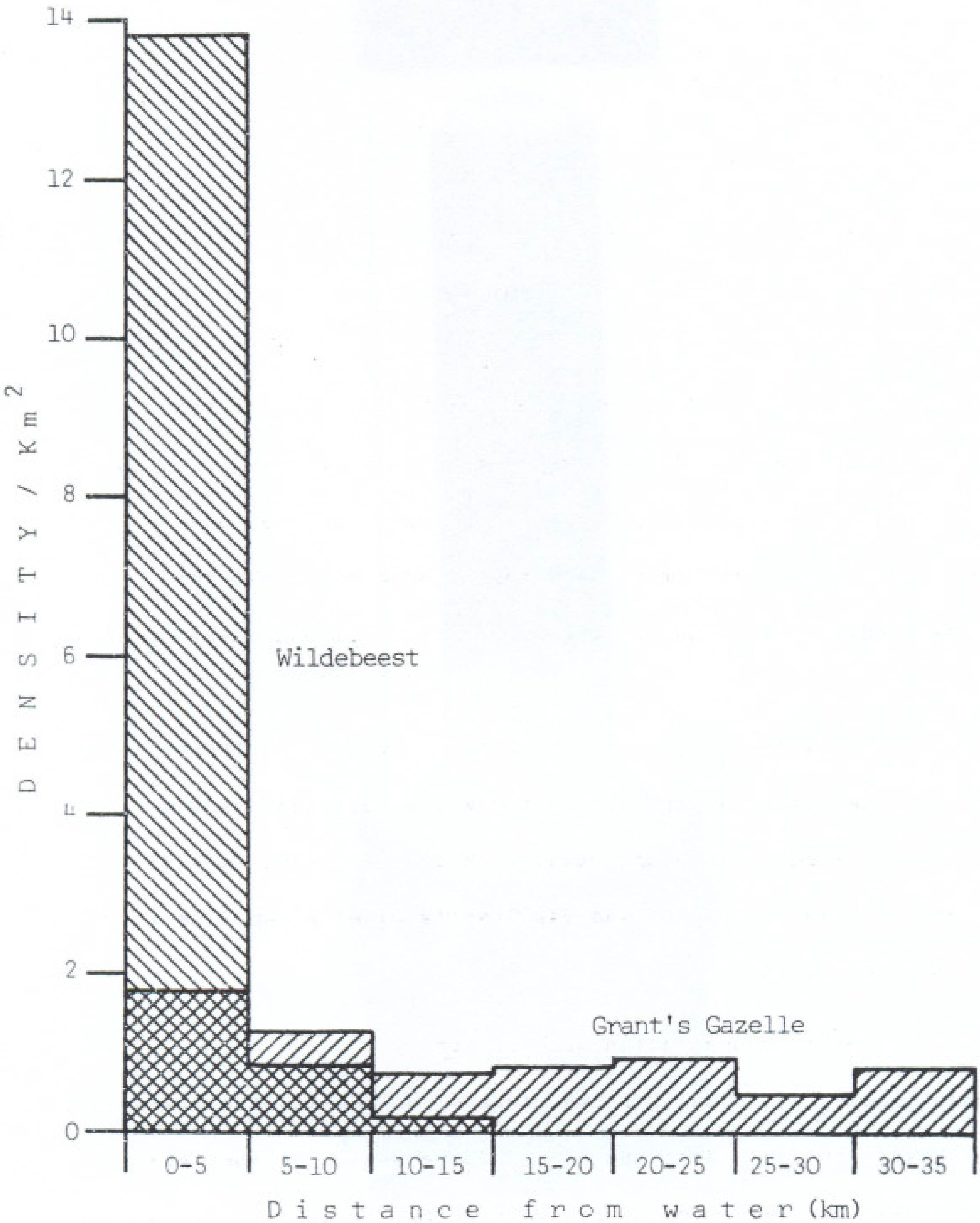
In arid and semi-arid rangelands the major limiting factor is water. Distribution data can be used to measure the distance from water of the various animal species, as has been done in Amboseli[46]. This will give an estimate of the maximum distance from water that the various species can travel. Inspection of the occupance maps will then indicate which areas are unavailable to a particular species on account of distance from water. Information of this kind can be used for planning the location of ponds and boreholes for livestock development programmes[35].

An example of the difference between two species in their dependence of water is shown in Fig. 14 for wildebeest and Grant's gazelle in Amboseli during the dry season. Wildebeest have to keep within 15 km of a water source, whereas Grant's gazelle can live in areas over 35 km from water.

Example 5 : Amboseli compensation calculation

When Amboseli National Park was formed in 1974 it was necessary to exclude Masai livestock from the Park. Compensation to the Masai pastoralists was made in various forms, one being a wildlife utilization fee. The latter was based on an analysis of the number of national park animals that use grazing areas outside the Park, i.e. the livestock

Fig. 14 Distribution of wildebeest and Grant's gazelle from water; data from 5 x 5 km occupance maps (Amboseli data).



ranching areas. Here wildlife are grazing in the ranching areas at the expense of the Masai landowners.

The wildlife utilization fee was calculated according to the following formula[41] :-

$$C = \frac{B}{W} \times (V - M)$$

where C = 'the opportunity cost', i.e. the cost to the Masai of having the Park animals grazing on their land

B = the average annual occupancy in kg. (biomass) of Park animals of areas outside the Park

W = average weight per animal

V = average value of each cattle unit

M = cost of herd management per animal

Values for the above formula were estimated as follows:-

(1) The average annual biomass occupancy of Park animals on surrounding ranchland was calculated by taking the average biomass of grazing ungulates present in the Amboseli basin during the dry seasons (when animals are concentrated) and subtracting from this the average annual biomass in the basin. This gives an estimate of the average biomass of Park animals that occupies areas outside the Park.

The biomass information was calculated using the 5 x 5 grid square animal occupance maps of the Amboseli basin.

(2) One wildlife unit was assumed to be equivalent to one livestock unit; this will overestimate forage losses to the pastoralists, but was used as a first approximation.

(3) The average value of each unit of cattle was assumed to be K.Shs. 134.

(4) The average weight of each animal was assumed to be 180 kg., i.e. close to the average weight of zebu cattle.

(5) The average cost of herd management was taken as K.Shs. 52 per animal.

Example 6 : Designing a tourist road system

Animal occupance maps, along with information on the distribution of habitats, can be used for designing tourist developments and road systems in a National Park. By careful planning it is possible to design a road network which will contain a large number of tourists without local overcrowding and overuse of a small area.

The animal distribution and habitat data can be used to identify a number of zones, each containing a representative cross-section of habitats, and hence of animal species. Within each zone a self-contained viewing circuit can be provided. In this way the volume of tourists can be spread more evenly, which is the basis for the optimum use of the park or reserve.

This approach has been followed in Amboseli National Park, where a road system has been designed for dispersing vehicles from the main concentration area[45]. Five self-contained circuits are planned which should help to improve the amenity value of Amboseli National Park (see Fig. 15).

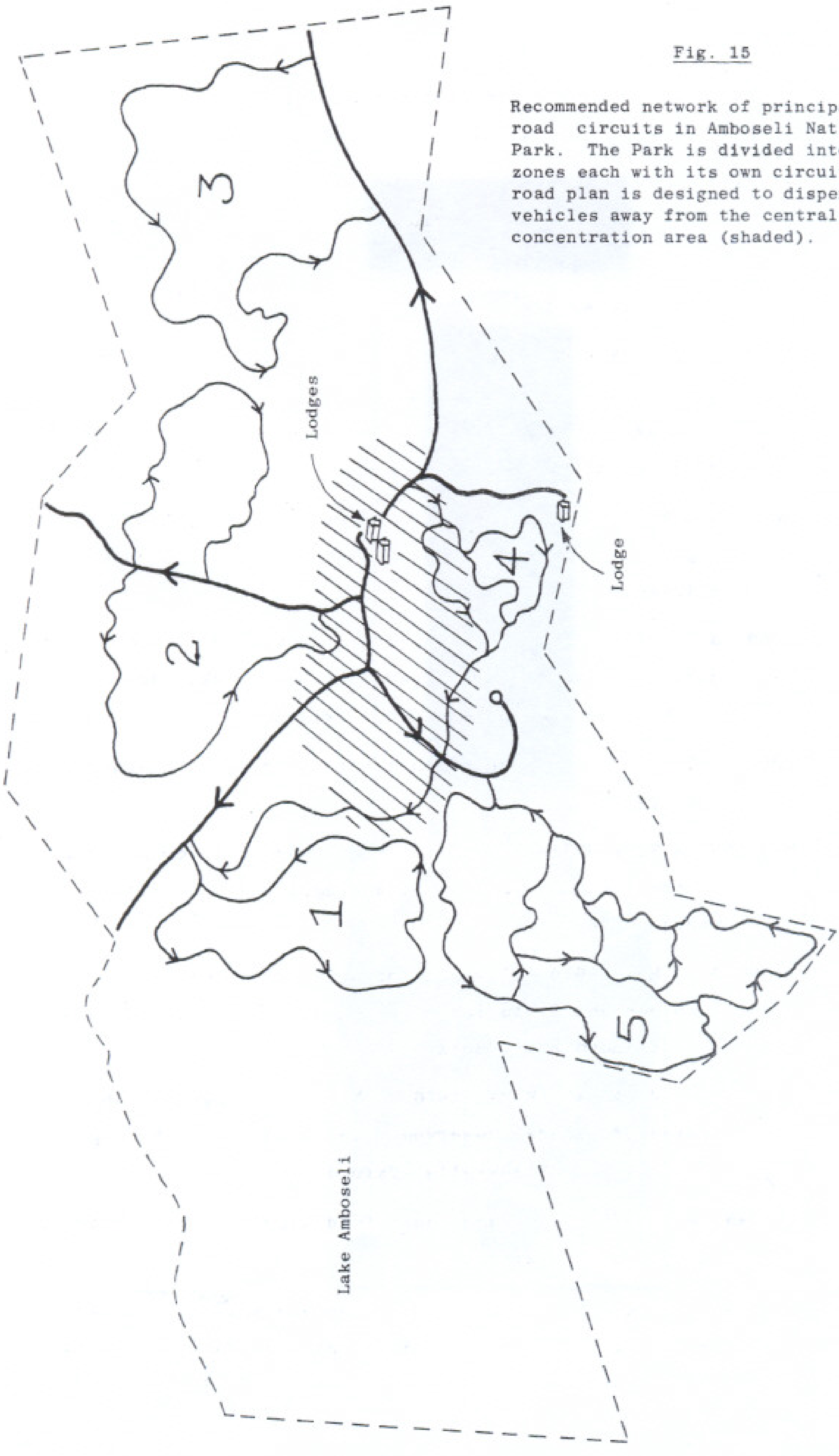


Fig. 15

Recommended network of principal road circuits in Amboseli National Park. The Park is divided into five zones each with its own circuit. This road plan is designed to disperse vehicles away from the central visitor concentration area (shaded).

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