THE GLOBAL ENVIRONMENT MONITORING SYSTEM

GEMS
SAHEL SERIES
NUMBER 3

NAIROBI
1988

Inventory and Monitoring of Sahelian Ecosystem

ANNEX 3:
USE OF LIGHT AIRCRAFT IN THE INVENTORY AND MONITORING OF SAHELIAN PASTORAL ECOSYSTEMS

ITED NATIONS ENVIRONMENT PROGRAMME
OOD AND AGRICULTURAL ORGANISATION
GOVERNMENT OF SENEGAL

SAHEL SERIES

1. Introduction to Sahelian Pastoral Ecosystems Project
2. Rainfall in the Ferlo (Sahelian Region of North Senegal) since 1919
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4. Sampling the Sahel
5. Monitoring Pasture Production by Remote Sensing
6. Inventory of Water Resources in the Ferlo
7. Woody Vegetation in the Sahel

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Executive Summary:

The GEMS Sahel Series is a product of the Pilot Project for the Inventory and Monitoring of Sahelian Pastoral Ecosystems. This project was set up to demonstrate and assess the GEMS methodology for ecological monitoring in a West African pastoral ecosystem.

The present document, the third in the series, is divided into two major sections: the first is a manual for the low-level reconnaissance flight; the second is an analysis of the results obtained by repeated flights over two areas in Senegal.

The manual introduces the concept of using light aircraft for ecological monitoring, and briefly discusses various techniques other than that of the systematic low-level reconnaissance flight (SRF), whose description and criticism form the basis of the rest of the document. A discussion of the use of the SRF for monitoring animal populations, especially sahelian livestock, is followed by a description of methods used to monitor vegetation and soils. The technical capacity of the aircraft, the navigational equipment and the expertise of the crew necessary for the success of the SRF are given considerable attention. The analysis of the resulting data is briefly discussed. The manual ends with an exhaustive checklist for the various members of the crew and ground staff associated with the SRF.

The analyses of the results obtained during four flights over the test zone of the Project and over a more wooded zone to the south are presented and discussed in some detail.

A bibliography of 50 titles is included.

Global Environment Monitoring System Program Activity Centre
SAHEL Series No 3

Title:
Use of Light Aircraft in the
Inventory and Monitoring of Sahelian Pastoral Ecosystems

Author: M. Sharman

Target audiences:
- Development agencies
- Range managers
- Managers of ecological monitoring projects
- Projects intending to use reconnaissance flights
- Observers on SRFs: manual and checklist
- Remote sensing projects

Objectives:

To provide

(1) an introduction to ecological monitoring by use of the low-level systematic reconnaissance flight

(2) advice on the use and limitations of such reconnaissance surveys in the pastoral lands of the Sahel

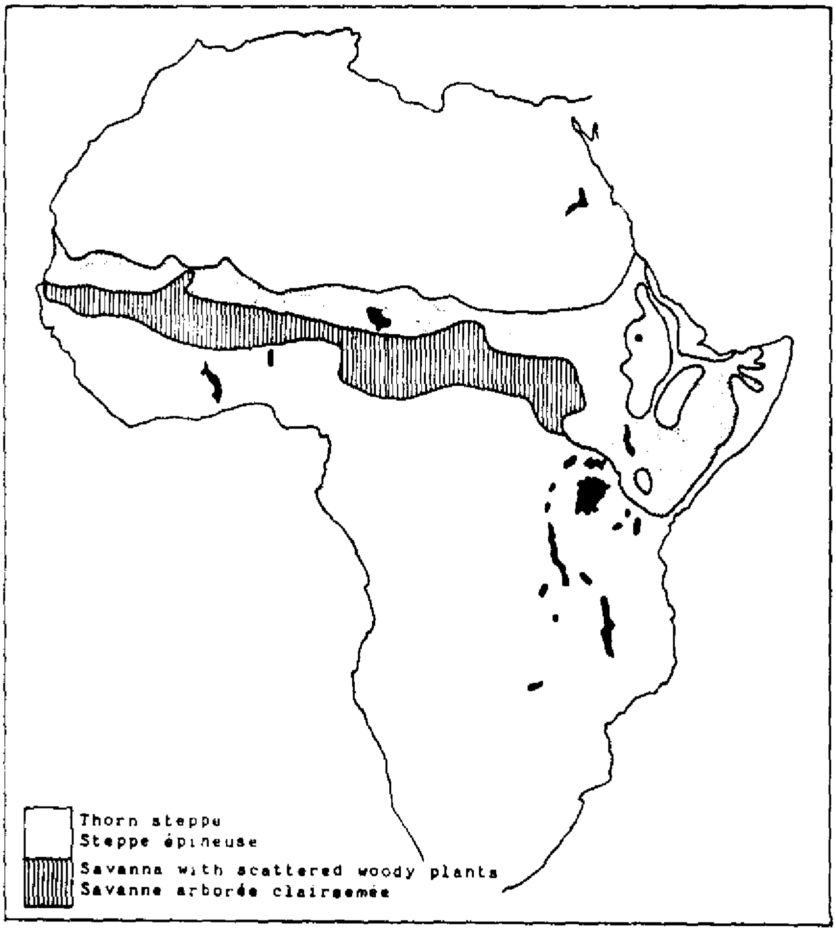
(3) a comprehensive manual and checklist for managers of such flights and participating crew

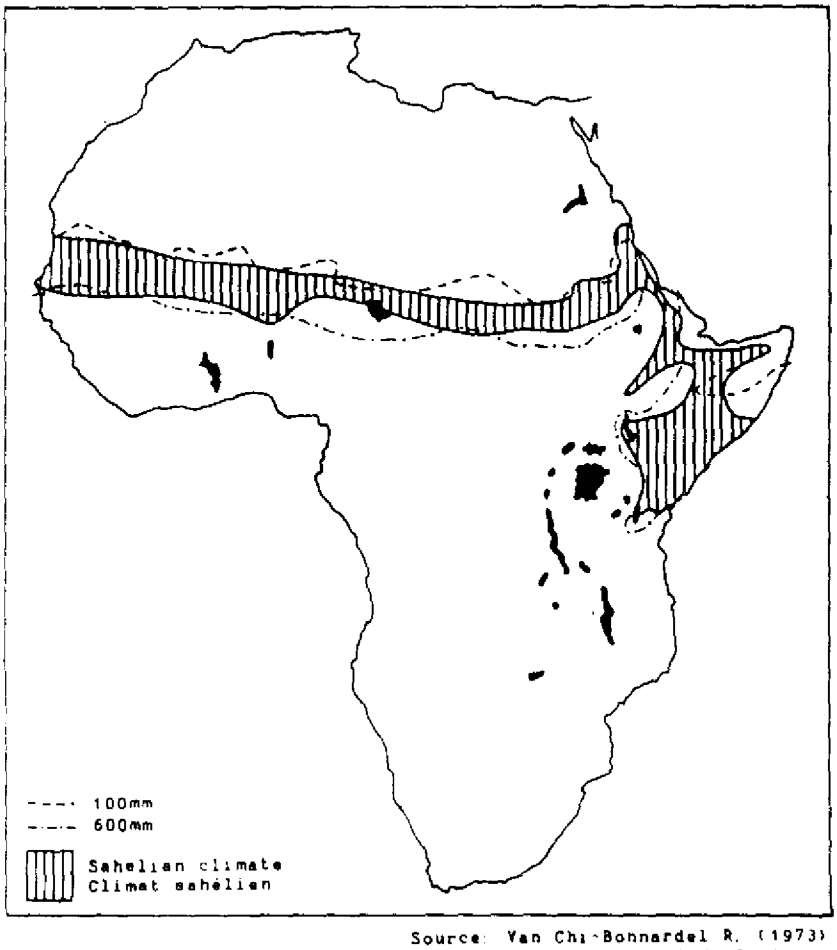
(4) a case study of the sahelian region of north Senegal.

One flew east, one flew west, one flew over the cuckoo's nest...

(First known reference to aerial survey.)

Frontispiece: The sahelian zone





Source: Van Chi-Bonnardel R. (1973)
L'Atlas de l'Afrique. IGN, Paris.
Editions Jeune Afrique. Paris.

Preface

From the available data it seems probable that the numbers of domestic stock in the Sahel have reached levels equal to those of the decade before the catastrophic drought of 1968-72. At the same time the condition of the rangeland has improved only slightly, if at all, from its degraded state immediately after the drought. Furthermore, in parts of Africa, extension of agriculture has meant that pastoralists no longer have access to some of their former pastures. If the future of pastoral peoples is to be assured, the condition of rangelands must be preserved and if possible improved. Unfortunately the protection of the pastures poses well-nigh intractable social and complex ecological problems. The ecological problems alone cannot be solved unless the dynamics of the ecosystem are understood, and understanding can only be achieved by approaching the ecosystem as a functioning whole. To this end, the United Nations Environment Programme's Global Environment Monitoring System (GEMS) set up the Pilot Project for the Inventory and Monitoring of Sahelian Pastoral Ecosystems, which was executed by FAO as part of the global network of GEMS monitoring projects.

Objectives of the sahelian monitoring project

There were two major objectives. Firstly, the project was to adapt the standard GEMS ecological monitoring methods to the inventory and monitoring of sahelian pastoral ecosystems. Thus data were to be collected from observations made at three levels (on the ground, from the air, and from satellites), using methods designed to encourage a systems approach in their presentation and use. Secondly, the project was to collect data which would improve understanding of the renewable resources in the world's arid lands.

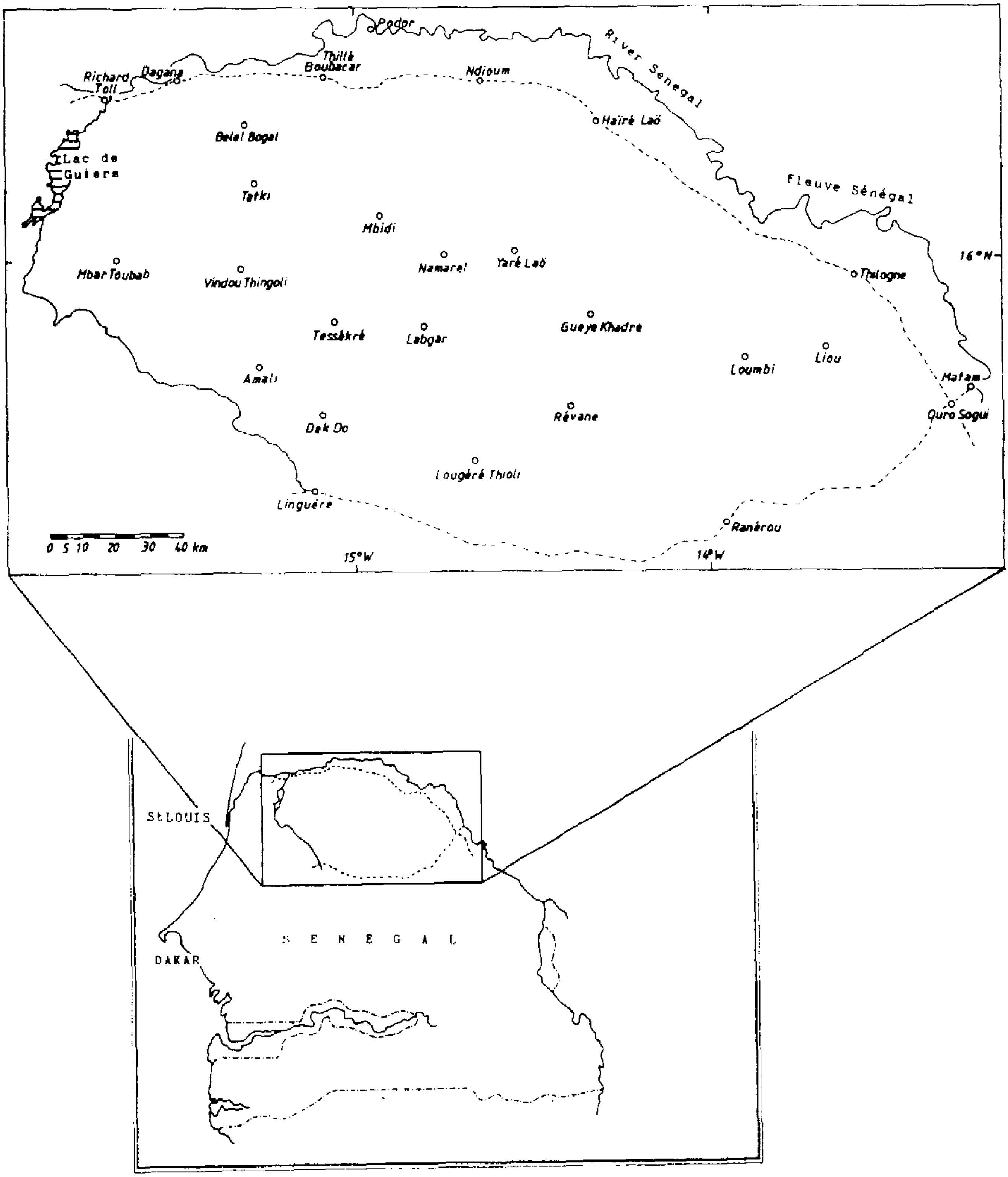
Choice of test zone

The ecology and economy of the north of Senegal is typically sahelian, and the area faces many of the ecological problems that confront the Sahel elsewhere. The zone chosen as a test area for the project, some 30,000 sq km of low-lying pastoral land (Figure 1), is bordered to the west by the shallow Lac de Guiers, to the north and east by the River Senegal, to the southwest by the fossil valley of the Ferlo, ending at Linguere, and to the south by the road between Linguere and Matam (on the River Senegal). This area corresponds roughly with that known traditionally as the Ferlo du nord, or north Ferlo. In the GEMS Sahe Series the test zone is known simply as the Ferlo.

Objectives of this document

This document gives an introduction to ecological monitoring by use of the low-level systematic reconnaissance flight. It thus describes one of the three data aquisition platforms used by the project. It provides advice on the use and limitations of such reconnaissance surveys in the pastoral lands of the Sahel, and forms a comprehensive manual and checklist for managers of such flights and participating crew. By way of illustration, its final pages present a case study of the sahelian region of north Senegal.

Figure 1: Location of the test zone of the Pilot Project



Use of Light Aircraft in the Inventory and Monitoring of Sahelian Pa toral Ecosystems

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1 Introduction

The Sahel, the southern border of the Sahara, extends in a 100-300 km wide band some 5000 km from the Atlantic to Ethiopia (Frontispiece). In the north the soils are sandy, supporting open steppe on low-lying, eroded dunes, while in the south open woodland grows on shallow, gravelly soils, over ferrugineous hardpan. This marginal land is exploited for the most part by pastoralists. Their livestock (cattle, sheep, goats, donkeys, dromedaries and horses) subsist partly on a small range of woody plant species and partly on annual grasses whose uncertain production depends on the amount and the timing of the rains.

There is now considerable evidence that continual excessive grazing pressure is steadily degrading the pastures (Berry 1984, GEMS 1986e, Mabbutt 1985, Orev 1982), and it is becoming increasingly obvious that important management decisions must be made if the land is to remain productive.

Any management decision must be based on reliable ecological knowledge. At the very least managers need to know the numbers, distribution and movements of animals in the area, and they must have a good idea of the capacity of the land. Unfortunately, a combination of factors, including the remoteness and inaccessibility of much of the Sahel, the extreme variability in rainfall and productivity, and the reticence of pastoralists to let their animals be counted, has meant that such basic data is rare; indeed, for the most part, it does not exist.

There is therefore a pressing need for efficient techniques of inventory, monitoring and mapping of sahelien pastoral ecosystems. Aerial surveys can provide much of the needed information with speed, convenience, and economy. GEMS has showed that when combined with data collected on the ground and from orbit, the aerial survey forms part of a efficient array of techniques for ecological monitoring (Gwynne and Croze 1981), and this three-tier approach to ecological monitoring now forms part of the standard GEMS methodology. To demonstrate and test this methodology in the Sahel, GEMS established the Pilot Project for the Inventory and Monitoring of Sahelian Pastoral Ecosystems. This project, based in Senegal, found that the three-tier approach worked well. This document is based on the experiences of the project in the collection of data from light aircraft.

1.1 History of the use of light aircraft in ecological monitoring

In East Africa wildlife was first counted from the air in the late 1950s, at the same time that the technique was being developed in north America. The first workshop on the use of light aircraft in wildlife management in eastern Africa was held in 1968. The Kenya Rangelands Ecological Monitoring Unit, which uses light aircraft extensively, was created in 1976. By 1978 about 200 people were employed in aerial survey work in Kenya alone (Taiti 1981). One consulting firm had surveyed 3.5 million square kilometers by 1979 (Watson and Tippett 1981), and by the early 1980s, the technique had been used in at least 17 African countries, including Botswana, Cameroon, Ethiopia, Ivory

Coast, Kenya, Mali, Niger, Nigeria, Senegal, Sierra Leone, Somalia, Sudan, Tanzania, Uganda, Upper Volta, Zambia and Zimbabwe.

1.2 Uses of light aircraft in ecological monitoring

The following paragraphs give a brief overview of the uses to which light aircraft can be put in the monitoring of sahelian pastoral ecosystems.

1.2.1 Animal census by light aircraft

The light aircraft is now very widely used for the census of wildlife, and is becoming increasingly used in the census of livestock. Reliable results are easily and quickly obtained in areas which would otherwise be difficult or impossible to survey. This report is especially concerned with this use of light aircraft.

1.2.2 Surveys of range condition and water availability

Range condition can be estimated visually from the air, from greenness and percent cover, and, backed up by data collected on the ground, very large areas can be rapidly assessed.

Surface water is availabile in the Sahel principally in and just after the rainy season. At this time of year the herders take their livestock to temporary wet-season camps far from their dry-season pastures. The assessment of surface water availability, perhaps most easily carried out from the air, is therefore useful in understanding the movement and dispersion of livestock.

1.2.3 Large scale photography

A well-known use of aircraft is in the collection of information by aerial photography. Photographs taken from light aircraft at low altitude can be used both for inventory and for monitoring the ecology of the Sahel.

1.2.3.1 Inventory

Vertical aerial photographs can be used for rapid and accurate mapping of geomorphology, drainage and vegetation distribution, soil types and the distribution and nature of erosion (Goosen 1976), as well as the distribution of human settlements and activities. This sort of study may be particularly useful in the Sahel, where maps, if available, may be out of date or inaccurate. It may be possible to use existing aerial photographs, thus avoiding the expense of the survey and of the equipment necessary for taking such photographs.

1.2.3.2 Monitoring habitat changes

Aerial photographs taken of the same area on successive years can reveal ecological changes in an easily assimilated and easily analysed form. The variables whose evolution can be followed include tree mortality and regeneration, erosion and the extension or abandonment of cultivation. Such studies can also provide evidence of the frequency of fire in the area. These photographs need not be rigorously vertical and so can be taken from light aircraft at relatively low altitude, but some feature on the ground must be identifiable in repeated photographs.

1.2.3.3 Monitoring human settlements

In a similar way, aerial photographs taken of the same settlement on successive years can reveal population, social and economic trends from the number and size of animal parks and the extent, number, shape, condition and building material of huts. In the Sahel, where census data are often not reliable, aerial surveys may be designed to estimate the human population by counting dwellings. This work should be supported by ground work in which the ratio of occupied to abandoned dwellings and the number of occupants per dwelling is sampled throughout the census zone.

The density of human settlement may be used, in an area where the median livestock holding is known, to estimate livestock numbers (Grimsdell et al 1981). This method is useful if there are few settlements in area and all of them can be spotted from a high-level total count. However, it cannot be used to examine the ecological relationships which influence the distribution of animals, and is of little use if livestock holdings vary with season or from household to household.

1.2.4 Remote sensing of green biomass

The spectrophotometer or radiometer has proved to be useful as a tool for the estimation ofgreen biomass in the Sahel through the measurement of radiation reflected from growing plants (GEMS 1986c, Grouzis and Methy 1983, Sharman and Vanpraet 1983, Tucker et al 1982, Vanpraet et al 1983). After calibration on the ground, a radiometer mounted on a low-flying aircraft can be used for the rapid quantitative assessment of standing green biomass (De Leeuw 1983), of prime importance for the estimation of grazing capacity in an highly variable environment. The accuracy of this technique is best over areas in which grasses are not mixed with legumes (Sharman and Vanpraet 1983).

1.2.5 Other uses

Preliminary surveys by light aircraft may be useful in interpreting satellite images of the area and in determining the boundaries of a study site. In some regions it may be possibile to land the aircraft to collect data, for example on species composition and structure, during the survey. This may lead to a stratified survey, for example one in which only a few of many aerial observations are checked by ground-truth data.

A light aircraft has also been useful in guiding ground teams to specific sites, such as villages for socio-economic studies, and for the rapid transportation of material and personel between field and base town. This has included the transport of undevelopped film for processing to a photographic laboratory, and delivery for immediate use in the field (Watson and Tippett 1981).

The rest of this document is concerned with the census of livestock and the estimation of various ecological parameters from a light aircraft.

2 Design of survey

2.1 Preliminary considerations

Every aerial survey will have certain principal objectives which must be clearly defined, in collaboration with the final users of the data, before attempting to design the survey. The funds available for the survey will in part determine how long the survey will take, and how accurate, and how precise, the results will be. It may be that satellite images or ground work would add greatly to the value of an aerial survey, especially if it is designed for habitat evaluation or ecological mapping. If so, the expensive and detailed ground-collected data must be used intelligently to supplement the cheaper low-resolution aerial data.

Aerial survey is not the best method of gathering some sorts of information, such as rainfall, plant species, age-sex structure of herds, animal condition or socio-economic data.

The area in which the survey is to be carried out will greatly influence its design. In the Sahel the terrain is mostly flat, occasionally significantly rolling. This means that while altitude can be fairly easily maintained, navigation is difficult. In some parts of the Sahel the ecology (such as woods, repetitive dunes, and the existance of major rivers) may constrain design.

The subject of the survey may well determine in which season the survey should be carried out. It may also mean that sampling effort can be concentrated in certain parts of the area at the expense of others in which the subject variable is known to be rare. Adminsitrative regions may either influence the distribution of the subject variable through different management practices, or occasionally present political problems for the survey.

Survey design is also influenced by considerations of (1) safety, because the lower the altitude the more accurate the data but the less safe the survey, (2) logistics, especially the equipment available and the location of airstrips and fuel depots, and (3) observation conditions, since in the Sahel turbulence and haze make observation difficult in the afternoon and surveys can realistically be planned only for the morning. Surveys should be designed so that the observers are not expected to work for more than two, or at the most, three hours at a stretch (§6.2.3)

The remainder of this document is concerned with decisions which need to be made concerning the design of the aerial survey of livestock in the Sahel.

2.2 Total counts and samples

The purpose of a total count in an area is to count every animal of the population of interest. This method is generally less useful than techniques based on samples. The principal objections to the method are:

(1) It is difficult to define a method for a systematic search in which no animals are recounted and no parts of the area are missed (Jolly 1981a). This is especially true in an area of few landmarks, such as the Sahel.

(2) Since the aircraft covers the entire area and also spends time circling herds while the observers count the animals it is costly in fuel, and hence not very efficient.
(3) The erratic movements of the aircraft tends to nauseate the observers, which reduces the reliability of their results.

In the Sahel natural boundaries are rare, making the definition of the area to be searched problematic. In general the total count is therefore not well adapted to sahelian conditions. It may sometimes be the method of choice for certain clearly defined and restricted regions, especially those such as the delta of the River Senegal (Tourrand and Jamin 1985), in which the river itself provides landmarks.

In contrast with the total count, the sample count is designed to estimate the total population without counting every animal. Methods for sampling systematically are easily designed. The cost of a survey which depends on estimating the population from a sample is generally lower than that of a total count. Since the flight patterns used in sample count often consist of flying along parallel lines, the observers are less subject to random movement and are less likely to get sick than are those involved in a total count. Sample counts depend less on determining the boundary of an area and are particularly well adapted to sahelian pastoral ecosystems which typically cover areas too large for a realistic total count.

The remainder of this document considers only surveys based on samples of the total population.

2.3 Stratified and unstratified surveys

"Stratified" sampling means that the area to be surveyed is divided up into sub-sections which are sampled independently, while "unstratified" sampling means that the area is sampled as a homogenous whole.

Statified sampling can be used either when variable of interest (usually some target species of animal) is relatively homogenous in definite sub-zones within a heterogeneous census area, or when some independant variable thought to influence the target species is distributed in such sub-zones. If possible, strata should be chosen so that there is little movement of the target species across their boundaries between successive surveys (Jolly 1981a). Sub-zones may be determined by physical features, perhaps with the aid of satellite imagery, or by any other criterion which helps to reduce sampling error. In the Sahel there are in general only three major sub-zones, defined by soil type and readily identifiable from the air, which could be used as the basis for sratification: gravelly zones, sandy zones, and zones of hydromorphic soils close to major rivers such as the Senegal and the Niger. The results of the surveys undertaken by the Project show low smallstock densities on gravelly soils and high densities on hydromorphic soils. Cattle densities are highest in the sandy areas and lowest in the gravelly ones. However, these relationships may not be true throughout the Sahel, since local management practices may influence animal densities; in the test zone of the Project there is a higher density of boreholes in the sandy area than in the gravelly area.

Unstratified samples may be used both in surveys in which the distribution of the variable of interest is unknown, and when the variable of interest is relatively homogeneous in the area. In a survey in which there is more than one variable of interest, it will probably be impossible to select strata which are internally homogeneous for all of the variables (Smith 1981).

Although Norton-Griffiths (1978) suggests the stratification of the survey area for reasons of convenience when it is greater than about 10,000 sq km, the Project found no logistic reasons to stratify its 30,000 sq km test zone.

In many cases it may be convenient to carry out the survey with equal sampling effort over the whole area and to stratify the census during the analysis (Jolly 1981a). This technique has the advantage that the stratification can then be made on the basis of any desired criterion, such as soil type or plant biomass. In a survey with several variables of interest, strata can be determined after the flight to help explain the distribution of each variable in turn. This flexible design is recommended by the Project for aerial surveys in the Sahel.

If stratification takes place before the survey, the flight may be designed such that each stratum is surveyed with different intensity, dependent on the difficulty of seeing the animals in the vegetation typical of the stratum (Norton-Griffiths 1978), or, if there is only one variable of interest, on its probable density in the stratum (Smith 1981), in which case sampling effort might be proportional to the square root of the density of the variable (Jolly and Watson 1979).

2.4 Transects and quadrats

Three major possibilities exist for the sampling of a population from the air.

The area to be surveyed can be divided into smaller regions or quadrats. The population found in a subset of these quadrats is then completely counted. Quadrat samples often suffer from large between-sample variance since they tend to include only a few of the range of habitat types in the area. Furthermore, this technique suffers from all the drawbacks of a total count (§2.2) and is not in general recommended for livestock surveys in the Sahel. However, quadrat sampling may be appropriate for certain surveys, such as one designed to determine the extent of charcoal burning in classified forests, or to count the houses in a selected subset of villages. It may also be useful if the results are to be compared to photographs of same area, with the aim, for example, of allowing otherwise enigmatic ecological structures seen on aerial photos of unsurveyed areas to be correctly interpreted.
The other two techniques involve the plane flying along pre-plotted straight lines.

The line intercept technique (Jolly 1979), in which an observer notes the time at which the aircraft crosses boundaries between one habitat (or soil type etc) and the next, is intended to estimate the relative areas of the different habitats. This method is best used only if the area will be crossed by many transect lines, and should be used with caution if the areas measured are likely to have irregular edges. For example, the surface area of the shallow Lac de Guiers (Figure 1) in the North Ferlo in Senegal changes with the season. Its measurement during an aerial survey by the line intercept technique would almost certainly give an incorrect result, as was shown by a computer simulation carried out by the Project. In the simulation the area of the lake was estimated 200 times for each sampling density (from 1 to 200 lines across the lake). The true surface area in the simulation was 143.2 sq km.

Note (1) that the estimates made from flights travelling north and south are less precise than those made from east-west surveys. This is a direct result of the variance in the length of possible flightlines in the two directions (76% and 43% of the mean distance respectively);
(2) that it is unlikely that any area will be crossed by as many as 100 flight lines in a survey. In the surveys undertaken by the project, two flight lines cross the lake north-south. Under the conditions of the simulation, these transects would estimate the lake to have a surface area of 117 sq km.

The results of this simulation show clearly that the line transect technique cannot be used to monitor changes in area of a habitat between successive surveys. This method cannot be recommended for the measurement of surface areas unless no other method exists and a very rough estimate, of unknown precision, is satisfactory. A similar caveat holds for the establishment of maps of habitat or soil type by line transect.

Table 1: Mean extreme values for the surface area (square kilometers) of the Lac de Guiers estimated by line transect.

Direction of flight		Number of flights across the lake							
		1	2	5	10	20	50	100	200
North-South	Minimum	26	33	62	81	99	112	127	128
	Maximum	301	277	226	201	181	167	161	157
East-West	Minimum	36	58	90	112	116	126	130	135
	Maximum	214	203	188	172	168	155	153	149

Note: Values as extreme as these are to be expected in 1 out of 20 surveys at the given densities.

The third technique is that of the strip transect (Norton-Griffiths 1978). All animals of the target species seen within a strip of known width are counted. The strip width is defined by two parallel wires or rods delimiting the field of view of the observer. The strip width must be correctly calibrated and the height of the aircraft above the ground must be accurately known in order to calculate the proportion of the census area that has been searched. The technique has been widely tested and statistical analyses (§2.9) and sources of bias (§7.2) are understood. For reasons which are examined later, this technique is well adapted to the survey of livestock in the Sahel, and the remainder of this document will be concerned with the strip transect technique of aerial survey.

2.5 Randomly and systematically spaced flightlines

When flightlines are at right angles to a baseline, there are two possibilities for the spacing of flightlines: the distances between adjacent flightlines can be random, or the lines can be spaced systematically, usually at equal intervals, across the field area.

Randomly spaced flightlines ensure unbiased sampling of the area and are useful when the object of the survey is to count the population, but not to examine its distribution within the area. Data collected using this technique are unlikely to suffer from resonance with regularly spaced natural phenomena, such as dune formations parallel with the flightlines.

Systematically spaced flightlines result a precise estimate of the total population of the target species but in biased estimates of its standard error (Pennycuick et al. 1977). The standard error is usually overestimated (Smith 1981), so that the stated confidence interval about the population estimate is generally too wide.

Large variance among individual transects, typical of most aerial surveys of sahelian livestock, reduces much of advantage that randomly spaced flightlines may have over regularly spaced lines (Jolly 1981a).

Systematic sampling is used when the object of the survey is not only to count the target species, but also to examine its distribution, and repeated surveys using unstratified systematic sampling can be used to estimate changes in population totals and distribution between flights. The survey should be designed so that transects do not resonate with features on the ground (§2.6).

Since the census area should probably not be stratified before the survey (§2.3), and since the distribution of livestock is of great importance in management decisions, the Project recommends the use of unstratified systematic flights for sahelian livestock surveys.

2.6 Orientation of flightlines

The orientation of the flight lines should be given careful consideration when the survey is designed. Within each stratum the flightlines should normally be parallel, in order to avoid problems of overlapping counts. If the area is stratified before the survey the flightlines in the various sub-zones may be at any angle to the flightlines in the other zones.

The factors influencing the orientation of flight lines for surveys in the Sahel, are, in decreasing order of importance:

(1) The habitat distribution within area to be surveyed. Flight lines should be oriented in such a way as to cut across ecological boundaries and not follow them, so that each flightline will contain roughly the same mean density of the target species. Thus if there is a major rive in the survey area, each flightline in an unstratified survey should ideally cross some of the riverine habitat.

(2) In order to have the highest possible sample size for a given sampling effort, the flightlines should if possible be oriented paralle with the shortest axis of the census zone.

(3) For some purposes it may be desirable to fly in such a way as to be able to map the flightlines onto the Universal Transverse Mercator (UTM grid. In this case the area cannot normally be stratified beforehand. Data collected in such a way can readily be incorporated into a geographic information system (GIS).

(4) The physical features in the survey area may influence the orientation of flightlines. Flightlines should not be oriented parallel with repeated linear features on the ground (§2.5). Surveys concerned with the distribution of livestock near river beds may require special flightlines. Boreholes and other mechanised water points are strong poles of attraction for livestock, and surveys may be designed to take them into account. In the lowlying and generally flat Sahel, aspect and altitude of the land play no role in determining the orientation of flightlines.

2.7 Percent of ground covered

The greater the proportion of the census area covered the better will b the precision of the estimate. There are 3 ways of increasing the percent of ground covered: fly higher with the same strip widths, use larger strip widths at the same altitude, and fly more transect lines across the area (sample at a higher density). There are costs associated with each of these techniques. High altitudes make the incorrect identification of animals more probable, while wide strip widths tire observers rapidly, and make it more likely that animals are missed as the observer sweeps his view from one side of the strip to th other. Increasing the number of transects flown across the area increases the length and the financial cost of the survey.
The surveys undertaken by the Project have shown that in the Sahel it is possible to census domestic livestock from 500ft, with strip widths of about 200m. Since the flightlines were spaced at 10km intervals, the surface which was censused covered about 4% of the whole area. This

sampling density gave confidence intervals of about 20% of the population estimate for cattle, 15% for sheep and goats (shoats), 30% for donkeys, 40% for horses, and 110% for dromedaries (Sharman 1982,1984). The precision of the estimates for cattle and shoats was acceptable for the purposes of the surveys. However, had the surveys been principally concerned with other domestic livestock, the flightlines would have had to have been more closely spaced, at least in the strata of higher livestock densities.

2.8 Frequency and seasonal timings of repetitions

Some surveys, for instance mapping habitat or geomorphology by aerial photography, may be designed to be made once and not repeated. However, it is more likely that surveys will be repeated. In the Sahel, where livestock is still largely transhumant, there are very often major seasonal changes in animal numbers. Interannual variability can also be high; for example, the rains in 1983 and 1984 were so poor that the Ferlo in north Senegal, normally pastured by over a million head of livestock, was virtually evacuated. Repeated surveys, if correctly designed, will allow seasonal or long-term trends to be followed, providing a much better management tool than would a single survey.

Repeated flights designed to follow long-term trends should be made at the same time in successive years. The season at which the flight takes place must be selected with care, depending on aims of survey and the schedule of any other ecological monitoring undertaken in parallel with the aerial survey. If finance and scheduling permit, a minimum of three flights per year should be undertaken for a sahelian pastoral ecosystem. These flights chould take place:

(1) at the end of the growing season to coincide with the period of maximum plant biomass and the collection of quantitative satellite data on production, and to measure the extent of gulley and sheet erosion;

(2) in the middle of the dry season to coincide with the highest concentration of livestock around the boreholes and to monitor the start of migratory movement of livestock;

(3) at the end of the dry season to monitor the pressure on the pastures, and especially the woody species, at their most vulnerable, and to measure the extent of wind erosion and fire.

2.9 Statistical considerations

Transect lengths are not usually equal, and thus sample units are not likely to be of the same size. Jolly's method II or III (Jolly 1969) should be used for the calculation of the confidence limits for the population estimate. Jolly's method II is preferable when the sampling fraction is greater than about 15%; beneath this threshold either method can be used (Jolly 1981a). In practice Jolly's method II is most commonly used and is recommended for use in sahelian livestock surveys.

2.9.1 Calculations

2.9.1.1 Estimate of the total population

The calculation of the estimate of animal numbers in the zone is straightforward, and is found by calculating the density of animals in the area searched and multiplying the result by the area of the study zone. For each species the steps are thus:

1 Calculate SUMs, the total number of animals counted during the survey
2 Calculate SUMa, the total area searched, taking into account the effect of the altitude of the aircraft on the strip widths
3 Calculate the species density d=SUMs/SUMa
4 Calculate the population estimate P=d*A, where A is the area of the study zone.

2.9.1.2 Standard deviations: Jolly's Method II

Jolly's Method II takes into account the different lengths (and areas) of the several transects across the study zone by using the variance between the areas of the transects and the covariance of the number of animals counted with the areas of the transects. The steps are:

1	For each transect, count	s,	the number of animals seen
2	For each transect, calculate	sSQ,	the square of s
3	Calculate	SUMs,	the sum of all the s
4	Calculate	sqSUMs,	the square of SUMs
5	Calculate	SUMsSQ,	the sum of all the sSQ
6	For each transect, calculate	r,	the area of the transect
7	For each transect, calculate	rSQ,	the square of r
8	Calculate	SUMr,	the sum of all the r
9	Calculate	sqSUMr,	the square of SUMr
10	Calculate	SUMrSQ,	the sum of all the rSQ
11	For each transect, calculate	sa,	the product of s and a
12	Calculate	SUMsa,	the sum of all the sa
13	Calculate	d,	where d=SUMs/SUMa
14	Calculate	dSQ,	the square of d
15	Note	n,	the number of transects
16	Note	L,	the length of the study zone perpendicular to the transects
17	Calculate	m,	the mean stripwidth
18	Calculate	N,	where N=L/m
19	Calculate	R,	where R=1/(n-1)
20	Calculate	sVAR,	the variance between the number of animals counted in the different transects, from sVAR=R*(SUMsSQ-sqSUMs/n)
21	Calculate	aVAR,	the variance between the areas of the different transects, aVAR=R*(SUMrSQ-sqSUMr/n)
22	Calculate	aCOVARs,	the covariance of the number of animals and the areas, from aCOVARs=R*(SUMsa-(SUMs*SUMa)/n)

23 Calculate popVAR, the population variance, from

popVAR=(N*(N-n)/n)*(sVAR-2*d*sCOVARa+dSQ*aVAR)

24 Calculate SD, the standard deviation, from SQ=square root of popVAR

25 In a table of t, look up t, with n-1 degrees of liberty at the appropriate level

26 Calculate CL, the confidence limits about the population estimate from CL=t*SD

2.9.2 Clumping of domestic species

Domestic animals are not distributed at random, and the probability of finding an animal depends upon whether or not one has just been found. Domestic animals collect in herds, which are themselves not distributed at random; the frequency distribution of the number of herds per unit of rangeland is neither Poisson nor negative binomial. Herds are highly clumped, giving transect densities which are positively skewed because low and medium numbers of livestock are found on most transects, but high numbers on very few (Grimsdell et al. 1981). Variance is therefore typically large and population estimates of domestic stock are generally imprecise. In the Sahel the livestock are at their most dispersed in and just after the rainy season, when surface water is availabile. More precise estimates will be had from flights at this time of year.

The more precise is to be the population estimate, the higher the proportion of the census area that must be covered, because of the linear relationship between the inverse of the sampling fraction and the standard error of population estimate (data from Grimsdell et al. 1981). Increased precision can also be obtained for a given sampling effort by counting in more, but smaller, independent sample units. However, the subunits of a transect are not independent. Thus increased precision cannot be obtained by treating the densities of the target species in small subsections of transects as if they were seperate and independent estimates of population density.

Some species which are relatively rare are also highly gregarious, and will tend to be absent from most transects but at relatively high densities in a few. Thus, for example, in all of the censuses of the Ferlo, the relative density of dromedaries between transect lines is so strongly skewed that the standard error is larger than the mean population estimate, and the lower confidence limit is therefore negative. This may be avoided if the data can be transformed, typically by a logarithmic or square root transform, before calculating the mean and standard error (Pollard 1977). A logarithmic transform gives rise to a geometric mean, which is smaller than the arithmetic mean; that is, it takes more account of the many small values and less account of the few high values of density (Sokal and Rohlf 1969). On being transformed back, the lower confidence limit will be closer to the mean than is the upper one. The correct interpretation of such limits is given in Snedecor and Cochran (1980). Jolly has suggested a rough way of calculating confidence limits for untransformed data (page 214 of Low Level Aerial Survey Techniques, ILCA monograph 4).

2.10 The systematic reconnaissance flight in the Sahel

In aerial survey literature "systematic" has come to be used to describe a survey in which the aircraft flies along regularly spaced transects.

The Systematic Reconnaissance Flight (SRF) is therefore a technique for making an aerial sample of an area, which may be either stratified or unstratified, with regularly spaced parallel flight lines along which data is collected in strip transects (2.4). These strip transects are often divided into small sub-units for purposes of recording and analysis (§2.5) and for mapping, although the resulting maps must be interpreted sensibly (§6.3.1.5).

A basic introduction to the Systematic Reconnaissance Flight is given in Norton-Griffiths (1978).

The SRF is particularly well adapted to sahelian pasturelands, where the tree cover is sparse, and where there are no great problems of visibility. Few of the domestic species are cryptic - although donkeys may be difficult to see from the air. While goats and sheep cannot be distinguished from the air, especially in mixed flocks, the other domestic species are not easily misidentified.

Although the Sahel is generally flat, so that aircraft could fly at 300-400ft without risk of hitting hillsides, observation conditions are good enough to allow surveys to take place at 500ft, thus increasing the margin of saftey and the proportion of the area covered (§2.7). Even at this altitude, the observers are unlikely to miss many animals. While photographs of herds taken with a 50mm lens can be interpreted, photo counts of shoats are likely to be difficult, and an 80mm objective is preferable. Strip widths of 150-300m on each side are practicable. For surveys designed only to census cattle, the survey can be made at up to 1000ft with strips of up to 500m (Milligan et al. 1979).

Navigation in the Sahel poses special problems. While Norton-Griffiths (1978) states "the only practical method of navigation is by reference to ground features ... ground features must always be the primary navigation aid" and stresses the need for maps, most of the Sahel is monotonously flat and lacking in useful "ground features", and maps tend to be unreliable. In fact, the only practical method of navigation for aerial surveys in the Sahel is with the aid of a global navigation system (§6.1.1.2).

Boreholes present special problems for dry season aerial surveys of the Sahel. Animal densities near boreholes typically increase throughout the morning until several thousand head are concentrated into an area far smaller than a square kilometer. Should the sample strip pass through such an agglomeration, the mean density on the transect will be inflated, leading to a biased population estimate and increased inter-transect variance, and hence decreased precision. Precision can be improved if the parts of the census zone near boreholes, and other areas of high density, are stratified out and the animals in them counted separately (Norton-Griffiths 1978). This may involve breaking off the survey and taking photographs of the animals from a lower altitude. The standard error of the final population estimate is calculated from the normal transect count and not from the counts of the high density areas. Population totals are calculated by adding the high density counts to the normal transect counts. If the relationship between time of day and the number of animals present at a borehole at the season of the survey is known for several boreholes, it may not be necessary to break off the survey to photograph or count the assembly, and the mean number of animals at a borehole could be assumed instead. Data on time of day and the number of animals present at a borehole could be collected by a specialised aerial survey flying over several selected boreholes throughout the morning.

3 Animal Census

3.1 Wildlife

Most large species of wild mammals have almost completely disappeared from the Sahel. Many of the surviving species are either crepuscular or nocturnal, and are present at extremely low densities. Aerial survey is unlikely to be an efficient method of census of these animals, but in some cases it may, nevertheless, be the best method available.

An aerial census designed to count sahelian wildlife must be designed with these species in mind; a survey designed to count domestic species is not suitable for counting jackal, aardvark and small solitary antilope. Not only is relative visibility quite different for the domestic and wild species, but their relative numbers make the two sorts of survey incompatible. For instance, in a recent 14.5 hour survey of the Ferlo the observers counted 44,000 head of livestock and only 15 wild animals.

The census should be designed to search most intensively in areas of probable refuges. For most species this will mean increasing the sampling density as human densities decrease. There are likely to be considerable problems of the statistical interpretation of the results, given the extremely low densities, and it may prove impossible to map the distribution of surviving wild animals in relation to existing or proposed land use.

3.2 Livestock

Sahelian livestock are easier to see and identify than are wildlife, partly because domestic species are fairly conspicuous and occur generally in herds. The range of species types and body sizes is small, so that the observers have a restricted set of search images.

Since in general it is impossible to tell sheep and goats apart from the air, and the two species have different ecological impact, data collected on the ground may be needed to provide an estimate of the ratio of the two species in various sub-zones.

Domestic species concentrate around water points at very high densities, which poses problems of interpretation of the data (§2.10).

3.3 Age structure of population

In areas where calves are kept seperate from adults, some idea of the age structure of cattle herds can be had by recording calves seperately from adult animals. In the experience of the Project, it has proved impossible to determine reliably the percentage of calves in mixed herds from 50mm photos taken through perspex. Special census techniques are needed if the age structure is to be estimated accurately from the air (eg Douglas-Hamilton et al. 1981). However, in most areas of the Sahel the aerial survey is probably not the method of choice for the determination of the age structure of the population, since relatively reliable data can be had from limited ground surveys, or, frequently, from the existing literature.

3.4 Estimation of herd size

The larger the herd, the more probable it is that part of the herd will fall outside the strip. The distribution of herd sizes recorded on the survey is thus biased (Jolly 1981a). If herd size is of interest, Watson and Tippett (1975) suggest that the observer should estimate the number of strip widths which would include the whole herd. The aircraft should then leave the flight line and circle the herd until it has been completely counted. This provides a direct measure of the distribution of herd sizes. For the purposes of the population estimate for the whole survey, the observer divides the number of animals in the herd by the number of strip widths which would include the whole herd. If this technique is to be used in a census of sahelian domestic stock, the survey should be designed so that only a fraction of the number of herds is counted, since as many as 15 herds of cattle and 20 herds of shoats may be expected, on average, in 100km of transect (data from Sharman 1982).

3.5 Carcasses

The Sahel is notorious for catastrophic droughts which are said to have killed many millions of head of livestock since the beginning of the 1970s. However, sahelian domestic stock is highly mobile, and the pastoralists undertake long migrations in time of drought. A decrease in the number of animals in a survey area from one year to the next may therefore arise from heavy mortality or from large-scale migration.

Aerial surveys in which the ratio of live to dead animals is counted can help to distinguish mortality from migration. This technique has been used to effect for elephant populations (Douglas-Hamilton and Hillman 1981), for which the time of death can be established within known limits by the presence or absence of a patch of discoloured ground around the carcass. There is no data on the length of time that the carcasses of sahelian livestock can be seen from the air. However, since they are frequently disarticulated and eaten by cattle, it is probable that any carcass visible from the air is only a few weeks old. The ratio of live animals to carcasses can therefore probably be considered to indicate the current death rate.

3.6 Animal Movements

In some parts of the Sahel the livestock move out of wet season pastures when the surface water dries up. Their mobility is provoked by the severity of the dry season. In other places in the Sahel where water is permanently available at artificial water points, livestock move only when the pastures are exhausted. If aerial surveys are to provide an adequate picture of livestock distribution and movement, there must be at least 3, and preferably more, flights throughout the year (§2.8).

Primary production in the Sahel depends not only on the quantity but also on the timing of the rains, and is thus highly variable. It may therefore be difficult to maintain a regular pattern of reconnaissance flights over a selected area of the Sahel unless it is thought to be worthwhile to survey the area even when it contains almost no livestock.For example, in 1983 and 1984 the production in the Ferlo was so low that almost all livestock left early in 1984, well before the end of the 1983 dry season, and remained far to the south of the Ferlo through the whole of the disastrous 1984 rainy season.

Because transhumance takes place over such large distances, it may be necessary to consider monitoring far outside the nominal study area, both to the more arid and the more humid side of the area, in order to follow the transhumance when it occurrs. This is an expensive solution, which may require international cooperation on the sensitive political question of livestock movement across international borders. Furthermore, in good years there may be no transhumance, and the area to the more humid side of the nominal study area may contain little or no livestock. The area would still have to be monitored, in order to produce comparative baseline data, and the survey might profitably be designed to monitor crops as well as livestock, assuming that an appropriate client could be found.

4 Habitat Monitoring

Many attributes of plants and soils can usefully be monitored from the air (§4.1 and §4.2). This allows the aerial survey on the one hand to follow the evolution of the environment under the existing management practices and on the other hand to examine the distribution of livestock in relation to their habitat.

In an aircraft which has space for a pilot and three passengers, the two rear seats can be occupied by observers whose task it is to record every animal (from a given range of species) which is seen on the strip transect. At the same time, ecological observations can be made by the front seat observer.

In what follows the observers are referred to as "he", but this is not intended to imply that women do not make good crew.

Unlike the rear seat observervations, the ecological observations are conveniently made at regular intervals. The best sampling schedule in the featureless Sahel is probably on the minute every minute, although it may be possible to use a global navigation system (GNS) to determine when to make the observations (§6.1.1.2).

Since the ecological observer is collecting systematic data at regular intervals, it is probably best recorded directly onto checksheets so that variables are not omitted by mistake. If a tape recorder is used the observer should have at hand a list of the variables to be collected. In practice it has been found that writing observations down helps to alleviate boredom and maintain attention. It is self-evident that the larger the number of variables to be measured each minute, the shorter the time that can be devoted to each one. If the ecological observer has too many decisions to make he will get frustrated, his judgement will suffer and he will tire rapidly.

4.1 Habitat parameters for a sahelian pastoral ecosystem

4.1.1 Qualitative assessments

Much of the ecological information collected on an aerial survey is either nominal or ordinal data in the sense of Siegel (1956), and is qualitative in that it involves classification but no numerical estimate. The observer should have had enough experience in classifying the variables that will be collected on the survey that a consistent choice is made between classes, with very little hesitation. This implies a thorough preparation by the organisers of the survey, both in deciding how the range found within the variable is to be classed and, probably, in the collection of a reference library of slides. Since classification of qualitative data is subjective, the same ecological observer should always take part in any surveys whose results are to be compared.

Any variable which can be measured quantitatively could instead be assigned to an ordinal class, often with no great loss of information.

4.1.1.1 Erosion

There are three sorts of erosion found in the Sahel. Each sort may be subdivided by its extent:

Gulley erosion: Traces (one or two small dendritic gulleys in area)
Some (several small dendritic gulleys in area)

	Much (well-formed network of gulleys)
	Extensive (widespread major ravines)
Sheet erosion:	Traces (small dams of plant material)
	Some (patches of naked earth with conspicuous dams)
	Much (patches of naked earth with clear erosion rims)
	Extensive (small cliffs clearly visible at edges)
Wind erosion:	Blown sand (airborne dust or sand during survey)
	Some (deposits of sand visible behind obstacles)
	Much (large areas of scoured naked soil and deposits)

Sheet erosion is often hard to detect from the air. Before taking part in surveys the ecological observer should familiarise himself on the ground with the appearance of sheet erosion in the Sahel; although it is rarely spectacular, it is probably responsible for the wholesale transport of seeds into hollows from surrounding areas, and is thus ecologically significant.

4.1.1.2 Traces of grass fires

Traces of grass fires become difficult to see after a few months. For most purposes, fire should therefore be recorded simply as traces "present" or "absent". If necessary, the marks left by the fire can be classed; for example, into:

Traces (woody vegetation charred, ground discolored)
Some (woody vegetation charred, ashes visible)
Recent (recent fire which has left much of vegetation untouched)
Extensive (recent fire which has removed most of grassy vegetation)

These categories are not altogether satisfactory, since the severity of the fire and its age are classed on the same scale.

4.1.1.3 Extent of bare earth, standing grass and stubble

The extent of bare earth, standing grass and stubble can be measured quantitatively (§4.3.2.1). Alternatively, an ordinal scale can be used for all three variables. The observer should consider only those areas not concealed by tree canopies. A suggested ordinal scale is:

Continuous:	other categories almost or entirely absent
Widespread:	other categories present in small but significant quantities
Patchy:	intermittent with other categories present in equal amount
Some:	present in small but significant quantities
Negligible:	almost or entirely absent

4.1.1.4 Greeness

The primary production of an area can be estimated visually by an experienced observer by considering both the proportion of the ground covered by grass and its greenness (Western, pers comm). The Project has not had the opportunity to test the use of this parameter in the

Sahel, where annual species grow rapidly during the short, unimodal rains, and are brown for the rest of the year.

4.1.1.5 Extent of tree cover

As for the previous variables, tree cover can be measured quantitatively (§4.3.2). If preferred, the following two ordinal scales could be used together:

1 - categorise the general aspect of the area

Clumped: almost all woody plant growth in dispersed thickets
Patchy: significant unevenness in cover of woody vegetation
Even: woody plants reasonably evenly distributed over area

2 - consider only areas in which there is standing woody vegetation (ie inside clumps of trees)

Thicket: almost no grass or naked earth visible between crowns
Closed: many crowns touch
Open: most crowns separated by 1-3 crown diameters
Dispersed: crowns well separated, by 3-10 crown diameters
Scattered: woody plants widely separated
Absent: few or no woody plants

If these observations were compared with ground data the categories could be calibrated against measured tree densities. Subsequent comparison with recent high-level aerial photographs or very high-resolution satellite images such as those from SPOT would make it possible to make up-to-date maps of the nature and extent of the tree cover in the field area.

4.1.1.6 Extent of tree mortality

In the Sahel it is impossible to estimate tree mortality among standing trees from the air in the dry season, since many living trees have no leaves. In many areas it is also difficult to get a reliable estimate in the rains, since Acacia albida sheds its leaves in the wet season.

While current mortality cannot be readily measured, in some cases the number of prostrate trees acts as a "trailing indicator" of tree mortality. However, this parameter must be given its correct ecological interpretation. Dead trees are likely to be culled rapidly near human habitation, and the proportion of prostrate trees is not necessarily an index of the status or trend of the population. The proportion of standing to prostrate trees can be recorded on the following scale:

Extensive: almost all trees prostrate
Much: majority of woody vegetation is prostrate
Some: many prostrate trees, but most standing
Little: a few prostrate trees, great majority standing
None: no prostrate trees

4.1.1.7 Extent of agriculture

Estimating the extent of agriculture in the pastoral regions of the Sahel poses special problems for the SRF because (1) wherever fields are seen they are clumped, usually along dry riverbeds, but these cultivated areas are very widely dispersed, (2) in the dry season it is difficult to tell abandoned fields from cultivated fields, and (3) they are not always entirely enclosed, or the fence is buried in sand, making it sometimes difficult to say whether or not the plane is over a field.

Although an aerial survey could be designed to collect this data, low-level flights may not be the best method for measuring the extent of agriculture in the northern Sahel. In areas principally used for rearing livestock, the results will probably be difficult to interpret. Where recent cover is obtainable, high-level aerial photography is better adapted, although the problem of abandoned fields and dilapidated hedges is if anything more acute. Satellite images (Landsat, and especially SPOT) may also be used to examine the extent of large fields.

If the extent of agriculture is to be measured during an SRF, it could be done by a modified one-zero sampling in which the ecological observer records whether or not fields were seen within a given distance of the aircraft during the course of each minute. If fields were seen, their extent could be graded, for example, by:

Small-time: one or two small fields seen
Occasional: several small fields seen
Intensive: few large or many small fields seen
Extensive: more than half of minute spent over fields

In agriculturally oriented areas, the crop type could be noted. These are likely to include millet, sorgho, groundnuts and cotton, and, near major rivers, rice and sugarcane.

4.1.1.8 Extent of reafforestation

The low-level reconnaissance flight in general, and the SRF in particular, is not well adapted to the estimation of the extent of reafforestation in the Sahel, because the probability of flying over an area of reafforestation is extremely low.

4.1.1.9 Extent of charcoal burning

The extent of charcoal burning is best measured during a survey designed for that purpose, but useful data can also be collected during a livestock-oriented SRF. The ecological observer should look for circular black scars on ground or the presence of mounds, and record whether the burning is active or old, and the extent of charcoal burning on an ordinal scale, for example:

Absent: no traces of charcoal burning
Scattered: scars or mounds present but rare
Some: 2-5 scars or mounds visible near aircraft
Abundant: more than 5 scars or mounds visible near aircraft
Intense: most of ground cleared or covered by scars or mounds.

4.1.1.10 Availability of surface water

Surface water is probably of interest only in wet season surveys; in the dry season the only surface water in the Sahel is likely to be in the major rivers such as the Niger and the Senegal. Although the state of drainage may be of interest for some surveys, in most cases, if a wet season survey takes place within one or two days of a storm, it is of little use to record the amount of surface water visible since there is no way of knowing how long the water has been there or how long it will last.

4.1.1.11 Other parameters

While the preceding paragraphs have described many of the variables whose qualitative measurement is of interest in the Sahel, other features of the survey area could be recorded during the flight, including, for example, the colour of the soil, the stage of plant growth, or characteristics of the landscape such as the presence of termite mounds and the orientation of cattle trails.

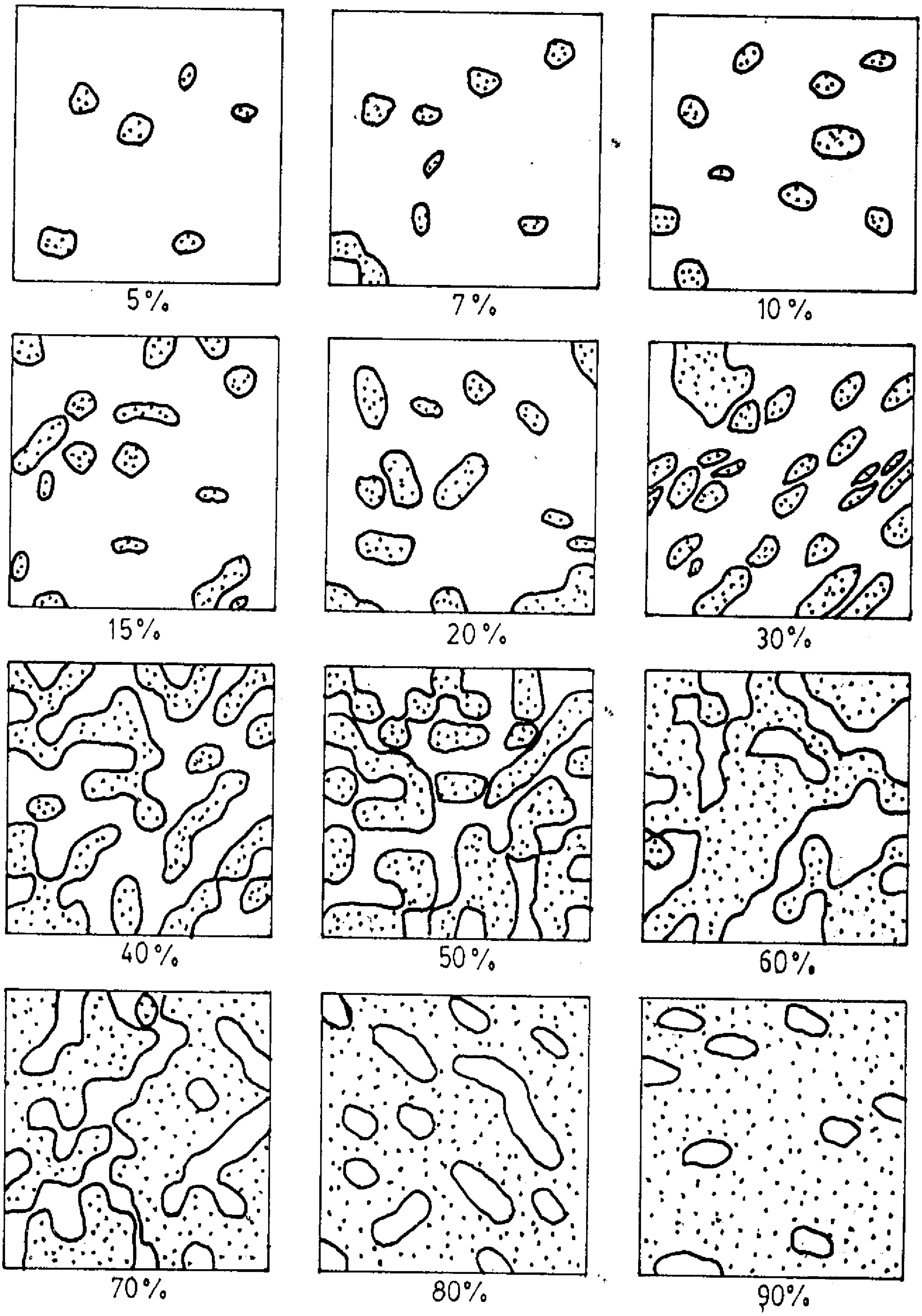
4.1.2 Quantitative assessments

Some of the data collected by an ecological observer can be recorded on an interval scale, frequently in the form of percentages. The subjectivity in the estimate can be reduced by the use of percentage sketches (Figure 2) with which to compare what is seen on the ground. The Sahel is typically highly heterogeneous, so that, for example, tree canopies may cover 30% of the ground in one spot and less than 1% only fifty meters away. Before he can record a measurement the ecological observer must therefore first decide on the limits of the "scene" in which to estimate. The Project has found it convenient to make ecological observations on an area of about 200m wide and 600m long. In order that the view is not oblique, the sample area starts as close to the side of the aircraft as possible.

4.1.2.1 Extent of bare earth, grass and tree cover

The extent of bare earth, standing grass, stubble and tree cover can be measured on an ordinal scale (§4.1.1.3 and §4.1.1.4). If an interval scale is to be used, the ecological observer should estimate cover to the nearest 20% unless there is less than 20% cover, in which case 10%, 5% and 2% could be used. The suggested intervals give an 8-point scale, which is probably as accurate as anyone can reliably hope to be, especially when making estimates very rapidly from an aircraft. Finer

Figure 2: Reference patterns for the estimation of percent cover



graduations would give only the illusion of increased precision.

4.1.2.2 Ecological use of low altitude aerial photographs

Aerial photographs taken obliquely are difficult to interpret quantitatively. It is doubtful that such photographs can be used to check the accuracy of the observer's estimates unless the angle of the optical axis of the camera relative to the vertical can be measured at the instant that the photograph is taken. Even in this case, complicated mathematics are needed to correct for vewing angle across the scene. The Project cannot recommend this technique.

However, percent cover can be accurately measured from photographs taken vertically from the aircraft.

If vertical photographs are to be used for quantitative ecological measurements, the camera should be fitted with a motor drive, a large magazine of color transparency film, an automatic timer, and a device to register the altitude of the aircraft and the time or location of the photograph on each frame. The interval at which photographs are taken will depend on the purpose of the survey.

In the Sahel, differences in the altitude of the land seen on any one photograph are likely to be small. Areas measured from vertical photographs and corrected for the altitude of the aircraft will in general be unbiased. Areas are measured from the photographs by any standard technique. Perhaps the most efficient method involves overlaying on the image a transparent sheet marked with a systematic unaligned random pattern of a known number of dots (Lawrence 1979). The data analyst then counts the number of dots falling in the different vegetation types or classes.

When designing the survey it should be borne in mind that the analysis of each photograph takes a long time. This technique is therefore particularly valuable in agricultural areas, where the crop types are to be recorded and the cultivated areas measured accurately. Photographic measurement of ecological parameters would not normally be recommended in the pastoral areas of the Sahel.

5 Logistics

The first logistic problems to be solved are to decide how the survey is to be managed and financed. Equipment, including the aircraft and its navigation system, must be hired or bought, and thoroughly checked. Contracts must be signed, insurance bought, and the necessary clearances arranged.

5.1 Survey design

Once the objectives of the survey are clear (§2.1), the team responsible for the design of the survey must chose the methods which will be used.

Decisions must be made on the limits of the survey area and its stratification, the orientation of flight lines within the strata, the strip width and interline interval, and the altitude and speed at which the survey is to be carried out.

The objectives of the survey will determine the variables to be collected. The person responsible for the analysis of the data must help to establish the system of coding and the design of checksheets, which should be tested using dummy data. When a satisfactory system is worked out, the list of codes must be duplicated and sufficient checksheets must be prepared for the survey. Sample code lists and checksheets suitable for a livestock survey in the Sahel are included at the end of this document.

5.2 Aircraft

The number of hours under survey conditions that the aircraft can fly without refuelling may play a part in determining the design of the survey. Arrangements must be made for refuelling, and if necessary, the maintenance of the aircraft in the field. An adequate system of altitude control must be installed and tested. Navigation equipment must be capable of guiding the aircraft along precise flight lines, and the pilot must be trained in its use. Any auxilliary sensing and recording instruments must be prepared and tested.

At least two crews have survived a crash and two other crews have been killed in surveys or training flights; material designed to increase the safety of the crew after a crash, including first aid kits, water, compasses and signalling devices, are extremely important.

5.3 Ground support

Provision must be made for the transport of the ground support teams. Their vehicles should be suitable for a search of the field area if the aircraft fails to appear at a rendezvous. In most areas of the Sahel Peugeot 404 pickups would be adequate.

The ground teams must prepare fuel depots before the survey starts and provide transport between airstrips and the field base during the survey. Ground support teams are also responsible for moving and reestablishing the field base if necessary.

On some surveys the ground teams will also be responsible for the collection of data, for which they should have the necessary training and equipment. If necessary the collection schedule should be coordinated with that of the air crew.

There should be adequate facilities at the field base for the immediate transcription from tapes to checksheets of data collected on the flights.

The ground crew should know both the plan of flight for the day, and the estimated time of arrival of the aircraft at an agreed airfield.

5.4 Information transfer

The data collected on the survey is useless unless it can be given to the users in a suitable form. This will usually mean considerable analysis, digestion and interpretation of the data, and its clear presentation in a document which is as simple and direct as possible. The appearance and ease of use of the final document is important, since it influences the user's assessment of the worth of the work. Competent personel must be found, some of whom should preferably have taken part in the survey, and provided with the necessary equipment (§6.2) to carry out this transformation.

Permission to publish the document must be obtained from the relevant authorities, and provision must also be made for its transmission to the users.

6 Equipment and personel

6.1 Aircraft

Many aircraft are suitable for aerial survey work. The 1979 workshop organised by the Global Environment Monitoring System discussed the merits of 13 possible aircraft (ILCA 1981).

The wing roots should be above the passenger cabin so that the observer's view is not obstructed. Forward visibility should be good for the pilot and front seat observer, who should also have a clear view of the ground near the side of the aircraft. For sahelian surveys the aircraft should be capable of flying slowly at low altitude for long distances without refuelling. It should be highly reliable in conditions in which the engines may be running in hot and extremely sandy air. The aircraft should be quiet both inside the cabin and out, comfortable, and safe at low speeds and low altitudes. A twin-engined plane is probably safer than a single engined one. Ideally it should also be cheap.

While helicopters are invaluable if frequent ground samples are needed, or if accurate counts are to be made of large herds or of concentrations of livestock at boreholes, they are generally noisy and very expensive to run. They are also less easy to keep flying in a straight line and more likely to crab than is a fixed-wing aircraft. A light fixed-wing aircraft is therefore better adapted to the needs of a standard livestock survey in the Sahel than is a helicopter.

The sahelian landscape has very little relief so that no special aerobatic abilities are needed. An aircraft adapted to short take-off and landings may be needed if ground samples are to be taken, since nearly everywhere scattered bushes and trees would present a hazard. If he is expected to land during the survey, the pilot must be able to recognise from the air the difference between pans of hard sand and sheets of soft blown sand. In the Sahel, firebreaks are often used as roads, and become potholed and hollow, and are then unsuitable as landing strips.

6.1.1 On-board equipment

Counts of large groups of animals from the air tend to be inaccurate (Stelfox and Peden 1981, Watson and Tippett 1981), and many survey units instruct their observers to photograph groups of 10 or more animals (eg Norton-Griffiths 1978, Stelfox and Peden 1981). The single-lens reflex cameras used by the rear seat observers should be fitted with motor drives. The pictures should be taken on fine-grain high-speed colour transparency film. The method for taking photographs of large groups of animals in the transect strip is described in Norton-Griffiths (1978). While not needed on most SRFs, a cine camera or video may be useful for some applications.

Thermal scanners have not been tested by the Project, but they are probably of little use in detecting livestock in the Sahel since the body heat of animals will be swamped in the reflected radiation from the ground.

The rear seat observers should use tape recorders for collecting data so that they do not need to take their eyes off the transect strip.

Spare cameras and tape recorders should be carried in the aircraft.

6.1.1.2 Navigation

Accurate aerial navigation by traditional means is difficult when flying at low altitude in the flat and featureless Sahel. Most systematic surveys will probably need navigational equipment such as the OMEGA Global Navigation System. These systems are expensive, and may cost as much as the aircraft.

At low altitude, contact with the GNS transmitters is sometimes lost. The locations given by the instrument are then the result of dead-reckoning by its computer. Local repeater stations set up in the field area would add to the cost of the survey but reduce the risk of the GNS temporarily losing contact with one of the transmitters, and would thus make the location of the aircraft, and hence the observations, more certain. Local conditions and the requirements of the survey will determine whether or not repeater stations can be justified. Satellite based GN systems are presumably more reliable in this respect.

Near the start of transects, as the aircraft is rapidly changing its heading, the GNS computer is sometimes unable to calculate fast enough, and the reported position is then incorrect. The pilot should therefore try to fly in a straight line into the the transect. It may be necessary to establish a preliminary waypoint on a projection of the flightline one or two kilometers outside the survey area.

Whenever the GNS is not dead reckoning the front seat observer should, at frequent intervals, record the position of the aircraft. In this way the track of the aircraft is known and subsequent analysis can take account of the distance of any given observation to ecologically important features such as water points, towns and rivers.

6.1.1.2 Altitude control

In rare cases it may be possible to use a barometric altimeter for altitude control in the Sahel because the terrain is so flat. Since surveys will probably take place in the morning (§2.1) the altimeter will have to be repeatedly corrected as the air heats up.

In general, however, a barometric altimeter is not accurate enough and differences in ground level are great enough to make it useless for the precision needed in aerial survey work. In the Ferlo, for example, geodesic points have altitudes varying between 3 and 63m (10-207ft) above sea level, so that a barometric altimeter could not be used.

Radar altimeters are well adapted to maintaining an accurate altitude above the ground at low levels. Slight bank of the amount likely to be experienced during the survey does not affect the altitude reported by a radar altimeter because the instrument emits and receives in a cone. While a radar altimeter may be inaccurate once the aircraft is more than about 600ft above the ground (Douglas-Hamilton et al. 1981), it is accurate in the range of heights most likely to be used on livestock surveys. A radar altimeter may occasionally be affected by high concentrations of iron in the ferralitic soils of the Sahel. A barometric altimeter should be checked frequently during the survey to make sure that the reading of the radar altimeter is reasonable.

If a radar altimeter is not available, good results have been obtained with a shadow meter. This simple device, described in Norton-Griffiths (1978), has not been tested by the Project. Its use may restrict the time of day over which the survey can be made, and it is easier to use from aircraft in which the pilot has a clear view of the ground on both sides of the fuselage.

6.1.1.3 Transect delimiters

Transect delimiters can be straight rods or taut wires attached under the wings parallel to each other and to axis of aircraft. They must be marked in such a way - for example, with alternate bands of black and white sticky tape - that they are clearly visible in the photographs, in which they will be out of focus. The width of the strip seen by the observer between these delimiters must be measured on the ground and in the air. These measurements are described in Norton-Griffiths (1978).

6.2 Crew

Although many people are sceptical of the results (Norton-Griffiths

1978), surveys may be possible using a single seater aircraft in which the pilot makes the observations. However, the expertise necessary to be a pilot-observer is rare, and most surveys are carried out with a pilot and 1-3 observers. With three observers, one, seated beside the pilot, takes ecological data and the other two, seated behind, collect data on the other variables of interest.

6.2.1 Requirements

Pilots need to be very highly qualified, with a minimum of about 1000 hours of flying time (conclusion of ILCA workshop 1979), and a thorough understanding of the needs of the census (Norton-Griffiths 1978). By temperament they should be ready to endure long hours of boring but exacting flying, during which they must maintain accurate course and altitude control. The pilot should be prepared to fly straight and level into and out of flight lines and avoid the temptation to bank sharply as soon as the transect is finished. This gives the front seat observer time to record altitude and position at the start and end of the transects. The pilot should also occasionally be prepared to circle widely between flightlines to allow the observers a few moments of relief from their concentration.

Observers must be familiar with all the equipment they will have to handle, and must be able to change films and cassettes rapidly. Before the flight, and where possible, between flightlines, they should check that their tape recorders are working correctly, that their cameras are focused at infinity, and that the shutter mechanism is working.

The motivation of the observers is extremely important. If full-time observers are used, they should not fly constantly. Motivation can be increased by participation in other activities of the survey team, such as design, experimentation, collection of ground-truth data, analysis, and the prepration of reports.

The boredom inevitably experienced by the observer during the flight is liable to lead to bias through loss of concentration, especially in areas of low animal densities. Up to a point, this is partly alleviated by having many variables to monitor.

6.2.2 Training

Watson and Tippett (1981) state that "competent observers are born, not trained... the method is essentially untransferrable". This opinion is not shared by other experts in the field. For example, Dirschl et al. (1978) describe techniques in which the trainees progress through increasingly complex tasks in the air and on the ground (using slides and other aids) to improve their ability to make rapid and accurate estimates of animal numbers. These techniques have been shown to improve observer's abilities (Stelfox and Peden 1981) so that they are highly competent within three months (Norton-Griffiths 1978). That training improves performance is also bourne out by Watson et al. (1981), who note that experienced observers are more accurate and consistent than are inexperienced observers.

Observers collecting ecological data need special training (Andere 1981), not only in estimating percentages but also in detecting and measuring environmental indices, such as wind erosion and different degrees of greenness, from the air.

Refresher courses for trained observers are also desireable, partly in order to monitor their performance.

6.2.3 Performance

The observers are required to concentrate for several hours at a time on spotting and making precise and rapid decisions based on glimpses of animals which may be only partly visible. They are subjected to random unpredictable movement, vibration, and continuous loud monotonous noise. In the Sahel the temperature in the cabin may often be more than 40°C (104°F). The observers must make decisions rapidly, with no chance of changing their opinion. These stressful conditions result in rapid fatigue and nausea, especially for less experienced observers.

Performance and reliability falls off rapidly with fatigue. In some cases the observer becomes unreliable after as little as an hour (Watson and Tippett 1981). These authors state that they "have never flown with an observer who was capable of more than two hours of continuous attention". Observers should certainly not be allowed to continue for more than three hours at a stretch (Norton-Griffiths 1978).

6.2.4 Regional cooperation

In the initial surveys in a country that has no trained pilots or observers, experienced crew can be brought in from elsewhere, especially from countries with a similar ecology. This cooperation is to the mutual benefit of the two countries, since the host country has the chance to learn the techniques and the crew from the donor country gain experience in different conditions. However, if surveys are to be undertaken frequently, it is impractical to continue to hire crew from other countries. National staff must be trained as observers and pilots.

6.3 Data Management, analysis and presentation

The responsibilities of the survey team include the analysis of the data and its interpretation. An initial report will ideally be produced within a few weeks of the end of the survey, and full report, including distribution maps, within about 2 months. The survey team must therefore have access to adequate facilities for handling and analysing data and for writing reports.

The data will normally be interpreted with reference to data from other sources, such as the established literature and maps, data collected on the ground, and satellite images. The analysis should be designed so as to make this integration and synthesis as straightforward as possible.

The finished report should be presented in a form in which the data is easily understood and used, and which if possible prevents its misinterpretation or abuse. Analysed data will frequently be mapped, so that the analysis should include the translation of the raw data into map-ready data.

6.3.1 Computational requirements

For small surveys the data can be worked up by hand, possibly with the aid of a programmable calculator. This has the advantage that the analyst gets a good feeling for the data and its limitations, but the disadvantage that analysis of the various relationships among the variables is laborious and repetitive, and mistakes can be made. The analysis is therefore frequently limited to the estimation of population totals and standard errors. This calculation usually follows Jolly's (1969) method II, described in §2.9.2 and in Norton-Griffiths (1978).

Most SRF surveys of livestock in the Sahel will produce a volume of data which would be difficult to analyse by hand. For example, the surveys in the Ferlo last 14 to 15 hours and cover 30,000sq km. With a sample of about 4% the rear-seat observers make some 3000 observations (totalling some 40-50 thousand animals), all of which include the time of the observation and the identity and number of the variable seen, and some of which also include supplementary information on the animal's coat colour, its behaviour, or its environment. At the same time the ecological observer collects between 850 and 900 observations of 10 parameters. If this data is analysed by hand, it is unlikely that many relationships will be examined.

For most surveys of sahelian livestock, then, it is preferable to analyse the data by computer. This approach has the advantage that the data once stored are always available, so that subsequent analysis, or comparison between surveys, can be made with ease. The disadvantages are those common to all computer-assisted analysis; the analist is remote from the data, and it is all to easy to "go fishing" rather than to test predictions of hypotheses.

6.3.1.1 Data collection

In order to calculate the density of animals on a transect the mean strip width on the transect must be accurately known. Since the width of the strip is proportional to the height of the aircraft above the ground, the altitude must be recorded at frequent intervals.

In a systematic census the observations should be located with reference to subsections of the transect line so that the distribution of the variables can later be plotted. The observations must therefore be recorded in relation to the ground position or the time.

The observers must have access to unambiguous definitions of the parameters to be counted - when do "huts" become a "village" and a "village" a "town"?

6.3.1.2 Software

The program, or more probably the suite of programs, used to handle SRF data must be flexible enough that it does not hamper the survey design, and that it can allow for changes between surveys in the nature of the variables collected and in the arrangement of the checksheets. It should be written in such a way that it is capable of easy modification It should allow for stratified and unstratified surveys, and the partia repetition of flightlines. It may need to allow for breaks in flightline while accurate low-level or circling counts are made of larg groups. It should accept data from external sources, such as satellite data or soil maps. It should either itself provide a range of suitable statistical tests, or prepare data files adapted for input into a standard statistical package. Above all, it must be tested rigourously before being used for the analysis of data.

6.3.1.2.1 Data verification

The transcription of data from tapes to checksheets, its coding and its recording on computer tapes or disks all need great care. The first task of a SRF data handling program is to check the data exhaustively for internal consistency. Thus, for example, the number of subunits on each transect should be the same for each observer, dates and times should be plausible, and all the codes used should be valid.

6.3.1.2.2 Analysis

The software under development by GEMS provides the following features.

Some sections of the flightlines may have been flown under conditions c poor visibility (blowing sand) or one of the observers may have been sick. The section may or may not have been reflown. The user has the option of excising bad segments from the full data set.

The user has the choice of whether or not to calculate and apply a phot correction factor for each observer and each species. The program provides alternative methods for calculating the correction factor, including regression, major axis, and the simple ratio between observer's estimates and the photo counts.

The data is corrected minute by minute for strip width according to th alitude of the aircraft, and from the resulting strip widths, the area searched is calculated. On systematic reconnaissance flights the tota field area can be calculated from the total transect length and the distance between transects.

The data sets collected by the two rear-seat observers are checked against one another to see if one observer consistently counted more animals than the other. If the user thinks it warranted, the low counts are corrected for the estimation of the population totals. If the data are available (Jolly 1981b), the observer's data can be corrected for bias due to differences in the visibility of the different species in the various habitats. After correction for bias, the program pools the minute-by-minute data collected by the left and right observers, since they are not independent estimates of animal densities.

The program allows the user to select from among the variables contained in the data files the ones he wishes to analyse. It transforms the data if necessary (§2.9) and calculates the population estimate and confidence limits for the selected species, using Jolly's Method II (Jolly 1969), which takes into account unequal lengths of transects.

For the preparation of distribution maps from data collected on systematic reconnaissance flights, the program works out the system of gridsquares best adapted to the given flightlines. For the variables selected, the program then assigns minute-by-minute data to gridsquares, casting data from minutes which span gridsquare boundaries proportionatley into the two squares. The data assigned to border grid squares and grid squares at the edges of unsampled areas within the field area, such as lakes, are corrected for the portion of the grid square surveyed.

Since livestock are generally distributed at low densities but clump in herds, the mean densities of livestock are often very different in neighbouring grid squares. Maps produced directly from the raw data give an impression which, for highly mobile animals, may not reflect reality, and which can be confusing to use. A smoothing algorithm can be used if the cartographer wishes to present easily-understood image to the user. The program will, if required, smooth the data using a simple algorithm in which the value of any square is taken to be the mean of the raw data in it and the surrounding eight squares. Maps prepared from smoothed data must be accompanied by clear documentation on the algorithm used, and especially on how edge squares are treated.

The program prepares and prints an error-free data set for use by future researchers.

6.3.1.3 Hardware

While small data sets should be treated by hand using a calculator, large data sets need to be handled by computer (§6.3.1). Until recently only mainframe computers have had large enough memories, but now many large micro- and small mini-computers are capable of treating SRF data. The user-available memory of the computer needs to be sufficiently large (around 256k) to accept the largest module of the analytic program and at least part of the data. The time taken to analyse the data is reduced if the data used by the program is accessible from hard disk (5-10Mb) during the analysis. A up-to-date backup copy of the data should be stored on floppy disk or tape.

6.4 The SRF and the Geographic Information System

A Geographic Information System (GIS) includes a computerised database containing thematic, and often temporal, geographic data from various sources. The software associated with the database allows the user, amongst other things, to calculate distances and areas, to filter or alter data from one dataplane by comparing it with data from different dataplanes, to carry out statistical analysis of spatial relationships or of relationships between dataplanes, and to map original or derived distributions of data. (For a detailed examination of selected GISs, see Tomlinson et al. 1976.)

One method of storing data in a GIS is in the form of a matrix of values, or rasters, with some form of geographic key to the matrix. The SRF technique gives rise, after appropriate treatment of the raw data, to a set of thematic data planes, each arranged in a systematic grid. Each cell in the grid is given a value in each data plane (eg the number of cattle per square kilometer). SRF data are thus well adapted for use in a GIS because geographically keyed rasters can easily be constructed from the gridded SRF data. Data from other sources can also be stored in the resulting GIS A GIS containing SRF data could be used, for instance, for the study of the causes of animal distributions.

It is highly recommended that SRF data are treated as geographically keyed data layers for both storage and analysis, and if possible that they are integrated into an operational raster-based GIS. This GIS need not be sophisticated, since the typical number of cells used per plane is likely to be under 1000, the number of planes will rarely exceed 20 or 30, and the operations to be carried out on the data are for the most part repetitive and belong to a strictly limited set. While most ecological monitoring units would not wish to spend financial or manpower resources to create such a GIS, some suitable micro-based GISystems, are now commercially available.

6.5 Documentation and presentation

6.5.1 Documentation

Great care needs to be taken to document exactly how the variables and classes were defined, how the data were collected, and how they were subsequently treated. The clean data set printed by the software should be fully identified with the dates both of the survey and of the printout, the survey code, and the names of the field area and crew members. It should be accompanied by full explanations of column headings and of all the codes used.

While interactive messages from the program should be easily understood by the analyst, the documentation should be provided in the language of the final user. The program under development by GEMS is therefore interactive in the analyst's language, but it prints the results in the user's language. The program itself is extensively documented in

English.

6.5.2 Materials and methods for presentation of data

A slide projector is indispensible, and binocular microscopes and light tables may be useful, for classifying slides and counting animals. The person responsible for analysis must have access to adequate equipment, including statistical tables, for the analysis and interpretation of the data collected on the survey (§6.3). Standard office equipment, including drawing material and a photocopier, and access to a roneostat machine, or another means of cheap reproduction, is needed for the preparation and publication of the report.

Other equipment such as cine cameras and projectors may be necessary for informing potential users of the activities of the unit.

Once the data are analysed, numerical results printed by a dot-matrix or line printer are acceptable for most purposes. If available, a good plotter can give publication-quality graphs and maps. Alternatively, the SRF grid-square data should be presented in a form which makes it easy for a cartographer to produce thematic maps for distribution to end users. These maps may use shading (choropleths - Lawrence 1979) or proportional circles to represent different densities, or if preferred, the data can be represented by contour maps (Gittins 1968).

7 Evaluation of SRF - possibilities and limitations

In the pastoral regions of the Sahel, managers often lack the necessary quantitative information on livestock numbers and distribution on which to base their decisions, partly because it has proved difficult to collect the necessary data on the ground. Low-level aerial survey is certainly the most practical, cost-effective, and quickest method for obtaining these data.

7.1 Reliability of results

While data from aerial surveys are usually much better than existing data on the numbers and distribution of sahelian livestock, they are not highly accurate.

There follows a summary of the five main theoretical drawbacks to the technique, most of which have been touched on in earlier sections.

1 It is impossible to eliminate entirely human error and bias in recognising and counting animals.

It is in fact unlikely that many errors arise in recognising livestock species in the Sahel, since there are very few species and, with the exception of sheep and goats, which have to be recorded as "shoats", they are reasonably easy to tell apart from the air.

Errors in counting arise in three ways: (i) the animals are hidden at the moment that the aircraft passes; (ii) although animals are in the open they are not noticed; (iii) the number of animals in a large group is poorly estimated.

The first type of error occurs principally when vegetation is thick. In the Sahel this is particularly important for animals hidden in thickets in the inter-dune troughs, in which is found much of the pasture at certain periods of the year.

The second type of error is especially important in the census of small solitary species, with which we are not in general concerned.

The third source of error - especially acute for shoats, which run together as the plane flies over - can partly be overcome by high quality initial and refresher training of the observers, and partly by taking photographs of all large groups. Unfortunatly animals on photos taken through perspex are often difficult to count. Although observer's estimates are often lower than photo counts, there tends to be little systematic relationship between the observer's estimate and the photo count (Stelfox and Peden 1981), so that it may be best to treat the two sources as independent estimates of group size.

The second and third types of error are made more likely if the observer is nauseated or tired (Watson and Tippett 1981), and may be aggravated by strip widths that are too large, or by flying too high or too fast (Stelfox and Peden 1981). Narrower strip widths give consistently higher, and presumably more accurate, estimates of animal densities, but at the same time precision is reduced, for a given effort, because of a reduction in the proportion of the area surveyed (Stelfox and Peden 1981).

2 The densties estimated on the different transects are highly variable. The population estimate is therefore not very precise.

It is very difficult to obtain precise estimates for animals that are highly grouped and that are otherwise present at low density (Stelfox and Peden 1981). When population estimates are presented with a wide confidence interval, it may be difficult to provide evidence of an increase or decrease in numbers between successive surveys. This problem can be largely avoided both by sensible stratification of the survey, and by planning a series of surveys, from which long-term trends can be shown even if the confidence interval of any given survey is wide.

3 Livestock in the Sahel are highly mobile, so that any one flight provides only a small part of the picture.

In order to understand and plot the distribution and movements of transhumant livestock, several surveys should be made every year.

4 Quantitative observations of ecology are difficult because (i) there are no obvious ways to delimit the area over which the estimate is to be made, and (ii) the view of the observer is oblique, and density seems to

increase towards the horizon.

These difficulties are partly overcome by taking vertical photographs. If specialised equipment is not available, it may be sufficient to take photographs as vertically as possible, possibly by holding the camera outside the aircraft. Although it may be expensive to get a realistic sample, of, say 1 frame per minute, this will contribute a very small proportion to the total cost of the survey.

5 Many authors have questioned the statistical validity of the results (Taiti 1981), especially in the interpretation of distribution maps based on unstratified systematic flights (Watson and Tippett 1981).

By presenting numeric data on distribution in the form of grids, rather than as mean densities in stratifications, the user is wrongly led to believe that the information is both precise and accurate. Grid-based distribution maps, which should only be used for the visual display of information (Norton-Griffiths 1981), may thus encourage invalid analysis based on small numbers of sampling units which are not independent (Watson and Tippett 1981).

All SRF data presented on maps based on grid squares should therefore be shown as symbols rather than as numbers.

7.2 Bias

In all SRF work, observers tend to undercount (Norton-Griffiths 1978). Surveys involving livestock may result in estimates which are from 3 to 59% too low (Watson and Tippett 1981), depending on the density of cover. In open Sahelian steppe experienced observers will underestimate by around 3.5% or less.

Bias results from:

1 Incorrect design of study

It is possible that the survey is designed in such a way as to seriously affect the results. Obvious sources of such bias are poorly designed total counts in which areas are recounted or missed (§2.2), or the incorrect orientation or placing of transects (§2.6).

2 Incorrect interpretation of results

Serious bias can result if the results are interpreted incorrectly, for example, if "correction" factors that are too high or too low are applied to the data.

3 Incorrect calibration of strip width

Animal densities are calculated from the number of animals counted in a given strip width. If mistakes were made in the calibration of the strip width the results will be biased.

4 Incorrect altitude control

The strip width seen on the ground is proportional to the altitude of the aircraft. If the instruments are malfunctioning, of if the data are worked up assuming an incorrect altitude, the results will be biased.

5 Crabbing of aircraft

Cross-winds can make the aircraft fly such that its fuselage is not parallel to its track along the ground. The observer will therefore see animals enter the strip not only across its nominal leading edge, but also across its outer or inner edge, depending on the attitude of the aircraft. The effective strip width is therefore larger than the nominal strip width. Since more animals are counted than would have been if the aircraft had been flying straight, a positive bias is introduced.

6 Bank of aircraft

Turbulence makes it impossible for the pilot to maintain the wings of the aircraft completely level. The strip of ground seen by the observer will therefore rock towards and away from the aircraft. Not only will animals enter the strip from the inner and the outer edges, but as the strip moves away from the aircraft the distance between the outer and inner limits of the strip on the ground increases rapidly. The mean strip width is therefore larger than the nominal strip width, and a positive bias is introduced.

7 Flushing animals out of strip

The noise of the approaching aircraft may frighten animals out of its path, thus introducing a negative bias. In practice, with the exception of shoats, sahelian domestic livestock does not react strongly to the aircraft. Shoats tend to run together and bunch as the aircraft passes over. While they occasionally run out of the strip, they also occasionally run into the strip from under the belly of the aircraft. It is therefore difficult to judge whether the count of shoats is in fact biased by flushing.

8 High counting rate

Locally high densities may oblige the observer to count rapidly for a long time. This usually leads to undercounting.

9 Crew fatigue

If the aircraft is flying too high or too fast, or if the strip is too wide, the observers tire rapidly, animals are missed and estimates become less accurate, leading to negative bias.

10 Observer slumped in seat

When calibrating the strip the observer may be alert and fresh, sitting upright in his seat. As the survey wears on, he may slump in his seat, thus lowering the position of his eyes and moving the region on the ground delimited by the markers further from the aircraft. The effective strip width is therefore larger than the nominal strip width and a positive bias is introduced.

11 Missed animals

Observers will always miss animals that are completely concealed. Dense vegetation therefore increases the probability that animals are missed. Group size of free-ranging cattle herds depends in part on the greenness and percent cover of the forage; the better the forage, the larger the herds. In conditions of medium visibility, the larger the mean group size of cattle, the greater the percentage of animals spotted (Newsome et al. 1981). Different habitats therefore give rise to different probabilities of missing animals.

It is not clear whether observation through perspex influences the percentage of objects spotted (see Norton-Griffiths (1978) and Watson et al. 1981 for conflicting opinions).

12 Miscounting animals

The probability that the observer will make mistakes as he counts depends in part on the size and colour of the animals he is counting, on their reaction to the aircraft, and on their tendency to form tightly bunched herds or flocks. Different species are therefore subject to different probabilities of miscounting.

13 Misidentification of species

If one species is likely to be mistaken for another, serious bias may result. This is especially important if one of the species is much less common than the other.

14 Variable visibility into and away from sun

A bright sky and ground, dust in the atmosphere and scratches on the perspex of the cabin window can make observations into the sun much more difficult than observations away from the sun. Up-sun observations are therefore more subject to undercounting.

7.2.1 Estimation and correction of bias

Bias cannot be estimated by comparing two methods and assuming that the one which gives the highest result is accurate (Jolly 1981b). One possible way of calculating bias is by counting an animal group in typical habitat from the altitude to be used on the survey and then counting the group again at a much lower altitude (Watson 1979). With sufficient such counts the relationship between the survey level estimates and the low level estimates (true counts) can be used to calibrate subsequent surveys. This method is expensive and relies on the observers remembering over which area the original count was made (Watson et al. 1981).

Ideally an individual correction for bias needs to be found for each combination of observer, species, group size and habitat. Unfortunately the bias affecting any given species in a multi-species survey is probably not the same as it would be in a survey designed to count only that species, and it may be extremely difficult to establish realistic individual correction factors.

Simple bias correction factors for each combination of observer, species and habitat can be established by comparing the observer's estimates with the number of animals seen on the photographs. This comparison cannot of course help to correct for animal groups that were missed entirely. In the experience of the Project the variance of the observer's estimate for a given photo count is roughly proportional to the photo count, so that regression lines cannot be used to adjust the correction factor for the size of the group.

7.3 Use of Data

Major users of SRF data include Government ministries and national institutions, public and private development organisations, and universities. These users have different needs, which should as far as possible be catered for by the survey. It is especially important to publish with the results both thorough interpretation, to point out their implications, and critical evaluation, to stress their limits.

7.3.1 In research

SRF data, combined with data from other sources, contributes to many different aspects of resource inventory and mapping. They also provide up-to-date information which can combined with social and political data for modelling the distribution of livestock, and are thus useful in identifying priorities for futher research.

7.3.2 In management

Flexible and responsive management descisions can be made only if accurate up-to-date data are available. It is notoriously difficult to get accurate information by interviews with pastoralists, and to monitor herd sizes from ground surveys. Aerial surveys provide an excellent overview of numbers and distribution of livestock. They may also be used to contribute to a better understanding of human population size and distribution in what are typically very low density areas, and hence which are difficult to survey by traditional means.

In most livestock development projects there will be a design stage which could usefully be influenced by the results of preliminary aerial surveys. The appraisal of the effects of the project might also be made partly by repeated aerial surveys through the life of the project. If the analyst has access to the results of several years of data collection by aerial survey, SRF data can be used to monitor and predict changes in livestock and wildlife numbers and distribution, and, in some areas, the nature and extent of cultivation.

The survey team should monitor how the SRF data are currently used in management and in making policy decisions, and may be able to make recommendations for their more efficient or thorough use.

7.4 Use of technique in a program of ecological monitoring

Properly managed, the SRF can provide reliable and continuous information on livestock, range condition, cultivation and wildlife on which can be based warnings of downgrading pastures, fire risk, and recommendations to Government on the management of the rangeland.

The value of the SRF depends upon its contribution to management and to development, and increases when it is used in combination with data collected by satellite and on the ground (Wilson and Adams 1977, Wilson 1979).

The technique is especially useful if by standardising the methods used the bias is kept the same from survey to survey. Under these conditions comparisons can be made from one site to another and within any given site over several years. Thus two population estimates P1 and P2, based on n1 and n2 transects respectively, are different (Pollard 1977) if

```
            (P1-P2)/SQR(var1/n1+var2/n2) > t((a/b)-2)

where       a = (var1/n1+var2/n2)^2
and         b = (var1/n1)^2 /(n1-1) + (var2/n2)^2 /(n1-1)
```

Furthermore, if

```
     F(n-1,1) = (mean of variances)/(variance of estimates)
```

is not significant, then population estimates can be merged (Cochran 1954) by calculating:

```
     variance = 1 / ( 1/var1 + 1/var2 + ... + 1/var(n) )
      pop est = ( P1/var1 + P2/var2 + ... + Pn/var(n) ) * variance
```

8 Checklist for systematic reconnaissance flight

The following is an annotated checklist found useful for sahelian low-level reconnaissance surveys. The first part covers equipment and the second the activities of those involved in the survey. The preparations for the survey are seperated into administrative and scientific parts.

8.1.1 Administrative organisation

Those responsible for the administration of the survey will prepare:
(i) contracts - with owners of aircraft and navigation equipment

- with pilot, observers, and ground staff
- with analysts, cartographers and editors of report

(ii) clearances - for foreign personel involved in the survey
- for bringing aircraft into country temporarily
- for carrying out low-level survey

(iii) insurance - for crew
- for aircraft
- for equipment used on survey

(iv) fuel supply dispersed as needed at various landing strips
(v) transport for ground staff to and from and within field area
(vi) sleeping arrangements for crew and ground staff in field area

8.1.2 Scientific organisation

The persons charged with the scientific design should establish the objectives of survey, design the survey, and determine the orientation and placing of transects, including the latitude and longitude of their ends. They must also prepare a list of codes and definitions to be used on the survey.

8.2 Equipment
The following equipment should be available during the survey:

8.2.1 In aircraft

(i) for refuelling: key to open fuel drums
fuel pump
fuel filter
funnel

(ii) for tyres: inner tubes
puncture kit
foot pump

(iii) for emergencies: first aid kit
matches and torch food in cans, canopener
water
flares
steel mirror
compass
binoculars

(iv) for strip markers: wire or rods to mark limits of strip coloured sticky tape
scissors
tape measure (30m)
large sheets of paper for marking landing strip
for calibration

(v) for observers: spare tape recorder(s)
spare camera(s)

spare sticky labels for cassettes and film cannisters

(vi) general: small can for waste (eg pencil sharpenings)
chamois window cleaner
water bottles for drinking during flight
toilet paper
sick bags

8.2.2 Pilot

(i) navigation: general map of survey zone
detailed maps of survey zone with flightlines marked
charts of landing strips
list of latitude and longitude of start and ends of transect lines for keying in waypoints to GNS

(ii) written authorisation from: civil aviation
military if necessary
foreign avaition bodies if necessary

8.2.3 Front seat observer

(i) time control: beeper set to beep at 1-min intervals
stop watch as back-up for beeper
chronometer for recording times on transects

(ii) checksheets: ecological check sheets
check sheets for noting position of plane
large envelope for completed check sheets

(iii) aids to observation: comparison grids (density card)
colour card for greenness
list of definitions (Figure 3)
camera with serial number
film

(iv) recording observations: clip board
pencils
pencil sharpener or penknife
eraser
calculator
notepad or cassette recorder for notes

(v) general: cotton wool for ear plugs

8.2.4 Rear seat observers

(i) recording observations: tape recorder with serial number
tapes
batteries
list of codes and definitions (Figure 4)

(ii) photography: cameras with serial numbers
motor drives
lenses taped to infinity
lens cleaning equipment

Figure 3: Sample sheet of instructions for front seat observer

INSTRUCTIONS FOR THE FRONT SEAT OBSERVER

The observations should be made on the minute every minute
The position of the aircraft should be made at regular intervals mid-way between the ecological observations; once a minute if possible. It is very important to record the position and the time at the beginning and at the end of every transect.

Ecological observations are made on an area as close to the right hand side of the aircraft as possible; try to make them on an area about 200m wide and 600m long.

Use the percentage sketches to help to estimate the percentages of woody cover, naked earth and standing grass.

Fire is recorded as Traces (charred woody vegetation) Some (charred woody veg + some ashes visible) Much (a recent fire which has left large parts of the vegetation untouched) Extensive (a recent fire which has damaged most of the vegetation)

Erosion gx gulley: Traces (one or two small dendritic gulleys in the area)
Some (several small dendritic gulleys)
Much (well-formed network of gulleys)
Extensive (major ravines)
sheet: Traces (small dams of plant material)
Some (patches of naked earth with dams of plant material)
Much (patches of naked earth with well-defined limits of erosion)
Extensive (small "cliffs" clearly visible at edges of erosion)
wind: Traces (airborne transport of sand: no other trace of wind erosion)
Some (some deposits of sand visible at bases of plants)
Much (many deposits of sand visible in tear-drop form)
Extensive (large areas of nakes sand with deposits)
Wind-bourne sand (obscuring details of ground)

Bare earth,
Standing grass,
Woody plants ... estimate to nearest 10% unless less than10% - then 5%, 2%

Radar altitude if the radar altitude is clearly false, mark 999. Collect the barometric altitude for each minute as well; this will be used to calibrate the radar altitude when the radar altitude is 999.

Every minute: look at watch, add 1 to minute shown, call out this time to RSOs
record barometric and radar altitude
record ecological data

On the half minute: record position of aircraft and time in seconds and minutes since the start of the transect

At the start of every line: call out line number, direction, to RSOs
record time and position of aircraft at the start

Figure 4: Sample species code sheet

REAR SEAT OBSERVER'S SPECIES CODES

SH shoats
CT cattle
DN donkeys
CM camels
HO horses

JC jackal
RG gazelle
OS ostrich
WH warthog

HT hut
HM tin-roof hut

VG village
TW town
TE tent

BH borehole
WA waterhole
WE well

BM boma

FR fresh carcass
BR bones + rotting patch

BD bad data

OTHERS:

CODES FOR COLUMN...

Di (Dispersion of herd) CATTLE ONLY
L = in line
C = clumped
D = dispersed

Co (Colour of animals) CATTLE ONLY
W = white (sometimes with black)
R = red (fewer than $\frac{1}{4}$ are white)
M = mixed white and red

Film will be (eg) FL01 or FR02 etc

Frames write in these columns the number of frames shot. Also note any blank frames! What you write will be rubbed out later when the films are counted, so don't write too hard!

Problem if you can't understand something you recorded, write T (for Tape) in this column.

The other columns will be filled in from the photos.

film marked with numbers on films and cassettes

(iii) general: cotton wool for ear plugs

8.3 Pre-flight activity
The following activities should be carried out before the survey or before each flight, as appropriate:

8.3.1 Persons responsible for organisation of flight

8.3.1.1 Administrative organisation

Before each flight the person responsible for the administrative organisation of flight should:
(i) agree with the pilot on the estimated time of arrival at a stated airfield
(ii) arrange that ground crew will be at the airfield to meet the aircraft to transport the crew to the field base
(iii) establish with both the air and ground crews the procedures to be carried out in case of emergency.

8.3.1.2 Scientific organisation

Before the survey starts the person charged with the scientific organisation of the flight should number the film to be used on the survey by (a) scratching the unique identification number onto the film leader itself, (b) scratching the same number onto the cannister, and (c) sticking a detachable sticky label with the number to the cannister.

Before each flight he should bring spare batteries, tapes, film, tape recorders and cameras to the aircraft.

During the pre-flight briefing of the crew, the person responsible for the scientific organisation of the flight should:
(i) check that observers have (a) a clear idea of objectives and methods of the survey, and (b) the correct list of codes and definitions to be used on the survey.
(ii) establish with the air crew (a) which transects will be flown on this flight, and (b) what to do if cameras or tape recorders malfunction.

8.3.2 Pilot

Before each flight the pilot should:

(i) for security, agree with the person responsible for the flight on the estimated time of arrival at a stated airfield
(ii) check that the plane's and pilot's documentation are present and in order
(iii) refuel the plane

(iv) check that the plane's equipment is on board and functional
(v) clean all windows
(vi) carry out all normal pre-flight checks
(vii) establish with front seat observer the order and direction of transects
(viii) warm up the GNS and file the waypoints in cooperation with the front seat observer
(ix) warm up the radar altimeter

8.3.3 Front seat observer

The front seat observer should:

(i) check that he has adequate data sheets
(ii) check that all his equipment is on board and functional
(iii) set up the beeper to beep every minute and check its operation
(iv) establish with the pilot the order and direction of transects
(v) help the pilot to enter and check waypoints in GNS

8.3.4 Rear seat observers

While on the ground before the flight each rear seat observer should check that:

(i) he has enough blank tapes for the survey
(ii) the tape recorder batteries are charged
(iii) he has spare tape recorder batteries and that they are charged
(iv) his tape recorder works; he should then (a) record on the first tape: the date, his name, the side of aircraft on which he will be sitting, and the tape number, and (b) play back and check that the information is correct

He should go on to check that:

(vii) he has enough film and that film is clearly and unambiguously numbered
(viii) camera batteries are charged
(ix) spare camera batteries are charged
(x) the lens is clean and taped at infinity
(xi) the camera shutter and wind-on mechanism work correctly.

He should then:

(x) load the camera and record the number of film on the tape recorder; detach the sticky label from the cannister and stick it to the camera body
(xi) set the ASA correctly
(xii) check that the shutter and exposure settings are correct.
(xiii) check that all the other equipment which he will be using is on board and functional

8.4 In-flight activity

8.4.1 Pilot

In addition to the pilot's normal duties, including informing traffic control of his activities and avoiding vultures, the pilot should:

(i) fly straight and level into the start of each flightline
(ii) announce the start of the flightline to the front seat observer
(iii) fly in a straight line between waypoints, using mainly the global navigation system supported by references to maps to double-check from ground features where possible
(iv) maintain altitude
(v) announce the end of the flightline to the front seat observer
(vi) fly straight and level out of each flightline
(vii) set up waypoints in cooperation with front seat observer when the initial set have been completed.

8.4.2 Front seat observer

The front seat observer should:

(i) record takeoff time
(ii) between flightlines: (a) record flightline number and direction, and (b) announce the number and direction of the next flightline to the rear seat observers
(iii) at the start of each flightline: (a) start beeper, (b) announce the start of the flightline to the rear seat observers, and (c) record the time, and the position and altitude of the aircraft
(iv) when beeper sounds: (a) call out the minute number to the rear seat observers, (b) record the altitude of the aircraft and (c) make and record ecological observations
(v) between minutes, record time and latitude and longitude of aircraft if GNS is not dead-reckoning
(vi) at the end of each flightline: (a) record the time, and the position and altitude of the aircraft, (b) announce the end of the flightline to the rear seat observers, and (c) stop the beeper
(vii) record landing time.

8.4.3 Rear seat observer

Between flightlines, each rear seat observer should:

(i) check that the camera is functioning correctly
(ii) if the film is near the end of the roll, change the film using the standard procedure described above
(iii) check focus, speed and aperture settings
(iv) check that the tape recorder is functioning correctly
(v) if it is near its end, change the tape cassette using the standard procedure described above
(vi) record the number of the next flightline when the front observer announces it

At the start of each flightline he should record "minute zero" on the tape. When the front seat observer calls out the number of the minute he must immediately record it on the tape.

Whenever he sights one or more animals in the strip he should:

(i) record their species and number
(ii) if there are more than about 10 animals in the group, (a) take photographs, and (b) record the number of frames taken

At intervals he should take a blank frame and record "blank frame" on the tape. At the end of each flightline he must record "end of flightline" and state the flightline number.

9 Cost

When considering the cost of an aerial survey the main questions are:
(i) how much will it cost to census a given number of square kilometers?
(ii) how much will the contemplated survey cost altogether?
(iii) are there any other means of collecting the data which would give as good or better data for the same or lower cost?

The major costs are likely to be the salaries of the personel and the purchase or hire of the aircraft. In greater detail, the costs associated with the survey can be broken down as follows.
The major non-recurring costs in an aerial survey are:
(i) the purchase price of the aircraft and navigation equipment
(ii) the training of the observers
(iii) the cost of developing or buying the software used in analvsis.
(iv) the cost of the computer and peripherals used in the analysis.

These heavy initial costs can be avoided by hiring the equipment, personel and software, in which case they should be calculated as part of the recurrent costs.

The recurrent costs are:
(i) aircraft hire and operating costs
(ii) hire of navigation equipment
(iii) salaries of pilot + observers
(iv) salaries of ground crew
(v) cost of establishing fuel dumps (fuel + transport)
(vi) cost of field base
(vii) data processing: salary of analyst, machine time, and hire of software
(viii) report writing and publication

Almost all of these costs are related to the length of time that the survey will take, and hence to the size of the survey area and the proportion of the area that is to be sampled.

The hire and operating cost of the aircraft can be calculated by dividing the flying time into three sections:

(i) the cost of aircraft flying from home to base airstrip in the field and back:

2 * (distance from home airport) * (cost per hour of hire of aircraft + cost of fuel per hour at cruising speed) / (cruising speed)

(ii) the cost of time spent counting animals:

(sum of distance along all transects) * (cost per hour of hire of aircraft + cost of fuel per hour at survey speed) / (speed during counting)

(iii) cost of flying between airfield and transect lines, and between transect lines:

(distance from airfield to start of transect, between transects, back to airfield) * (cost per hour of hire of aircraft + cost of fuel per hour at cruising speed) / (cruising speed)

10 A Case Study of the SRF: The north Ferlo

The reader is reminded that the Pilot Project for the Inventory and Monitoring of Sahelian Pastoral Ecosystems was charged with the demonstration and assessment of the recommended GEMS methodology for the inventory and monitoring of Sahelian rangeland ecosystems (GEMS 1986a, Le Houérou 1986). This methodology includes the use of data collected from satellites (GEMS 1986c), from low-level systematic reconnaissance flights, and from the ground (GEMS 1986b, 1986d, 1986e). The SRF was therefore used by the project as one of the sources of data to be integrated into a systemic study of the Ferlo, and was not regarded as an isolated technique.

10.1 Aim and organisation of this case study

The following pages are a presentation and critique of the SRF data obtained by the project, and are intended to help the reader to anticipate the sort and quality of data likely to be obtained by the SRF in the Sahel. After some remarks on the treatment of the data the document continues with a cartographic approach to the study of seven ecological factors: woody plant cover, grass-layer cover, naked earth, bush fires, and three sorts of erosion. It then goes on to discuss the numbers and distribution of livestock seen during the flights.

While this document is concerned only with data from SRF sources, treated one theme at a time, GEMS (1986f) examines the interrelationships in data from the SRF and other sources.

10.2 The project's SRFs

The project undertook four SRFs in the Ferlo. The first flight took place in 1980, followed by others in 1981, 1982 and 1983. A second 1981 flight had to be abandoned because of a failure of navigational and radar equipment in the aircraft. The 1980 flight took place at the end of the rainy season (October), and the other three in the dry season (May and June).

The flights were carried out between 0700 and 1130 hours at an altitude of 500 feet. Turbulence and atmospheric turbidity made afternoon flights impossible. Twenty-nine north-south flightlines, totalling 3070km, were flown in 1980, 1981 and 1982. In 1983 a flightline was added and three lines were lengthened, giving a total of 3170km surveyed. The mean width of the combined census strips of the two rear-seat observers was roughly 400m. Lignes were seperated by 10km; thus animals in about 4% of the area were counted.

10.3 Data analysis

The analyses and results presented here were carried out by the project, using programs written by project staff in BASIC. These programs are being reviewed and revised by GEMS and when adapted for general use will be available on request.

10.3.1 The SRF and the Geographic Information System

The typical GIS will have access to data consisting of many thousands, and frequently many millions, of cells in each dataplane. Given the 10x10km resolution of the project's SRFs and the 30,000 sq km in the test area, each dataplane to be considered in this case study contained roughly 300 cells. While this quantity of data would not justify the purchase of a full-scale GIS, it was nevertheless clear that to benefit fully from the information it had gathered, the project would have to analyse the data by computer. The project therefore established a proto-GIS, a computerised analytic system, for the rapid examination and manipulation of the diverse data available to it.

The project also undertook an SRF of a wooded pastoral area near to Tambacounda in Sénégal Oriental. These data were analysed using a programmable calculator in order to demonstrate the possibilities and the limits of analysis of SRF data by calculator.

10.3.2 Statistical considerations

10.3.2.1 Smoothing data for mapping

For analysis and mapping the Ferlo is treated as being divided into 10x10 kilometer squares. In the SRF the sample is collected in about 4% of each square, and therefore the number assigned to that square depends on the track of the aircraft relative to the position of the herds at the moment of passage. We should expect that the estimates of the numbers of animals will sometimes be lower, and sometimes higher than the true number. If the number and hence the density assigned to a single square depends largely on chance, the mean density for several squares is likely to deviate less from the true mean as over- and under-estimates compensate. For this reason the standard deviations about the population totals are estimated from mean densities for flightlines, and not from subunits along the lines. For this reason also, the project presents distribution data in the form of maps that are either composites of several flights or the result of mathematically smoothing the data before mapping them.

10.3.2.2 The smoothing algorithm

The value ascribed to a given cell in the grid is the weighted mean of the raw data in the cell itself and in each of its 8 neighbours. Edge cells have fewer neighbours; the value is then calculated from the existing neighbours. The weighting is inversely proportional to the distance between the centre of the cell and the centre of the neighbouring cell (Figure 5). Given that the mean distance of an animal seen in the cell is 0.25 of the length of the side of the cell from the centre of the cell, the raw data in the cell itself is weighted by a factor of 4.

Figure 5: Weights used in smoothing algorithm

0.7	1	0.7
1	4	1
0.7	1	0.7

The resulting value is divided by the sum of the weights, or 10.8 for cells with 8 neighbours, and the result is assigned to the central cell. Such smoothed data can not, however, be used in analysis, since the data values are no longer independent.

10.3.2.3 Contagious data and empty cells

Livestock are typically found in herds. This means that the probability of finding an animal at a given point is not independent of the presence or absence of an animal nearby. In statistical terms, the distribution of livestock is highly contagious.

The herds themselves are certainly not randomly distributed, but let us suppose for the sake of arguement that they are. The probability of finding a herd at a given point is therefore independent of the presence or absence of other herds in the neighbourhood. If the density of herds is sufficiently low, the frequency distribution of the number of herds counted per cell of the SRF grid will approximate the Poisson distribution.

The Poisson distribution can be used to calculate the density of herds such that with a 4% sampling intensity there is a fifty percent chance of flying over a cell and counting no herds. In one out of every two samples of a square 10 km on a side containing 17 or 18 herds a 4% census would fail to count a single herd. For cattle in the test zone, 17 or 18 herds is the equivalent of roughly 4.5 head per square kilometer, or about 20 hectares per head. The SRF data shows that cattle are at densities of less than 4.5 head per sq km over about 30% of the Ferlo. We cannot therefore assume that an empty cell in the SRF grid of the Ferlo represents an area in which there are no cattle, and the same conclusion holds for the other species of livestock. Since herds are probably in fact contagiously distributed, the problem is more acute in reality than it is for ideal, randomly distributed herds.

10.3.2.3.1 Handling the empty cells

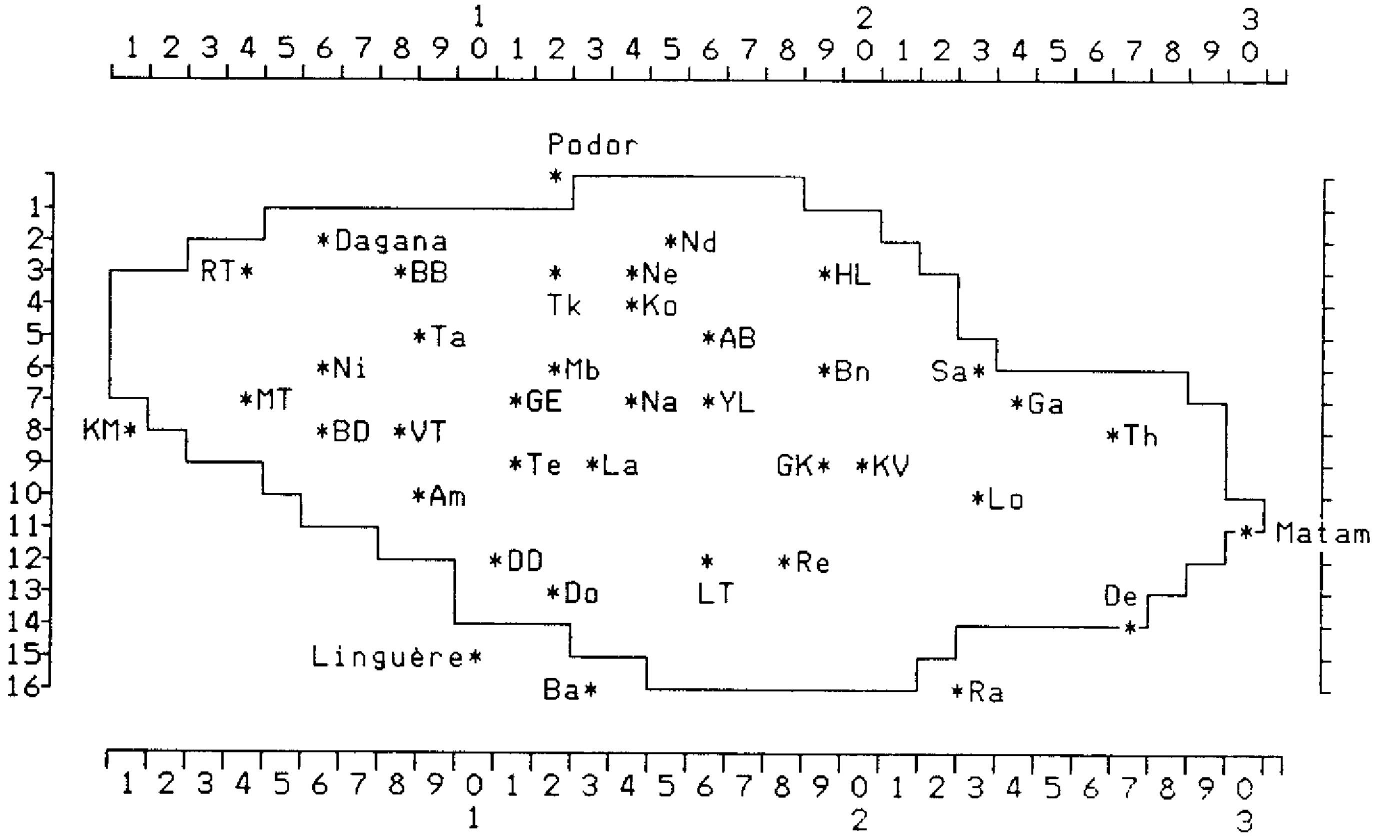
How can these apparently empty cells be taken into consideration in the analysis? If empty cells were to be treated as though they represented areas in which there were no animals, the large number of cells of zero density would give rise to a frequency distribution for which no conceivable transform could provide Normalised data. It seems improbable that a model of livestock distribution could be constructed under such constraints.

Given that the true density in most apparently empty cells is probably not zero, such cells could be treated as though they contained an unknown density, that is, as representing missing data. The frequency distribution of the remaining data is almost invariably log-Normal. The project recognises that it is quite possible that in at least some of the cells there was in fact no livestock, and that valuable information is lost by treating these cells as missing data. This is particularly true of those species characterised by low densities and irregular distribution, such as the dromedary in the Ferlo. Nevertheless, the project feels that the resulting bias is smaller than that which would have been introduced by treating the empty cells as representing a true density of zero.

10.4 Mapping of results by computer

The chorograms (maps composed of choropleths or areas of similar shading corresponding to data classes) which accompany this text were produced on a dot-matrix printer with a limited character-set and no proportional spacing. The horizontal and vertical scales are therefore different, originally corresponding to 1:2 350 000 and 1:2 000 000 respectively. Each cell of the maps represents an area of 10 x 10 kilometres. The map of towns and principal boreholes (Figure 6) will orient the reader. It should be noted that the dimensions of the symbols used for the choropleths are not proportional to the quantities represented.

Figure 6: Location of towns and major boreholes in the north Ferlo



KEY to names of towns and major boreholes

- Am Amali
- AB Atch Bali
- Bn Bano
- Ba Barkedji
- BB Belel Bogel
- Bo Boki Diallobé
- BD Boki Divé
- Da Dagana
- DD Dek Do
- De Dendoudi
- Do Dodji
- GE Ganine Erogne
- GK Gyeye Kadar
- HL Haïré Laö
- KV Kara Vindou
- Ko Kodiolel
- La Labgar
- Li Linguère
- LT Lougeré Thioli
- Lo Loumbi
- Ma Matam
- MT Mbar Toubab
- Mb Mbidi
- Na Namarel
- Nd Ndioum
- Ne Nénét
- Ni Niassanté
- Po Podor
- Ra Ranerou
- Re Revane
- RT Richard-Toll
- Sa Saldé
- Ta Tatki
- Te Tessékré
- Th Thilogne
- Tk Tiekinguel
- VT Vindou Thingoli
- YL Yaré Laö

The intervals between the classes represented by the choropleths are often in a logarithmic or semi-logarithmic sequence. Missing data are shown by interrogation marks (?). The area to the west of the Lac de Guiers was surveyed for the first time in 1983, and is therefore represented by interrogation marks on all maps of earlier flights.

10.5 Equipment

The project used the same aircraft for all of its surveys, a Partenavia P68 hired with its pilot from the International Livestock Centre for Africa (ILCA), Bamako. This plane was originally fitted for five passengers and a pilot, but the two middle seats had later been removed. It was equipped with an Omega global navigation system (GNS) and a radar altimeter with a digital readout correct to the nearest 10 feet, so that the pilot was able to fly accurately in the Sahel, a flat zone with no landmarks.

Steel wires marked with black and white tape were strung horizontally under the wings so as to define for each observer the upper and lower limits of a field of view, and thus the edges of the transect strip. A vertical wire across this strip marked the counting point.

The two rear seat observers (RSOs) were equipped with cassette tape-recorders to note the animals counted, and still camers with 50mm lenses and motor-drives to take slide photos of all groups of more than 10 animals. Beside the pilot, the front seat observer (FSO) used a cassette tape-recorder or checksheets to record ecological data (Figure 7), and a chronometer set to beep once a minute. He also had access to maps of the zone and a diagram showing different densities of occupation, for use in calibrating his estimates of ground cover.

10.6 The crew

There were four crew on the project's SRFs: the pilot, a front seat observer and two rear seat observers. The inflight duties of the various crew members are described in §8.4. In brief, the FSO was responsible for collecting data on the altitude and location of the aircraft, calling out the start of the minute to the RSOs, and noting the values of a series of ecological parameters each minute. The RSOs counted and recorded the number of animals crossing the counting point in their transect strip. The same observers were not always used on the four flights, and on two of them the FSO was changed during the survey (Table 1).

The two teams of RSOs had undergone professional training and were highly experienced, being on the staff of the Kenya Rangeland Ecological Monitoring Unit (KREMU) and flying regularly in the course of their duties. Of the four FSOs two (FSO 1 and 2) had had previous experience, but none of the four had had professional training. The changes in FSO during the 1980 and 1981 surveys accentuated the problems of observer bias in the estimation of the values of ecological parameters.

Figure 7: Example of checksheets for front and rear seat observers

SEFØ5 side L obs SS line 01 dirn S date 17Ø583

Min	Sp	Count	Photo	Pt	Tr	Gr	Wa	Di	Be	Co	Film	Frames	Problem
1											FL01		
2	CT	011	003	P	P	N	N	D	P	W		03	N
	SH	012											
3	CM	001											
	CT	050	047	S	P	N	N	L	M	W		04 05	N

SEFØ5 side F obs MS line 01 dirn S date 17Ø583

time on chron	call out	ALTITUDE barometer	ALTITUDE radar	naked earth	standing grass	woody plants	EROSION gulley	EROSION sheet	EROSION wind	RECENT FIRE	visi	NOTES
0	01	490	490	95	0	5	S	T	T	—	—	
1	Ø2	—	500	80	0	13	—	—	T	—	—	
2	Ø3	—	500	85	0	10	—	T	—	—	—	
3	Ø4	—	510	90	0	5	T	—	T	—	—	
4	Ø5	—	480	75	2	15	—	—	—	—	—	

Key to column headings of Figure 7

On both sheets:

Column	Code	Data to be entered
1- 5		Flight code and number
7	side	Side of aircraft on which observer is sitting
9-10	obs	Observer's initials or other ID
12-13	line	Line number
15	dirn	Direction of aircraft
70-75	date	Date (day, month, year)

On sheet for rear seat observers:

Column	Code	Data to be entered
17-18	Min	Minute number since the beginning of the flightline
20-21	Sp	Two-character Species code
23-25	Count	Visual count or estimate of numbers
27-29	Photo	Count of numbers seen on photograph
31	Pt	Part, All, or Several herds in the strip
33	Tr	Tree cover in vicinity of herd, coded nominally
34	Gr	Grass cover in vicinity of herd, coded nominally
35	Wa	Presence or absence of water in vicinity of herd
37	Di	Dispersion of herd (eg in line, clumped, spread out)
38	Be	Behaviour of herd (eg stampede, grazing, progression)
40	Co	Colour of coats of greater part of herd
42-45	Film	Film number (entered at atart of each film)
47-66	Frames	Number of frames shot, frame numbers
68	Prob	Any problems with count, identification etc

On sheet for front seat observers:

Column	Code	Data to be entered
16-17	Call out	Minute number to be announced to RSOs
19-21	Baromet	Altitude registered on barometric altimeter
23-25	Radar	Altitude registered on radar altimeter
27-29	Naked earth	Percent cover of naked earth
31-33	Standing gr	Percent cover of standing grass
35-37	Woody plant	Percent cover of woody plants
39	gulley	Extent of gulley erosion on ordinal scale
41	sheet	Extent of sheet erosion on ordinal scale
43	wind	Extent of wind erosion on ordinal scale
45	Recent Fire	Traces of recent fires on ordinal scale
47	Visi	Visibility on ordinal scale
	NOTES	Any brief comment

10.7 Ecological parameters

In all four SRFs the percentage of ground covered by the canopies of woody plants was recorded. Since the surface area of the woody plant layer changes relatively slowly (see GEMS 1986e), this data set provide a study of inter-observer reliability for the FSO.

In 1980 the observers were asked to make judgements on a large number o variables each minute. This heavy workload apparently resulted in the confusion and exhaustion of the observer, and therefore in data of limited quality for some parameters. This is particularly clear for th woody plant layer, for which no data were recorded in a third of the survey zone (Figure 8a).

10.7.1 Woody plant layer

In 1980 and 1981 the FSOs tended to judge the woody plant cover to be far less dense than did the FSO in 1982 and 1983 (Figures 8a to 8d). I any partially wooded landscape the phenology of the woody plant layer will presumably influence the judgement of the observers, but this cannot explain the differences in these datasets, since the 1980 flight took place in the growing season and the others in the dry season, when the woody plant canopy was in general less in evidence.

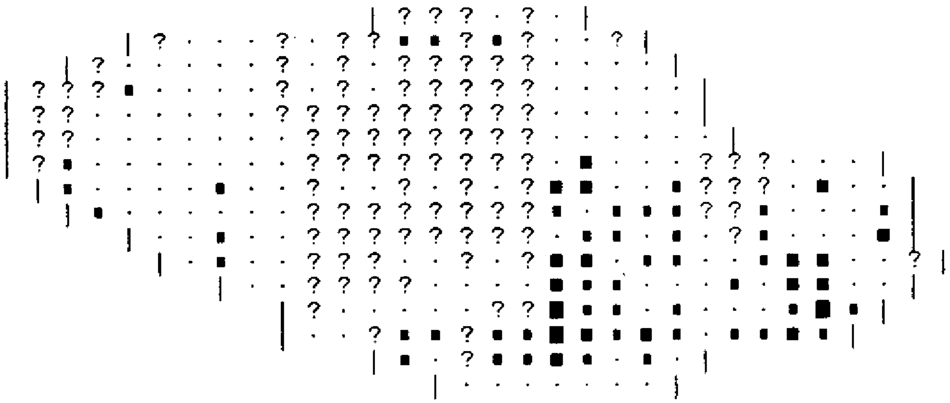
The observer's judgements differed by their greatest amounts in landscapes where the woody plants grow in long narrow patches. In 1982 and 1983 the FSO estimated that the clumped woody plants in the interdune hollows in the western Ferlo covered about 15 to 20% of the ground, while the other observers estimated that in the same area the woody plants covered less than 5% of the ground.

Aerial photographs of the centre, west and north-west of the Ferlo were used to provide an independent estimate of the woody plant cover. On each photo, 200 point samples were taken. The results, which should be treated with considerable reserve in view of the difficulty of estimating the woody plant cover from photographs at 1:50 000, suggest that the woody plants cover rather less than 20% of the ground, with 95% confidence limits of 8% and 30%, depending on the area tested.

Not only are there problems of inter-observer variability, but unfortunately there is also little similarity in detail in the distribution maps of woody plant cover derived from the data collected in 1982 and 1983, by the same observer (Figures 8c and 8d). For example, the observer tended to judge the woody plant cover in gravelly soils to be greater in 1982 than he did in 1983.

The most sensible way of using these data would seem to be to group the data from the various observers. This compounded data results in a thematic map (Figure 9) which corresponds well with the true distribution of woody plants as determined from data gathered in the field. The relatively densely wooded region in the gravelly south-west is dominated by Pterocarpus lucens and Combretum micanthrum, while the centre of the map represents the open steppe covered with Boscia

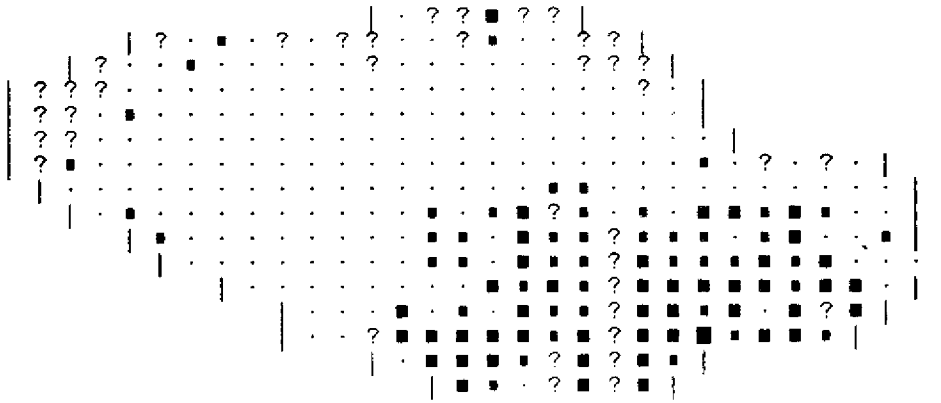
Figure 8a: Percent of,ground covered by woody plants 1980



Key

Symbol	Percent
	<= 0
·	0.1 to 5
•	5.1 to 10
▪	10.1 to 20
■	20.1 to 40
█	40.1 and over

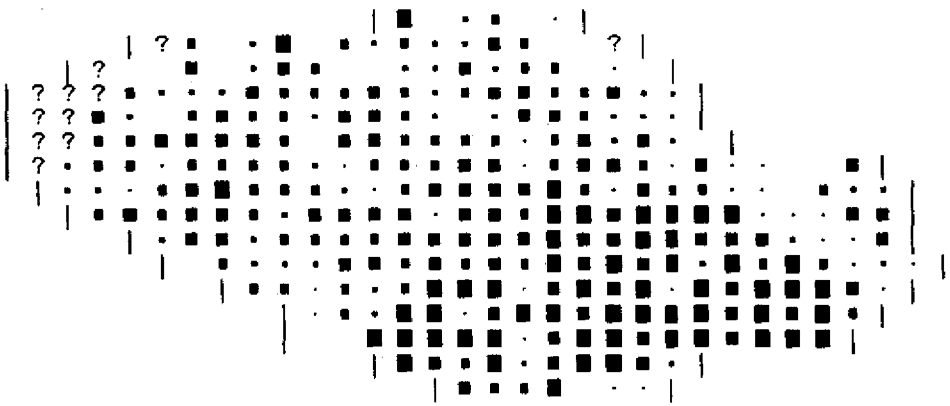
Figure 8b: Percent of ground covered by woody plants 1981



Key

Symbol	Percent
	<= 0
·	0.1 to 5
•	5.1 to 10
▪	10.1 to 20
■	20.1 to 40
█	40.1 and over

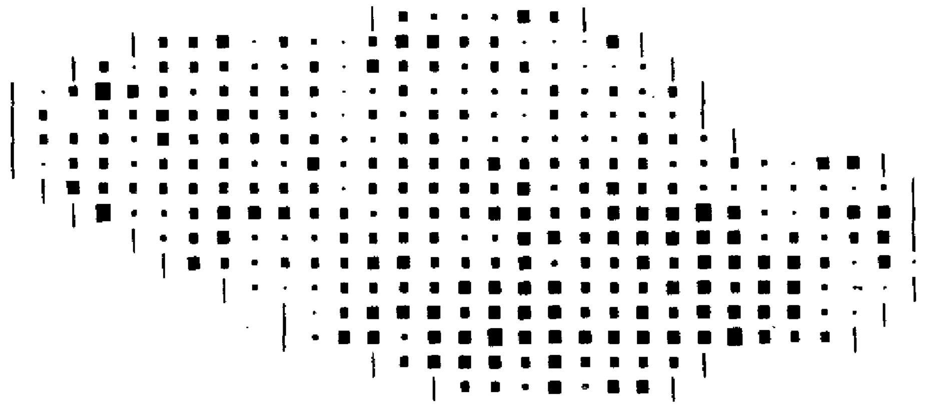
Figure 8c: Percent of ground covered by woody plants 1982



Key

Symbol	Percent
	<= 0
·	0.1 to 5
•	5.1 to 10
▪	10.1 to 20
■	20.1 to 40
█	40.1 and over

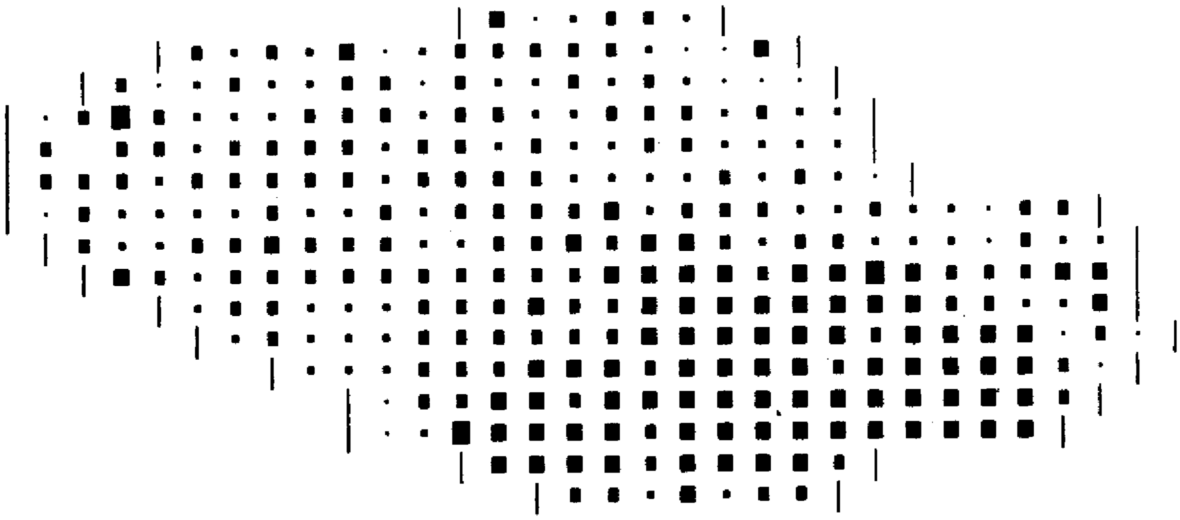
Figure 8d: Percent of ground covered by woody plants 1983



Key

Symbol	Percent
	<= 0
·	0.1 to 5
•	5.1 to 10
▪	10.1 to 20
■	20.1 to 40
█	40.1 and over

Figure 9: Mean estimate of ground covered by woody plants



Key

Symbol	Percent
	<= 0
·	0.1 to 5
•	5.1 to 10
▪	10.1 to 20
■	20.1 to 40
█	40.1 and over

senegalensis, and the community in the wooded region to the east of the Lac de Guiers is largely dominated by three Acacia species together with Balanites aegyptiaca. The forests of Acacia nilotica which were once found along the River Senegal are today vestigial. This reduction may in part be due to a change in climate (GEMS 1986b, 1986e), but many charcoal mounds and their scars were seen in these classified forests.

10.7.2 Standing grass

The FSOs were asked to distinguish between standing grass, grass that had fallen over or broken, stubble, and naked earth. At the end of the dry season the grass layer species, exclusively annual plants, are dried up, yellow, and often covered in dust. Standing grass can nevertheless be diagnosed from its distinctive colour and texture, setting it apart from fallen grass or straw, which looks less golden and smoother. In zones with appreciable areas of standing grass the estimation of percent cover is relatively easy. If the grass layer is mostly absent or thinly scattered, local differences in colour and texture of the soil can make judgements largely subjective. From the aircraft the ecologically important distinction between stubble and naked earth is frequently difficult to make.

Figure 10a shows the distribution of standing grass at the end of the growing season in 1980, and Figures 10b to 10d that of the end of the dry season. The nearly complete lack of standing grass at the end of the dry season in 1981 led to the FSO forgetting to record data for this parameter for more than 75% of the survey zone.

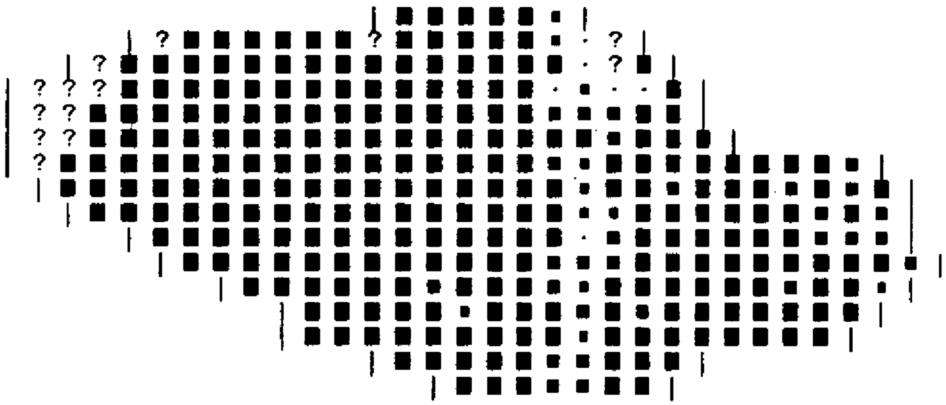
The proportion of the landscape covered with standing grass at the end of the dry season will obviously change from year to year. Inter-observer variability cannot therefore be compensated in the way that it can for the woody plants. However, it is likely that the observers would agree on the presence or absence of standing grass, even though their estimates of percent cover might differ widely. It nevertheless remains theoretically possible to construct a map which shows the probability that any given area will contain some standing grass at the end of the dry season.

Unfortunately such a map cannot realistically be constructed on the basis of the project's data, because only two dry-season surveys would contribute, the third being largely useless, having too wide an area in which no data were collected. As an approximation to such a map, Figure 11 shows the mean values estimated over these dry season surveys. This Figure is presented with considerable reservations as to its usefulness except in indicating the clear results of general and widespread overgrazing, especially in the north of the zone, where it is unlikely that standing grass will be found at the end of the dry season.

10.7.3 Naked earth

At the end of a good growing season the grass layer cover in the sandy Ferlo is nearly continuous. If it were to be maintained by correct

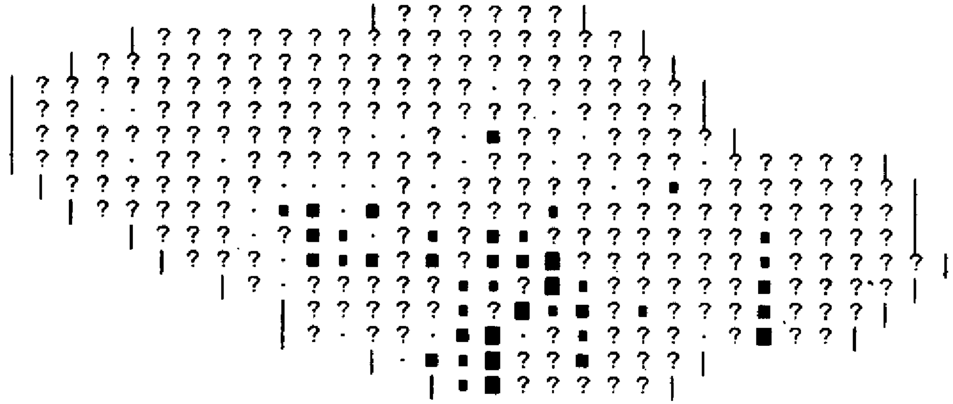
Figure 10a: Percent of ground covered by standing grass in October 1980



Key

Symbol	Percent
	<= 0
·	0.1 to 5
▪	5.1 to 10
▪	10.1 to 20
■	20.1 to 40
█	40.1 and over

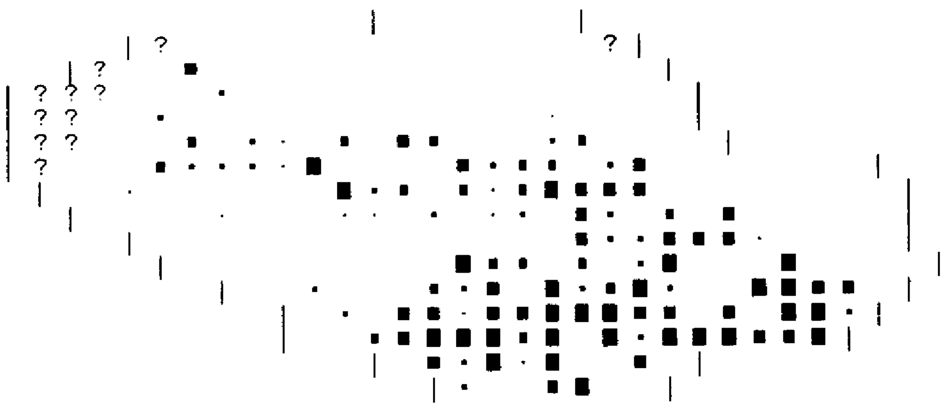
Figure 10b: Percent of ground covered by standing grass in May 198



Key

Symbol	Percent
	<= 0
·	0.1 to 5
▪	5.1 to 10
▪	10.1 to 20
■	20.1 to 40
█	40.1 and over

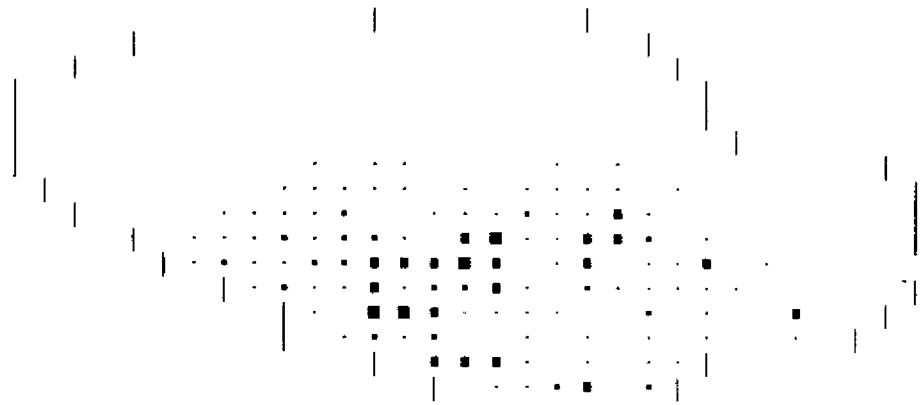
Figure 10c: Percent of ground covered by standing grass in June 1982



Key

Symbol	Percent
	<= 0
·	0.1 to 5
•	5.1 to 10
▪	10.1 to 20
■	20.1 to 40
█	40.1 and over

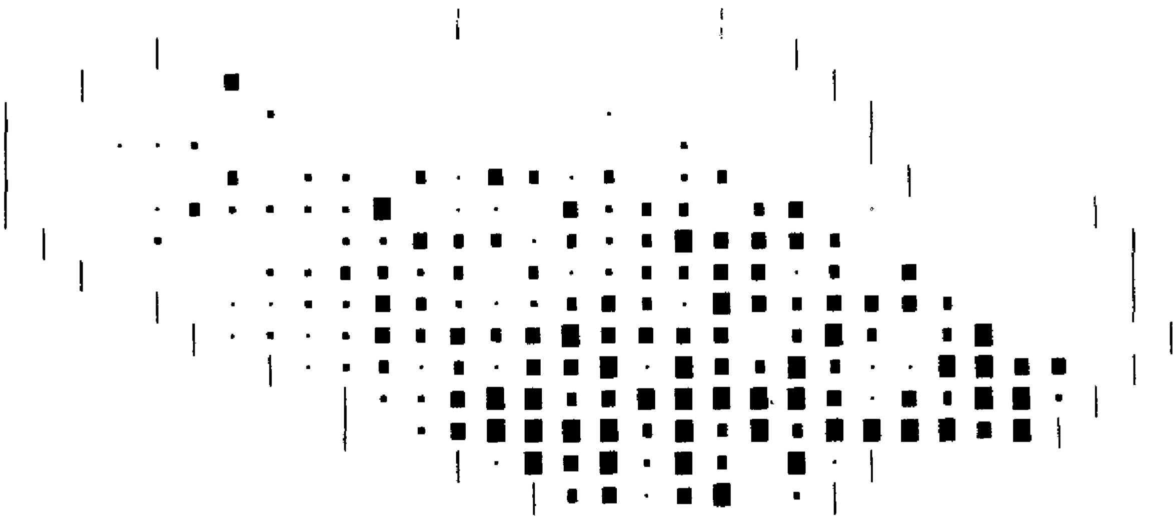
Figure 10d: Percent of ground covered by standing grass in June 1983



Key

Symbol	Percent
	<= 0
·	0.1 to 5
•	5.1 to 10
▪	10.1 to 20
■	20.1 to 40
█	40.1 and over

Figure 11: Probability of standing grass at the end of the dry season



Key

Symbol	Percent
	<= 0
·	0.1 to 2
•	2.1 to 5
▪	5.1 to 10
■	10.1 to 20
█	20.1 and over

range management until the end of the dry season, the plant cover would protect the soil against erosion. Naked earth, on the other hand, is an invitation to erosion by the wind or by the first rainstorms. The plants in the gravelly zone are clumped and large expanses of neked earth appear naturally between the clumps. The risk of erosion by water (principally sheet erosion) in this zone is therefore higher than it is in the sandy zone.

The map of the situation in 1980, at the end of the rainy season, when plant cover is at its greatest, shows (Figure 12a) that large stretches of naked earth are indeed exposed in the gravelly zone in the south east. Widespread patches of naked earth were also recorded near the river, which in some cases corresponds to harvested areas under cultivation, but other major areas of naked earth in the centre of the sandy zone probably correspond to the sterilised patches, often sealed by a hydrophobic algal layer, that ground surveys have noted in this region.

Unfortunately for the long-term well-being of the pastures, the SRF data also show clearly that in both the sandy and gravelly zones the grass layer does not remain continuous until the end of the dry season. Data were not collected on naked earth in 1981, but in 1982 and 1983 the extent of naked earth was alarming. Few zones had less than 40% of their surface denuded (Figures 12b and 12c). The compound map of the two years gives an impression of sadly degraded rangelands (Figure 13).

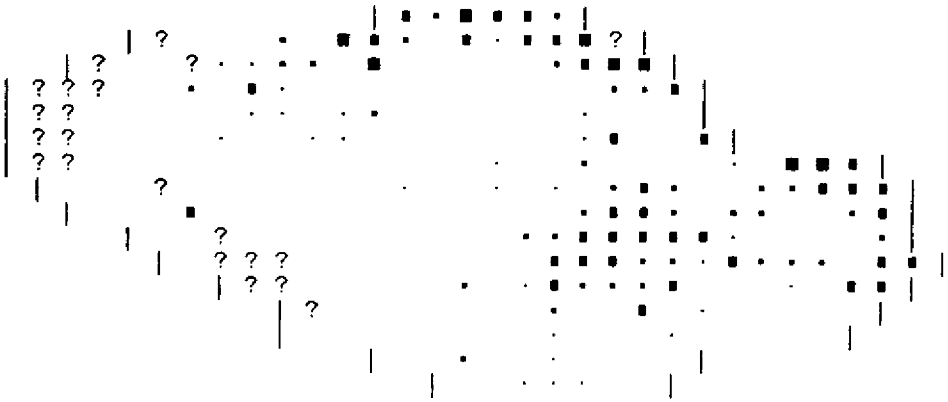
The inherent inter-annual variability in the exposure of naked earth rules out the possibility of using these data to quantify observer bias. Nevertheless bias can probably be detected, since in 1982, after a reasonably good rainy season, in 95% of the survey area the observer recorded naked earth covering more than 40% of the ground under the aircraft. In 1983, after a far poorer rainy season, the same observer judged that 75% of the Ferlo to had more than 40% of the ground denuded.

In part, no doubt, this difference is due to differences in the mental definition used by the observer in the two flights. The observer can not always be certain what it is that he sees on the ground, a hundred and twenty metres below. By "mental definition" is therefore meant the decision of the observer that a given combination of colour and texture indicates, for example, stubble eaten down to ground level, and that another combination indicates naked earth with a pellicular crust. There seems to be no way to put such a definition into objective unambiguous words, and it is inevitable that decisions made on the basis of such a mental definition will change as the definition drifts, not only between years, but also in the course of the survey, depending for instance on the position of the sun, the alertness of the observer, and the decisions he has made in the previous few minutes.

10.7.4 Fire

Bush fires in the Ferlo principally involve grass layer plants. Fires are rare in areas producing less than about 700 kilogrammes per hectare (see GEMS 1986f). Most bush fires are probably caused by human

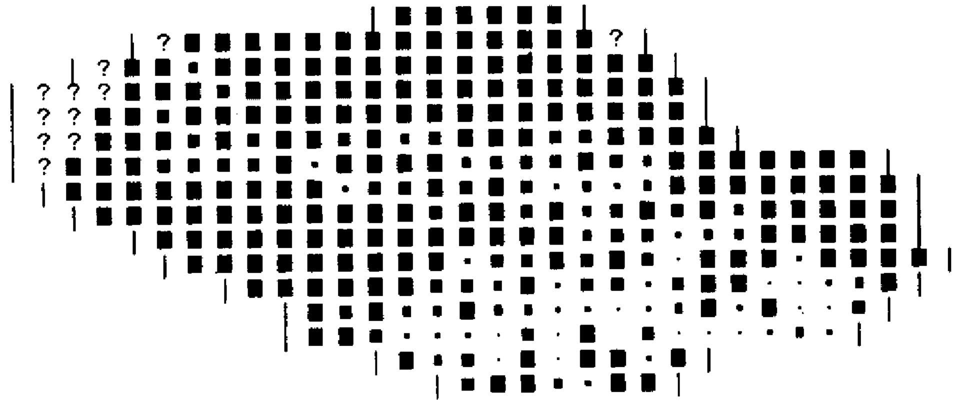
Figure 12a: Percent of gróund covered by naked earth in October 1980



Key

Symbol	Percent
	0.1 to 20
·	20.1 to 40
•	40.1 to 60
▪	60.1 to 80
■	80.1 to 90
█	90.1 and over

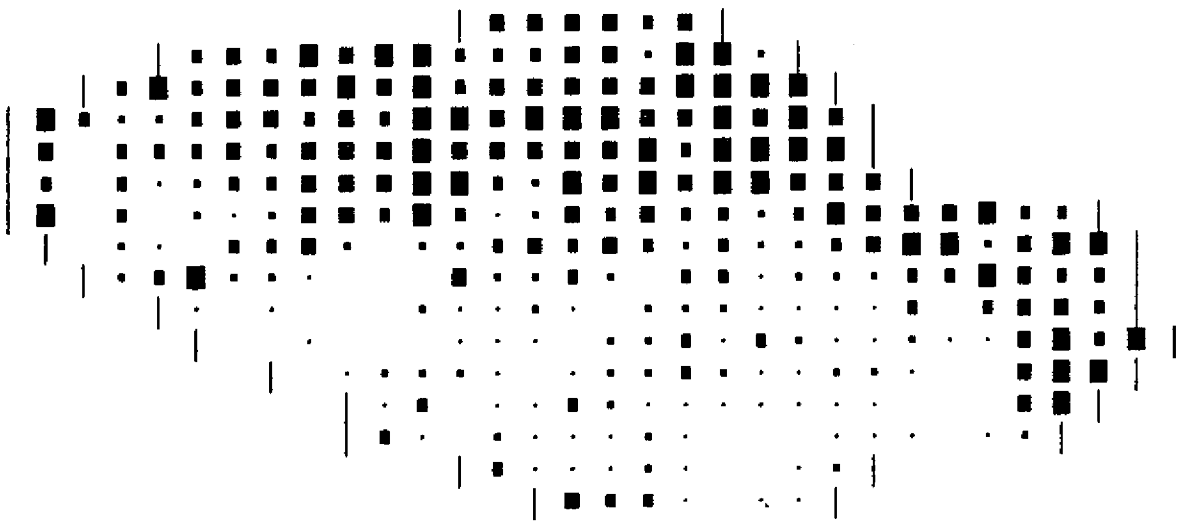
Figure 12b: Percent of ground covered by naked earth in June 1982



Key

Symbol	Percent
	0.1 to 20
·	20.1 to 40
•	40.1 to 60
▪	60.1 to 80
■	80.1 to 90
█	90.1 and over

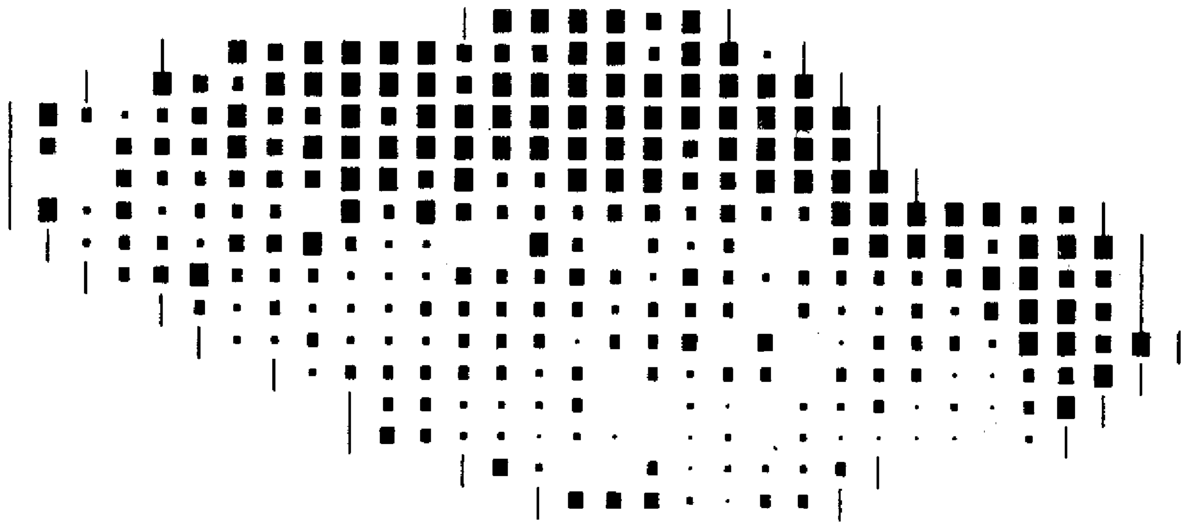
Figure 12c: Percent of ground covered by naked earth in June 1983.



Key

Symbol	Percent
	0.1 to 20
·	20.1 to 40
▪	40.1 to 60
▪	60.1 to 80
■	80.1 to 90
█	90.1 and over

Figure 13: Mean estimate of percent naked earth in the dry season



Key

Symbol	Percent
	0.1 to 20
·	20.1 to 40
▪	40.1 to 60
▮	60.1 to 80
■	80.1 to 90
█	90.1 and over

negligence, by the careless discarding of a lighted cigarette or failure to extinguish a camp fire. Some are deliberately set, occasionally with no apparent reason (Giffard 1974).

The effects of fire in the Sahel are incontestably deleterious, with the volatalisation of nitrogen, a complete loss to the ecosystem, the sterilisation or destruction of seeds and seedlings, and the removal of stubble, straw and fallen leaves, which reduces or eliminates the soil's protection against erosion. Such modifications to the superficial soil layers, and hence to the germination conditions, has repercussions on the species composition of the grass layer in the future (Penning de Vries et al., 1982). The livestock suffers the complete loss of the grass layer and, since sahelian grasses are annuals, is not compensated by fire flush, as it is in areas with perennial grass species.

Early bush fires start at the end of the rains, in September and October (Figure 14a), and the rangelands continue to suffer fires until May or June, when there is little or nothing left to burn, and the rains start. The light ash of grass fires is blown away and traces of fire are soon obscured by dust (project data suggest that dust storms have been unusually frequent in the last few years). At the end of the dry season the traces of fire are largely obliterated. The areas in which fire can be detected from the air are in all probability smaller than the true areas that have burned.

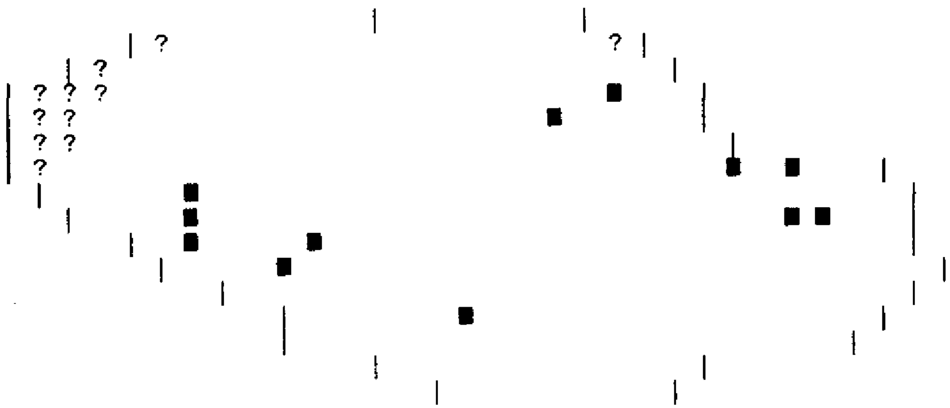
The extent over which traces of fire were detected by the SRFs in 1982 and 1983 is therefore all the more alarming. In 1982 the FSO recorded traces of fire in 10% of the zone. Half of this, some 1500 square kilometers, was in the Vindou Thingoli-Amali-Labgar triangle, an area of high livestock density (Figure 14b). In June 1983 roughly 20% of the Ferlo bore traces of fire visible from the air, most of which (some 4700 square kilometers) was in the gravelly region in the south-east (Figure 14c).

10.7.5 Erosion

In the geologic past, erosion has leveled much of the Ferlo, so that today steep slopes are rarely found in the zone. Where the soils are mostly sandy, water erosion is rarely spectacular, but it is probably nevertheless ecologically important even in the sandy zone in transport of fine soil particles, seeds and other organic matter off dune crests and slopes and into interdune hollows. Sheet erosion in the gravelly zone has in some places laid bare the underlying hardpan, a sterile crust of laterite.

In the Ferlo, four sorts of erosion can be detected from the air: sheet erosion, gulley erosion, wind erosion, and erosion by livestock. Sheet erosion shows as characteristic patches on the ground, partially bordered by small dams of detritus. Occasionally well-defined rims can be made out, formed by tiny cliffs a few centimetres high at the upper limits of the eroded area. Small dendritic ravines indicate gulley erosion. Wind erosion deposits sand in characteristic shapes behind plants and other obstacles. Regular heavy use of an area by livestock

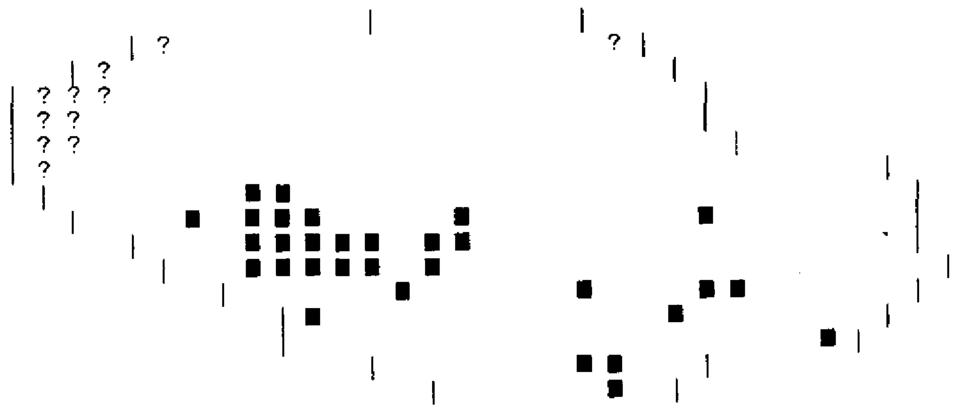
Figure 14a: Traces of fire visible in October 1980



Key

Symbol	Presence/Absence
|	Absent
■	Present

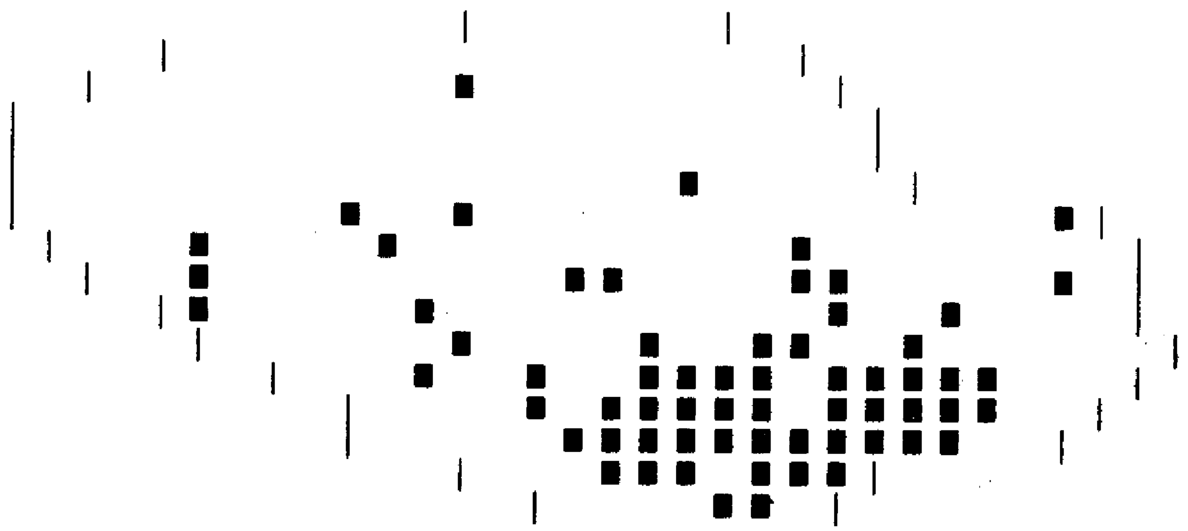
Figure 14b: Traces of fire visible in June 1982



Key

Symbol	Presence/Absence
|	Absent
■	Present

Figure 14c: Traces of fire visible in June 1983



Key

Symbol	Presence/Absence
	Absent
■	Present

leaves traces whose shapes are less regular and which can normally be easily distinguished from the signs of wind erosion. The FSO also recorded wind erosion when movement of sand was visible at ground level. In areas of wind erosion, visible traces of the other forms of erosion were normally obliterated.

Although the observers recorded the severity of erosion on an ordinal scale, inter-observer differences in definitions have made it necessary to reduce this data to simple presence or absence of erosion, and all the data from the four SRFs has been compounded to create Figures 15a-c.

10.8 Animal parameters

The data collectd by the RSOs are considerably more reliable than are those collected by the FSO. Rather than make estimates, the RSO count every animal that crosses their counting point on the transect strips. Their judgement is required to decide whether or not an animal is in the transect and to which species it belongs, but these are relatively easy decisions to make, and are not subject to wide inter-observer differences. The bias inherent in the data and the statistical treatment of these data is well understood (eg Jolly 1981a).

10.8.1 Population totals

Six livestock species are found in the Ferlo (sheep, goats, cattle, donkeys, horses and dromedaries).

Table 2 shows the population estimated for each of these species by the four SRFs.

10.8.2 Confidence limits and changes in population totals over time

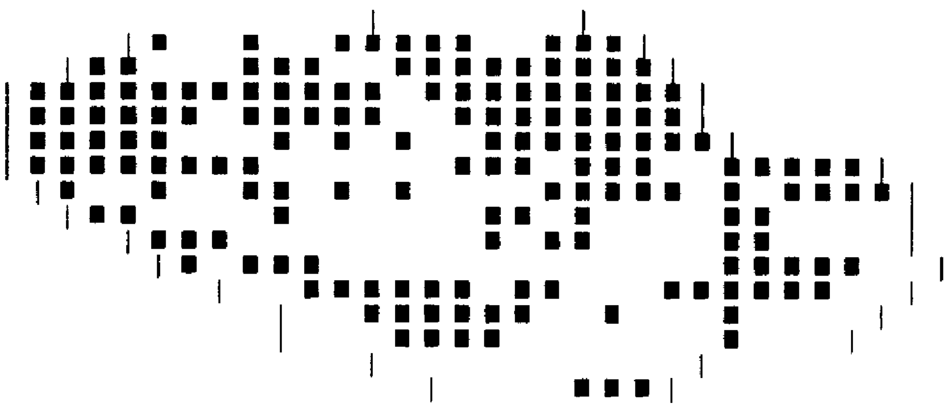
The standard deviations of the populations estimates, expressed as a percentage of the total population, are of the order of 15%, 20%, 30%, 40% and 100% for the five species respectively. A difference of 5% or 10% in the population of a given species cannot therefore be detected by SRFs at this sampling intensity, unless consistent changes in one direction are recorded in a series of surveys.

10.8.3 The 1981 survey

Population estimates for all the species are roughly 1.7 times larger in 1981 than they are for the other three years. Five possible causes might give such a result:

1 The SRF is subject to large random errors
2 There was a major influx of mauritanian livestock from the north
3 There was a major influx of senegalese livestock from the south
4 The southward transhumance was smaller in 1981 than in other years

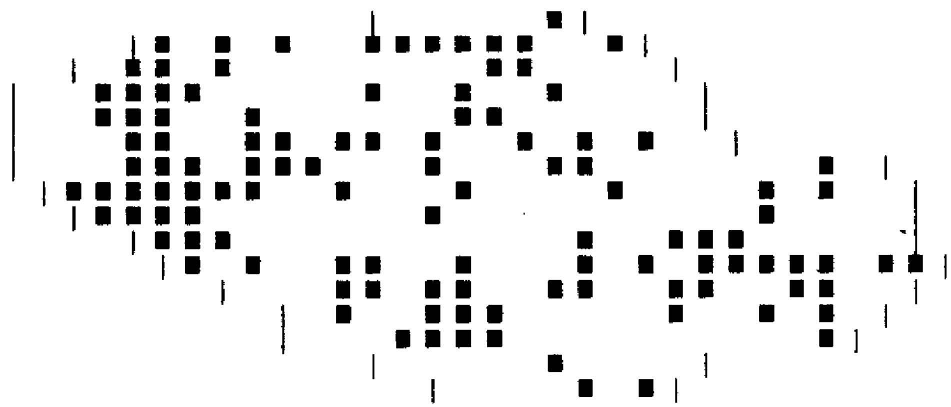
Figure 15a: Distribution of wind erosion seen during surveys



Key

Symbol	Presence/Absence
	Absent
■	Present

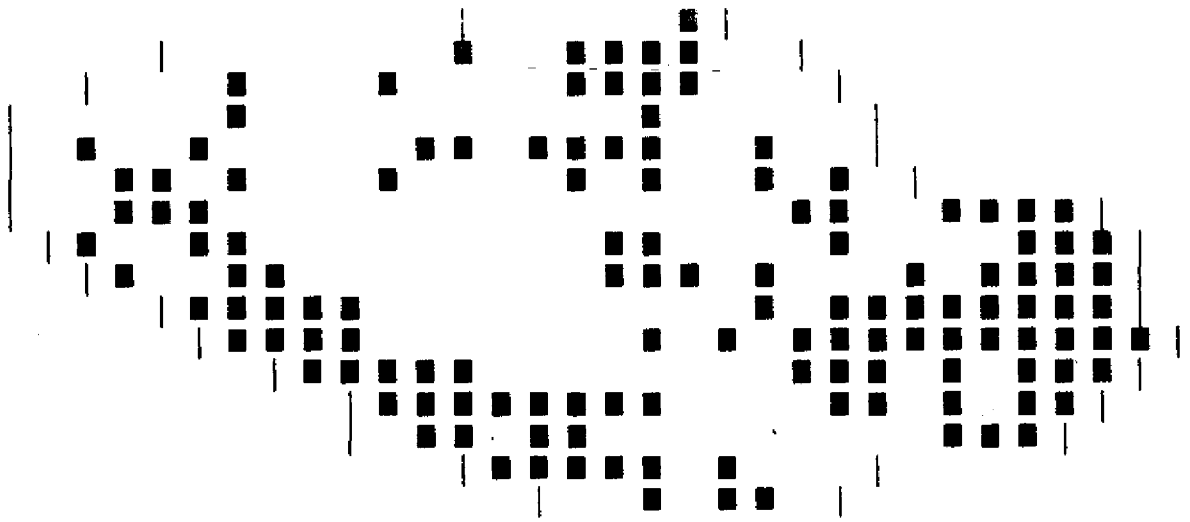
Figure 15b: Distribution of gulley erosion seen during surveys



Key

Symbol	Presence/Absence
	Absent
■	Present

Figure 15c: Distribution of sheet erosion seen during surveys



Key

Symbol	Presence/Absence
		Absent
■	Present

Table 2: Changes in SRF crews

Year	Pilot 1	Front seat observer 1	2	3	4	Rear seat observers team 1	team 2
1980	X	X	X			X	
1981	X		X	X			X
1982	X				X	X	
1983	X				X	X	

Table 3: Total populations estimated by four SRFs

Species	Year of survey			
	1980	1981	1982	1983
Shoats	726 000	1 231 000	683 000	700 000
Cattle	367 000	602 000	325 000	385 000
Donkeys	25 600	27 000	12 500	23 000
Horses	9 700	10 000	6 000	8 000
Dromedaries	1 000	2 000	2 500	6 000

Table 4: The probable livestock populations in the Ferlo at the start of the 1980s

Species	estimated population	
	absolute numbers	expressed as TLU*
Shoats	703 000	105 000
Cattle	360 000	288 000
Donkeys	19 000	10 000
Horses	7 500	7 500
Dromedaries	2 500	2 500

* 1 TLU = 250 kg

5 There was an error in calibration of the strip widths for the survey.

Many years of experience in East Africa and the United States have proved that the SRF is reliable, and is not subject to random errors of this scale. The first suggested cause of the anomalous 1981 figures may be rejected.

Senegalese herdsmen prefer cattle with white or piebald coats, while the Mauritanians prefer animals with russet coats. It is therefore easy to distinguish Senegalese and Mauritanian herds from the air. In 1980 3.1% of the cattle herds were made up of russet-coloured animals. In 1981 the proportion was 2.8%, and in 1982 and 1983 0.9% and 4.3% respectively. There was probably therefore no massive influx of mauritanian livestock.

A hypothetical influx of animals from the south is highly improbable, since by the end of the dry season the herds are usually moving south.

It is unlikely that the high 1981 figure results from a smaller volume of transhumance than usual, since the 1980 SRF took place in the rainy season, when in principle all the herds that pasture in the Ferlo are in the area. The populations should therefore be larger in 1980 than they were in 1981, no matter how small the volume of transhumance.

This leaves us with the fifth option. The populations of shoats, catle, donkeys and horses were all 1.7 times larger in 1981 than in the other three years. Only the population of dromedaries did not show a similar increase, and since the standard error of the population estimate of dromedaries is of the order of 100%, this non-conformity to the general trend has probably no profound implication.

In general, then, the evidence for an error in calibration is strong. The error almost certainly arises from an under-estimate of the width of the strip searched by the observers. For the rest of this case study the numbers quoted for the 1981 survey are divided by 1.7.

10.8.4 Livestock population estimates

Given the remarkably close correspondence in the population totals estimated from the 1980, 1982 and 1983 surveys, the data are pooled to give a combined estimate of the population totals of domestic species in the Ferlo at the start of the 1980s (Table 3). The corrected 1981 figures were not included in this estimate.
The total livestock population of the Ferlo is somewhat over a million head, or 400 000 TLU, which pasture on some 30 000 square kilometres. As will be seen in the following paragraphs, the livestock density nevertheless varies considerably over the Ferlo. The smallstock (shoats) contribute about 25% to the total of TLU, and the cattle roughly 70%. The other species only contribute some 5% to the total population expressed in TLU.

10.8.5 Populations of wildlife species

By comparison with the long list of species recorded for the area at the beginning of the century (Barral 1982), very few wildlife species are to be found in the Ferlo today: warthog (Phacochoerus aethiopicus), aardvark (Orycteropus afer), striped jackal (Canis adustus), redfronted gazelle (Gazella rufifrons) spotted hyaena (Crocuta crocuta), and of the birds, a relict population of ostrich (Struthio camelus).

The SRFs of the Ferlo were designed to count livestock populations. During a survey the project counted around 44 000 head of livestock, and about 15 animals of other species. The population totals of wildlife species cannot be calculated from these data, but it seems probable that they can be numbered in the dozens rather than the hundreds.

10.8.6 Distribution of livestock species

10.8.6.1 Distribution of smallstock (shoats)

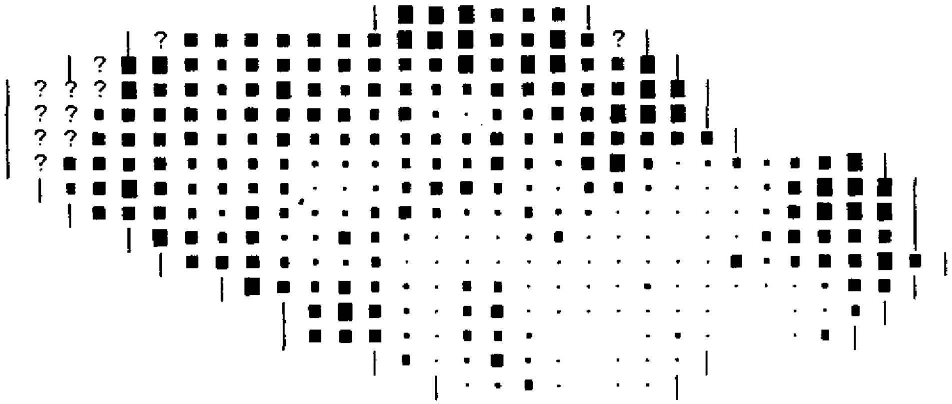
There is a striking similarity in the (smoothed) distribution of shoats recorded by the four flights of 1980, 1981, 1982 and 1983. Figure 16 (a-d) shows the near complete absence of shoats in the south-east of the Ferlo, corresponding to the gravelly, largely uninhabited quadrilateral Revane-Ranerou-Dendoudi-Loumbi. By contrast, shoats are found in high densities along the strip from Matam through Saldé to Haïré Laö, and in fairly high densities in the area to the north of Mbar Toubab, Tatki and Aatch Bali. There is a fourth region of occasionally high shoat density along the fossil river Ferlo, although in 1982 there were very few near Amali.

The map derived from the 1980 growing season survey shows a higher concentration of shoats along the river Senegal than do those of the dry season surveys. Other variations in shoat densities tend to be local and probably of limited significance. If their cause is not an artefact of the techniques of data gathering and mapping, they may arise from small-scale movements of herders and their stock.

10.8.6.2 Distribution of cattle

The distribution of cattle recorded by the SRFs is slightly more variable between years than is that of the shoats (Figure 17a-d). Nevertheless, the visual impression remains recognisably similar from year to year; as for the shoats, few cattle were recorded in the gravelly south-east, and there is a concentration in the strip between Matam and Haïré Laö. In the west there is a concentration of cattle whose centre which apparently moves north-south from year to year.

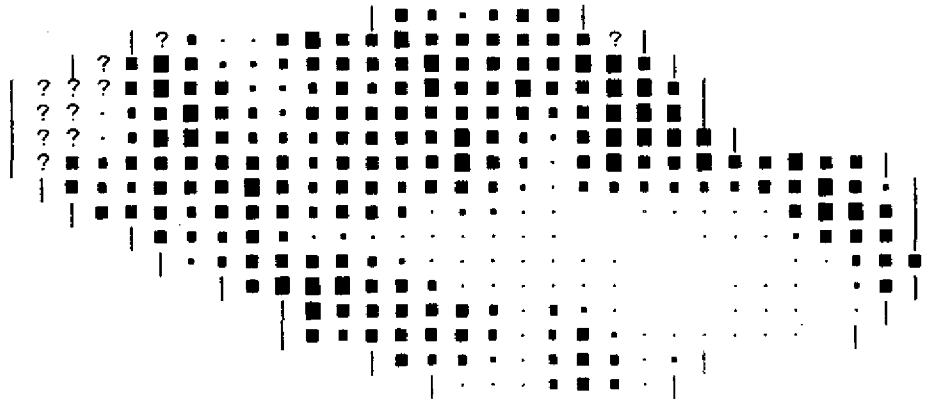
These four sets of data, effectively a series of snapshots of continually shifting livestock populations, suggests that cattle populations are more mobile than are shoats, especially in the north of the zone. Cattle depend on grass-layer plants to a greater extent than igure 16a: Smoothed distribution of smallstock (shoats) in October 1980



Key

Symbol	Density (head/sq km)
	<= 0
·	0.1 to 5
•	5.1 to 10
▪	10.1 to 20
■	20.1 to 50
█	50.1 and over

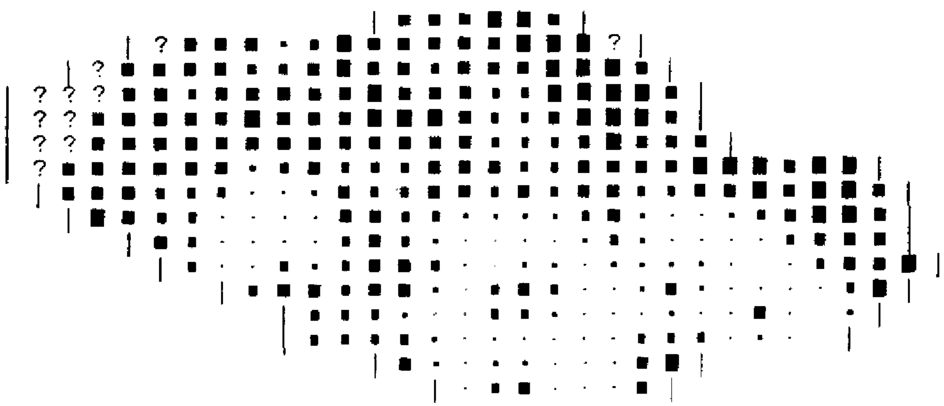
Figure 16b: Smoothed distribution of smallstock (shoats) in May 1981



Key

Symbol	Density (head/sq km)
	<= 0
·	0.1 to 5
•	5.1 to 10
▪	10.1 to 20
■	20.1 to 50
█	50.1 and over

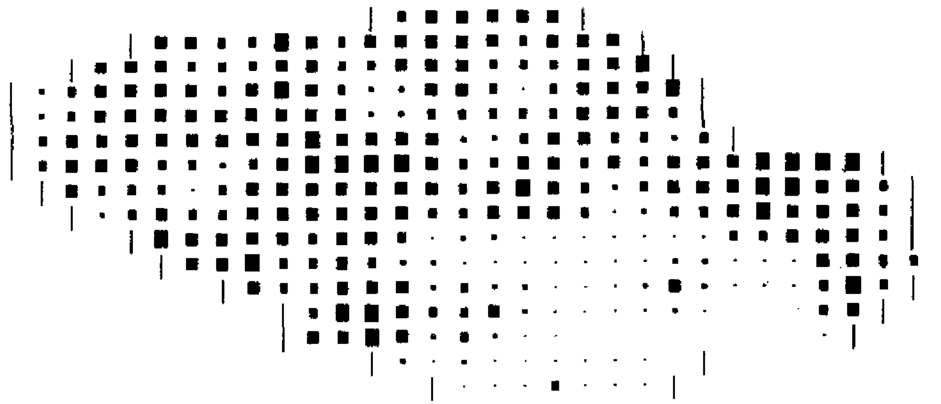
Figure 16c: Smoothed distribution of smallstock (shoats) in June 1982



Key

Symbol	Density (head/sq km)
	<= 0
·	0.1 to 5
▪	5.1 to 10
▪	10.1 to 20
■	20.1 to 50
█	50.1 and over

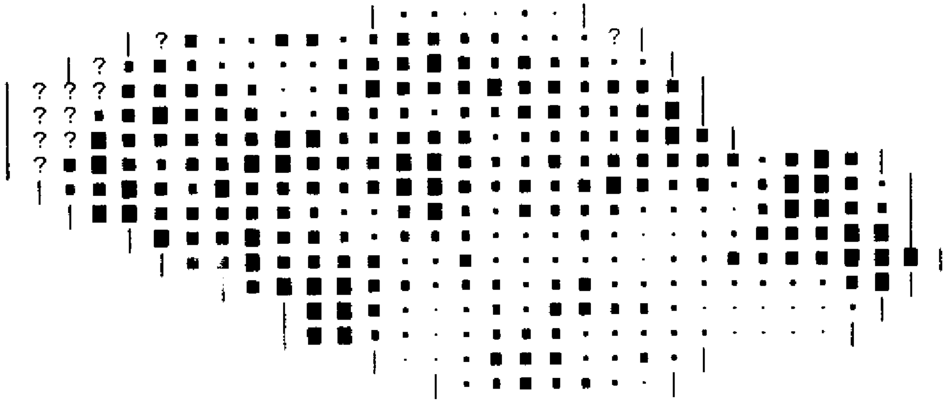
Figure 16d: Smoothed distribution of smallstock (shoats) in June 1983



Key

Symbol	Density (head/sq km)
	<= 0
·	0.1 to 5
▪	5.1 to 10
▪	10.1 to 20
■	20.1 to 50
█	50.1 and over

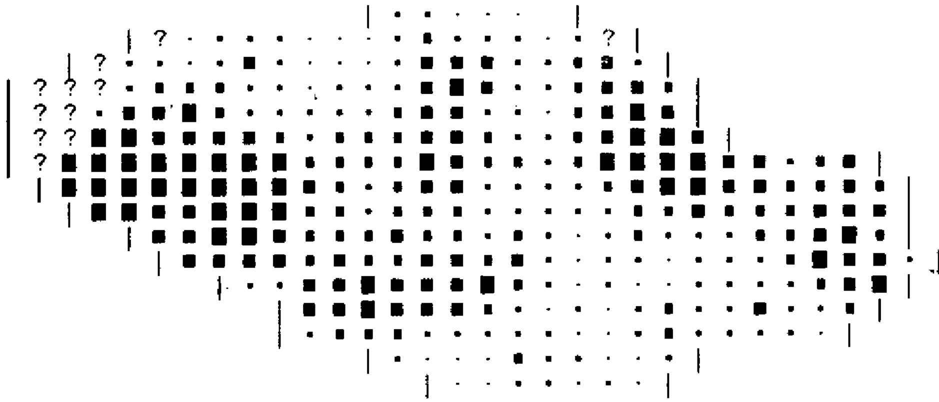
Figure 17a: Smoothed distribution of cattle in October 1980



Key

Symbol	Density (head/sq km)
	<= 0
·	0.1 to 2
•	2.1 to 5
▪	5.1 to 10
■	10.1 to 20
█	20.1 and over

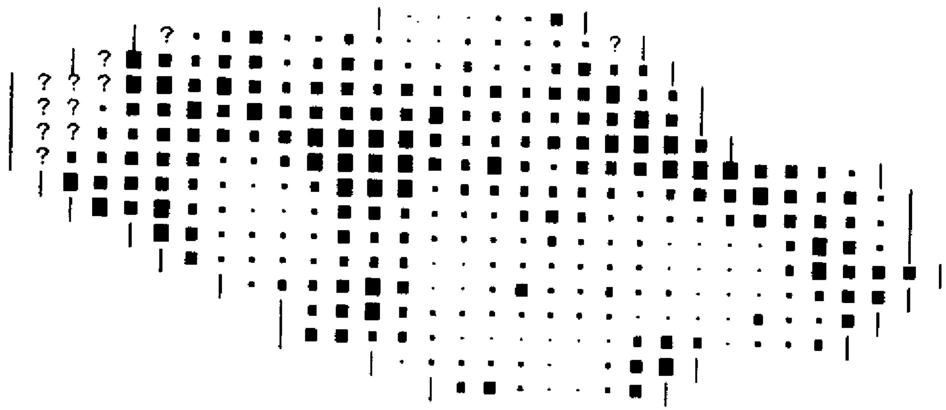
Figure 17b: Smoothed distribution of cattle in May 1981



Key

Symbol	Density (head/sq km)
	<= 0
·	0.1 to 2
•	2.1 to 5
▪	5.1 to 10
■	10.1 to 20
█	20.1 and over

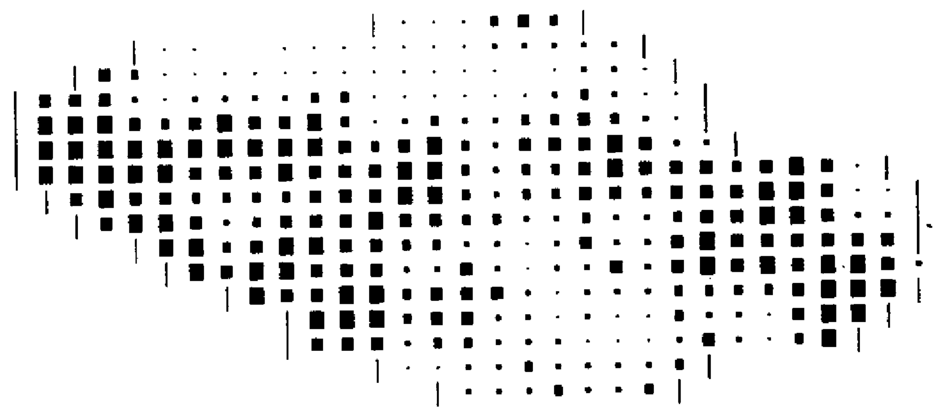
Figure 17c: Smoothed distribution of cattle in June 1982



Key

Symbol	Density (head/sq km)
	<= 0
·	0.1 to 2
•	2.1 to 5
▪	5.1 to 10
■	10.1 to 20
█	20.1 and over

Figure 17d: Smoothed distribution of cattle in June 1983



Key

Symbol	Density (head/sq km)
	<= 0
·	0.1 to 2
•	2.1 to 5
▪	5.1 to 10
■	10.1 to 20
█	20.1 and over

do shoats, and once the grass has been eaten, the cattle must move south. This is the interpretation placed on the near-total lack of cattle in the north of the Ferlo in June 1983. Even when the grass has gone, shoats, especially goats, can stay behind, browsing from bushes and trees. Near the river, high populations of shoats can be kept alive through the dry season by feeding them with byproducts of cultivation.

10.8.6.3 Distribution of donkeys

As can be predicted from the total population figures, the density of donkeys in the Ferlo is generally far lower than those of shoats and cattle. The smoothed distribution maps (Figure 18a-d) show a relatively uniform density of donkeys in the areas of the Ferlo, and the absence of donkeys in the gravelly zone.

This uniform distribution may in part arise from the use of the donkey as a beast of burden, one or two of which are owned by nearly all the families in the area. A rich man might have a hundred times as many cattle as a poor one, but he would only have a few more donkeys.

Smoothing might mask a real variability in the distribution of donkeys. However, the similarity of the four maps suggests that donkeys are in fact quite evenly distributed in the areas of sandy and hydromorphic soils.

10.8.6.4 Distribution of horses

Horse populations in the Ferlo are quite uniformly distributed at very low densities (Figure 19a-d), with rarely more than 1 horse per square kilometer. Horses were most frequently seen near the road between Matam and Haïré Laö, and in the western part of the Ferlo south-east of the line joining Tatki and Labgar. The gravelly zone supports very low densities of horse populations, as does the central part of the Ferlo near Kodiolel, Namarel and Revane. The comments on the uniformity of the donkey population distribution are equally valid for the horse population.

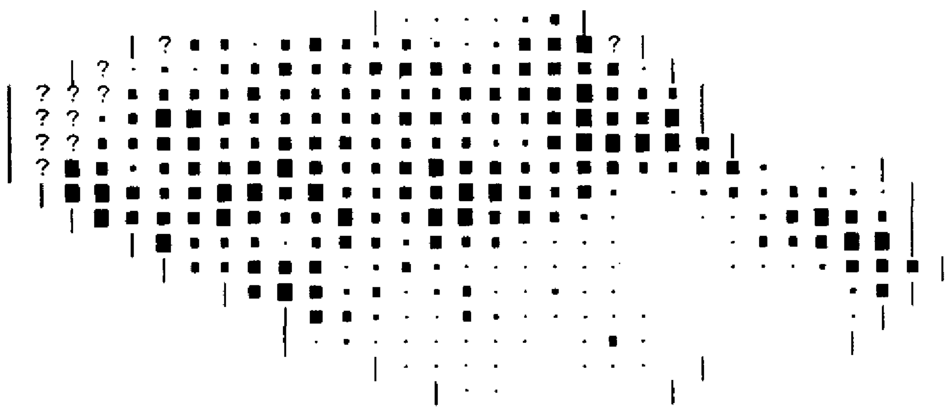
10.8.6.5 Distribution of dromedaries

Dromedaries in the Ferlo usually belong to Mauritanian herders on transhumance. In 1980, 1981 and 1982 they were mostly seen in the western and northern part of the survey zone, but in 1983, after a bad rainy season, they were also seen well to the south and south-west (Figure 20a-d).

10.8.7 Mean distribution of livestock populations in the dry season

By compounding the data collected over several dry seasons (1981, 1982 and 1983) it is possible to construct maps which clearly show the mean dry season distribution of the various domestic species, without

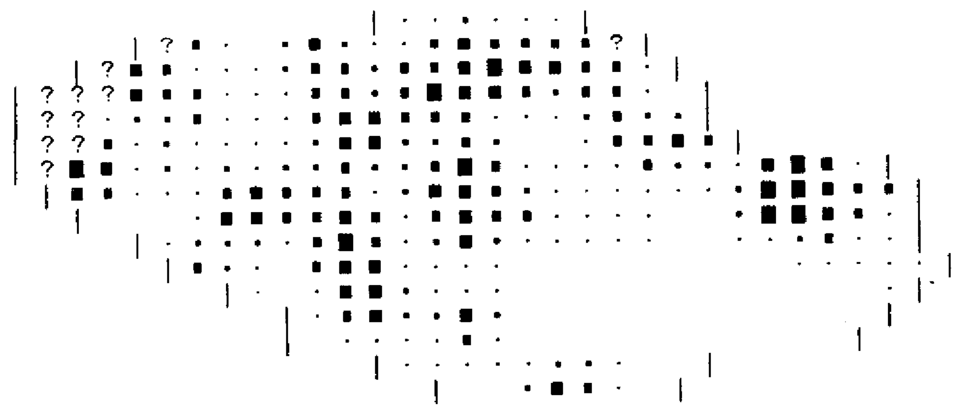
Figure 18a: Smoothed distribution of donkeys in October 1980



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.3
▪	<= 0.5
▪	<= 1.0
■	<= 2.0
■	2.01 and over

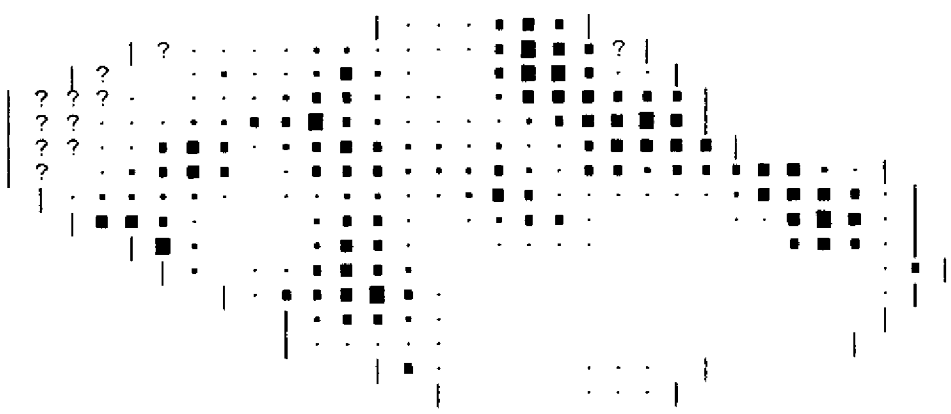
Figure 18b: Smoothed distribution of donkeys in May 1981



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.3
▪	<= 0.5
▪	<= 1.0
■	<= 2.0
■	2.01 and over

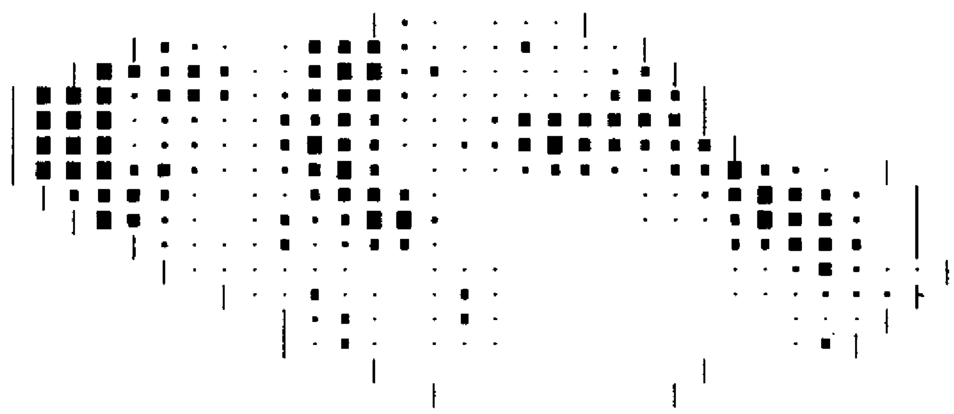
Figure 18c: Smoothed distribution of donkeys in June 1982



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.3
•	<= 0.5
▪	<= 1.0
■	<= 2.0
█	2.01 and over

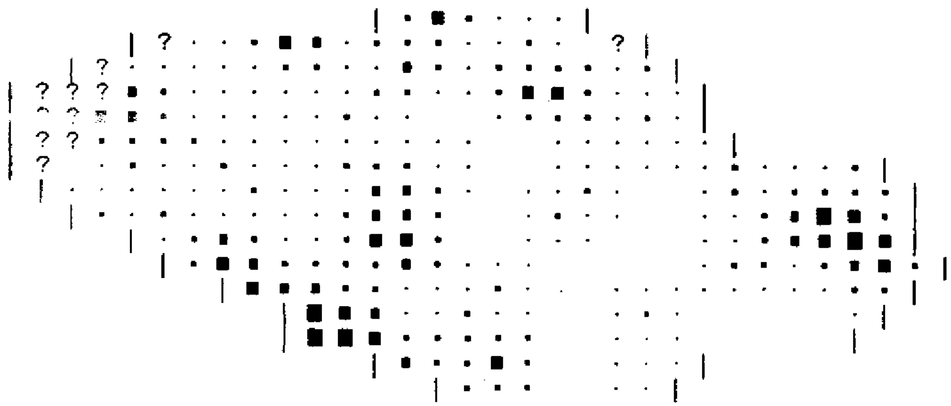
Figure 18d: Smoothed distribution of donkeys in June 1983



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.3
•	<= 0.5
▪	<= 1.0
■	<= 2.0
█	2.01 and over

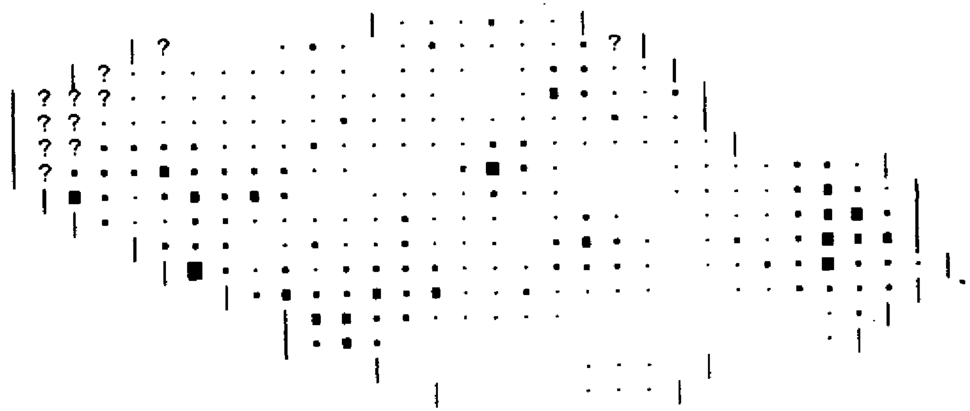
igure 19a: Smoothed distribution of horses in October 1980



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.3
▪	<= 0.5
▪	<= 1.0
■	<= 2.0
■	2.01 and over

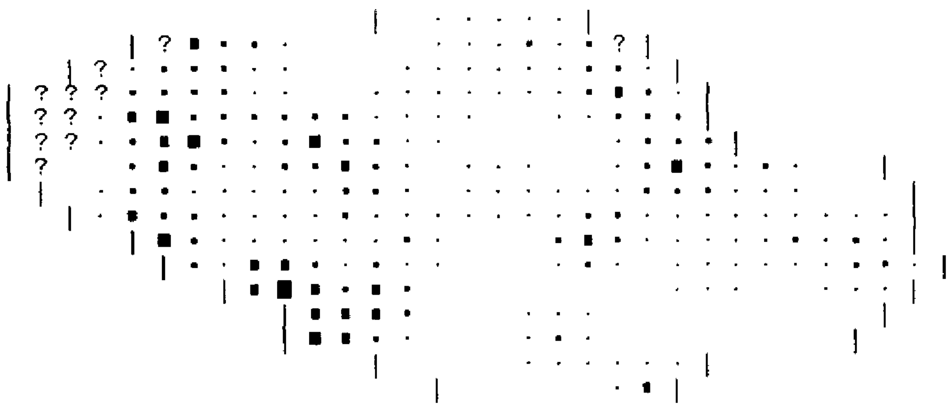
Figure 19b: Smoothed distribution of horses in May 1981



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.3
▪	<= 0.5
▪	<= 1.0
■	<= 2.0
■	2.01 and over

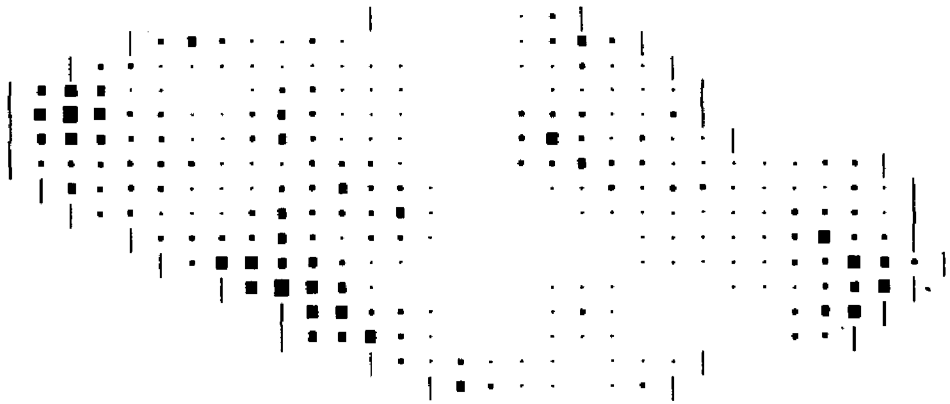
Figure 19c: Smoothed distribution of horses in June 1982



Key

Symbol	Density (head/sq km)
	<= 0.0
	<= 0.3
	<= 0.5
	<= 1.0
	<= 2.0
	2.01 and over

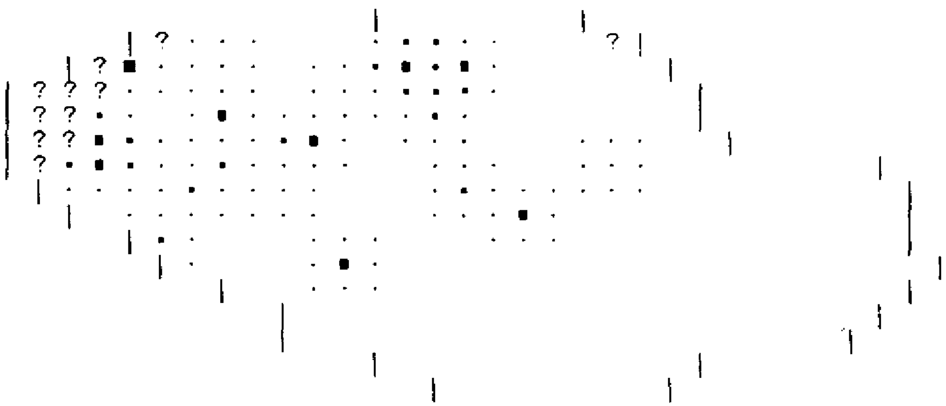
Figure 19d: Smoothed distribution of horses in June 1983



Key

Symbol	Density (head/sq km)
	<= 0.0
	<= 0.3
	<= 0.5
	<= 1.0
	<= 2.0
	2.01 and over

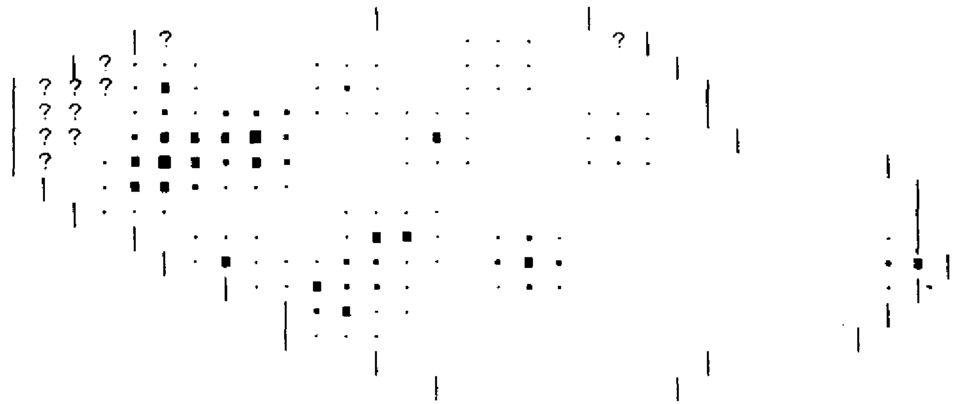
Figure 20a: Smoothed distribution of dromedaries in October 1980



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.1
▪	<= 0.2
■	<= 0.5
■	<= 1.0
█	1.01 and over

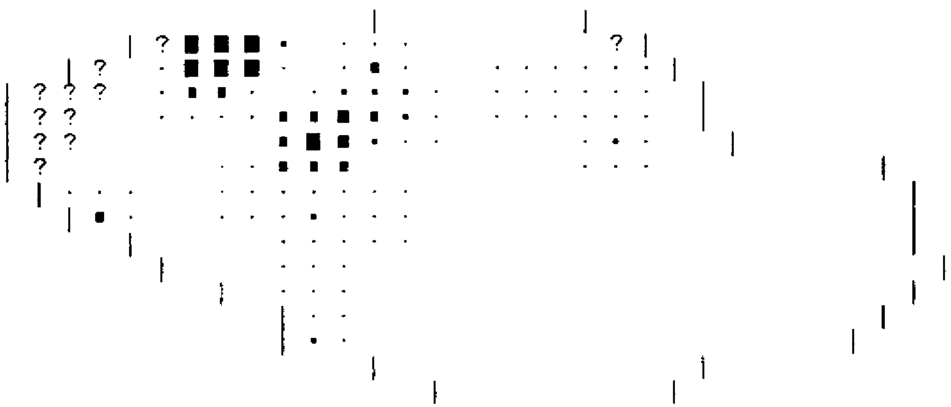
Figure 20b: Smoothed distribution of dromedaries in May 1981



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.1
▪	<= 0.2
■	<= 0.5
■	<= 1.0
█	1.01 and over

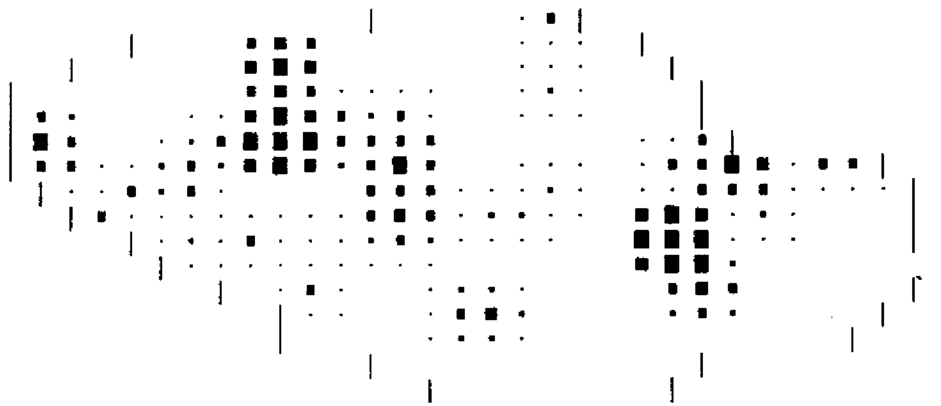
Figure 20c: Smoothed distribution of dromedaries in June 1982



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.1
•	<= 0.2
▪	<= 0.5
■	<= 1.0
█	1.01 and over

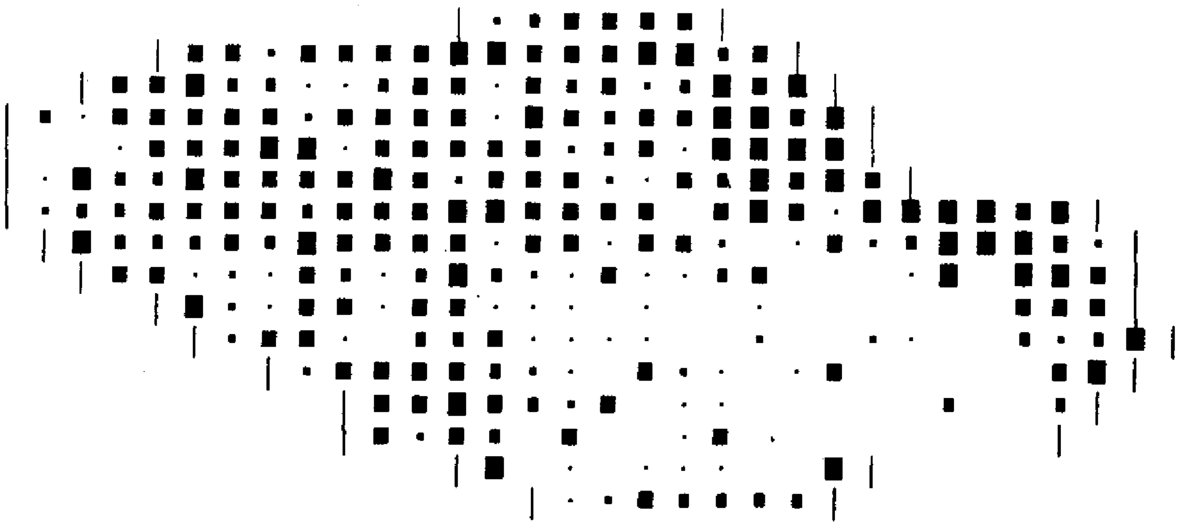
Figure 20d: Smoothed distribution of dromedaries in June 1983



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.1
•	<= 0.2
▪	<= 0.5
■	<= 1.0
█	1.01 and over

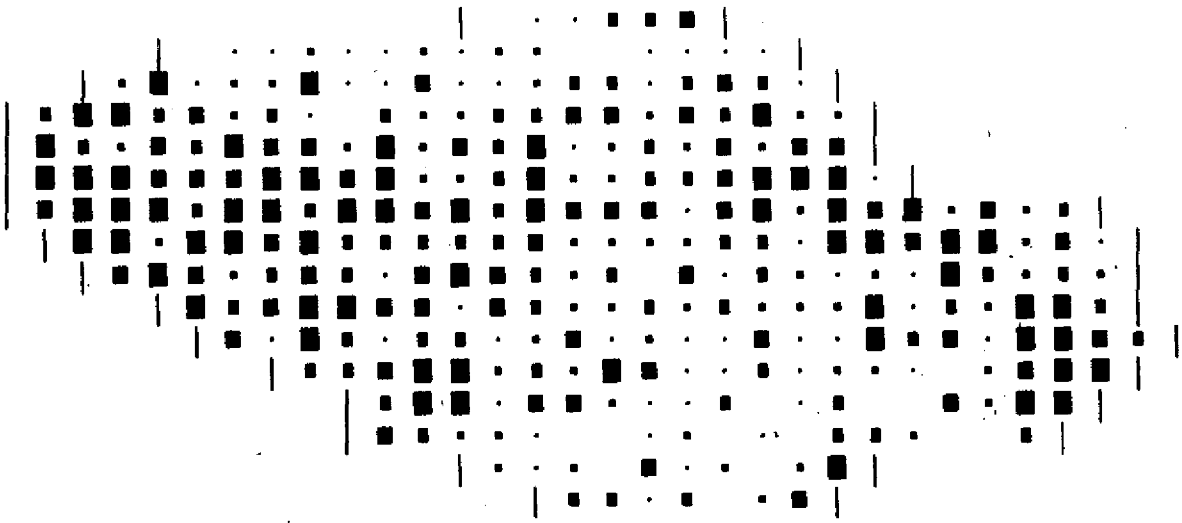
Figure 21: Mean distribution of smallstock in the dry season



Key

Symbol	Density (head/sq km)
	<= 0
·	0.1 to 5
•	5.1 to 10
▪	10.1 to 20
■	20.1 to 50
█	50.1 and over

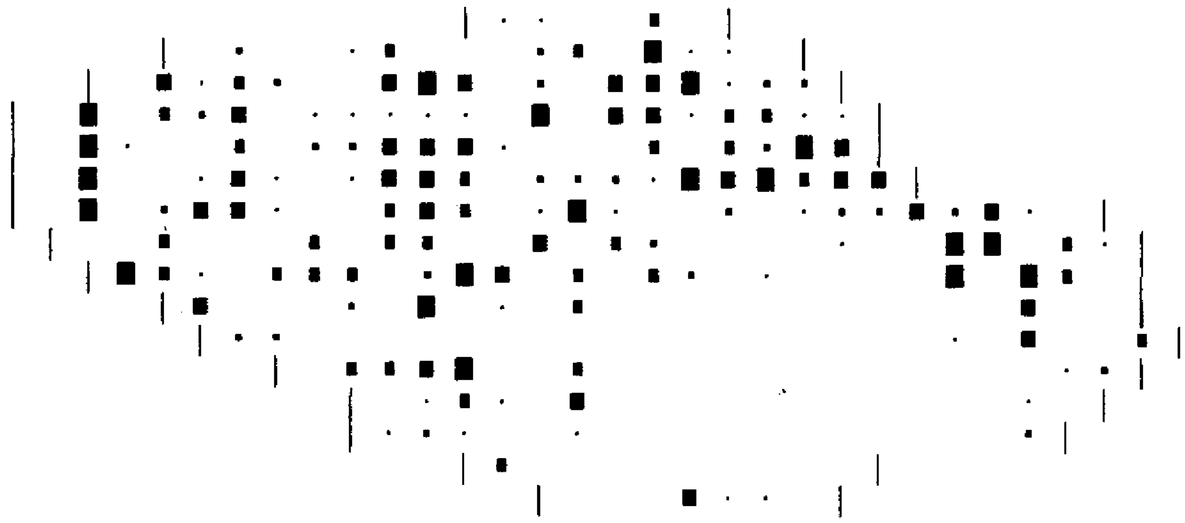
Figure 22: Mean distribution of cattle in the dry season



Key

Symbol	Density (head/sq km)
	<= 0
·	0.1 to 2
▪	2.1 to 5
▪	5.1 to 10
■	10.1 to 20
█	20.1 and over

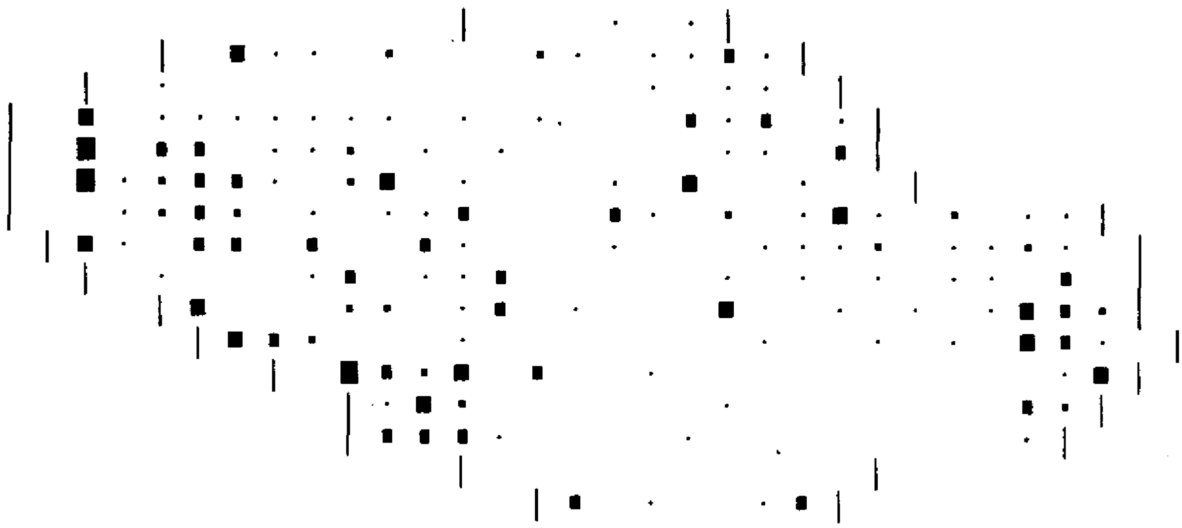
Figure 23: Mean distribution of donkeys in the dry season



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.3
▪	<= 0.5
▪	<= 1.0
■	<= 2.0
█	2.01 and over

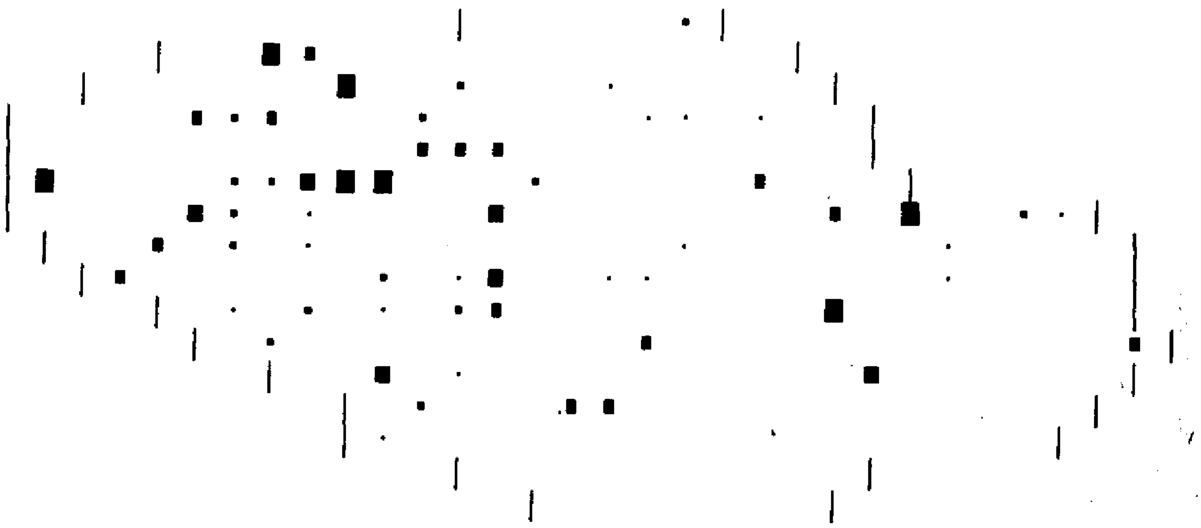
Figure 24: Mean distribution of horses in the dry season



Key

Symbol	Density (head/sq km)
	<= 0.0
.	<= 0.3
▪	<= 0.5
■	<= 1.0
■	<= 2.0
█	2.01 and over

Figure 25: Mean distribution of dromedaries in the dry season



Key

Symbol	Density (head/sq km)
	<= 0.0
·	<= 0.1
▪	<= 0.2
▪	<= 0.5
■	<= 1.0
█	1.01 and over

smoothing the data (Figures 21-25). These maps bring out the generalised absence of livestock in the gravelly south-east of the Ferlo, where only cattle are present, in very low densities. The strip of high livestock densities between Matam and Haïré Laö is clearly seen for all species except the dromedary. While shoat populations can be found everywhere in the Ferlo except the south east, cattle populations show a bimodal distribution, with centres to the east and west, and a notable trough in population densities in a central north-south band.

Although their densities seem a little less uniform in these compounded dry-season distribution maps, donkeys and horses can once again be seen to be evenly spread over the regions in which they are found. However, the compounded map of dromedary distribution is ecologically meaningless, given the high mobility of the herds.

10.9 Distribution of carcasses in 1980

In October 1980 the observers counted nearly 300 carcasses during the survey. A focus of mortality in the east of the Ferlo, between Matam and Saldé, corresponds to an area of high cattle and shoat densities. The strip between Saldé and N'Dioum also showed a relatively high density of carcasses. While the west of the Ferlo seemed to be largely free of carcasses, the gravelly region near Kara Vindou and Loumbi seemed to suffer disproportionate mortality given the low livestock densities in this region.

Very few carcasses were seen in the dry season surveys. The reasons for this result are obscure, although livestock mortality is typically higher at the start of the rains than it is during the dry season.

10.10 Critique of mapping techniques

10.10.1 Smoothed maps

Smoothing the data allows the major features of livestock distribution to emerge clearly. The technique is particularly useful for mapping the distribution of species whose densities are typically high. With animals whose population densities are low and whose distributions are irregular, the method shows its limitations. Each isolated observation gives rise to a patch of nine squares. Sophisticated techniques which avoid this problem are currently used in computerised image processing for satellite data, but such techniques are inappropriate for low-resolution SRF data derived from small sampling fractions. A simple modification to the algorithm to take account of low-density species is to smooth data only if at least two of the nine cells contain data.

10.10.2 Compounded maps

The technique of compounding data from the same season in successive years gives rise to a generalised impression of livestock distribution for that season which may be useful for many management purposes. In this respect it corresponds to the technique of plotting a running average for time-series data, and with a sufficient number of repeated surveys a series of running-mean distribution maps could be produced.

Such a series would provide the many considerable advantages, but suffer from the same drawbacks, of other running means (Kendall 1973). In an ecological monitoring program the major disadvantage of maps compounded over several surveys is that it might mask interannual changes. However, such changes would probably be of such an order that the analyist would in any case recognise that the maps should not be compounded.

10.11 The Tambacounda survey

The southern limit of the survey zone near Tambacounda (N13 44 W13 40) is defined by the road RN1 between Koumpentioum, Tambacounda and Goudiri (Figure 26). The survey zone is 230 kilometers east-west by 40 to 80 km north-south. This area corresponds to a group ranching scheme run by the Projet pour le Devéloppement de l'Elevage en Sénégal Oriéntal (PDESO). The survey took place at the end of the dry season, in June 1982. Rain had fallen three days before in a violent storm. Puddles were still visible from the air in most parts of the survey zone.

According to the results of the survey, the two major livestock species in the scheme are shoats (Figure 27), numbering 29 000 +/- 13 000 head, and, more numerous, cattle (Figure 28) with 66 000 +/- 15 000 head. Mean densities varied greatly from flightline to flightline, with the result that the confidence limits are wide, at 46% and 22% of the respective population estimate. Shoat densities were lower than they were in the Ferlo, and the species is probably more common in the west of the region and well to the north of Tambacounda. Cattle were concentrated into three areas, in the west, in the centre north of Tambacounda, and in the extreme east.

The density of livestock was low in the classified forest north of Tambacounda, but other classified forests had no noticeable effect on livestock densities (Figure 29a and 29b). Livestock concentrations seem highest near to roads and tracks (Figure 30a and 30b), but the network of riverbeds played no part in determining distribution, as far as could be seen (Figure 31a and 31b). This lack of dependence might have been a direct result of the recent rain.

10.12 Conclusions and Discussion

An ecological monitoring program which uses systematic reconnaissance flights as one of its data-gathering platforms should ideally use the same front seat observer for each survey (if the FSO is to estimate values of ecological parameters). Unfortunately, a single observer may make widely different judgements of the same parameter on successive surveys, as can be seen from the estimates of woody plant cover in 1982 and 1983. These differences cannot be ascribed to slight differences in the alignment of the flightlines, since the direction of the difference in bias is too consistent between the two surveys. The project tried to overcome the problem of inter-observer variability by including a sketch of land cover at different percentages as part of the FSO's on-board

Figure 26: Tambacounda study zone: Area covered by the Projet de Developpement de l'Elevage dans le Senegal Oriental

Figure 26a: Villages and tracks

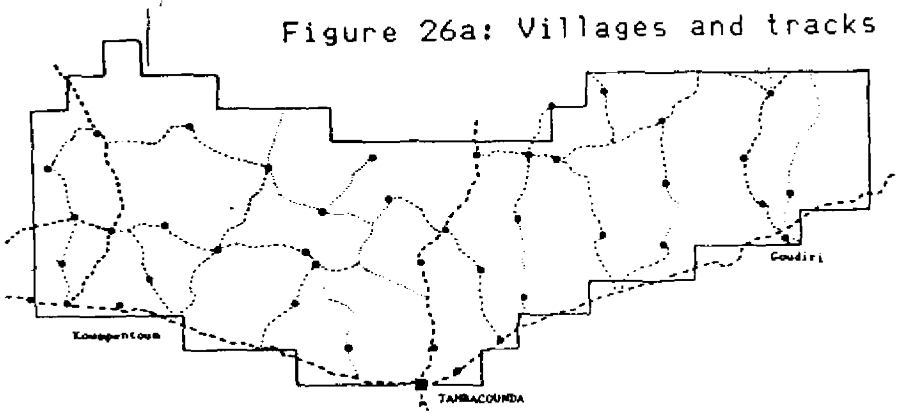


Figure 26b: Water courses

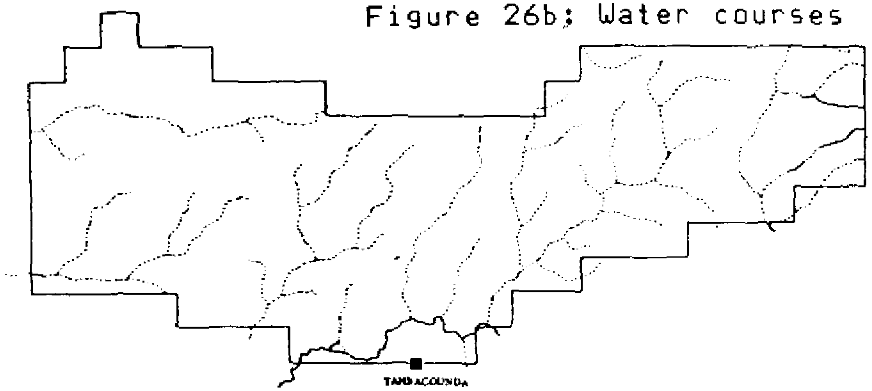
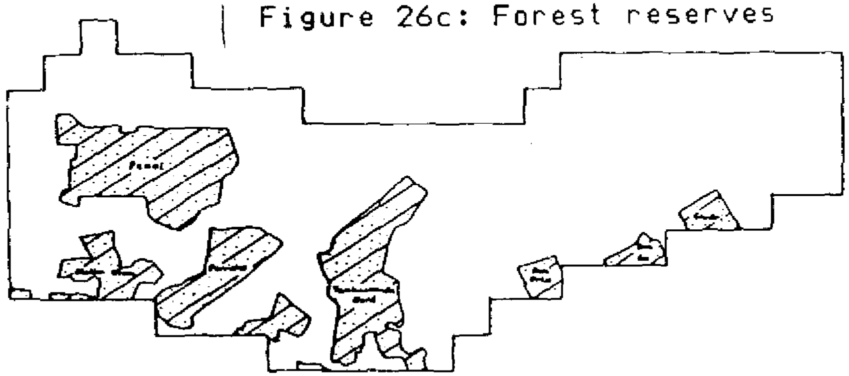


Figure 26c: Forest reserves



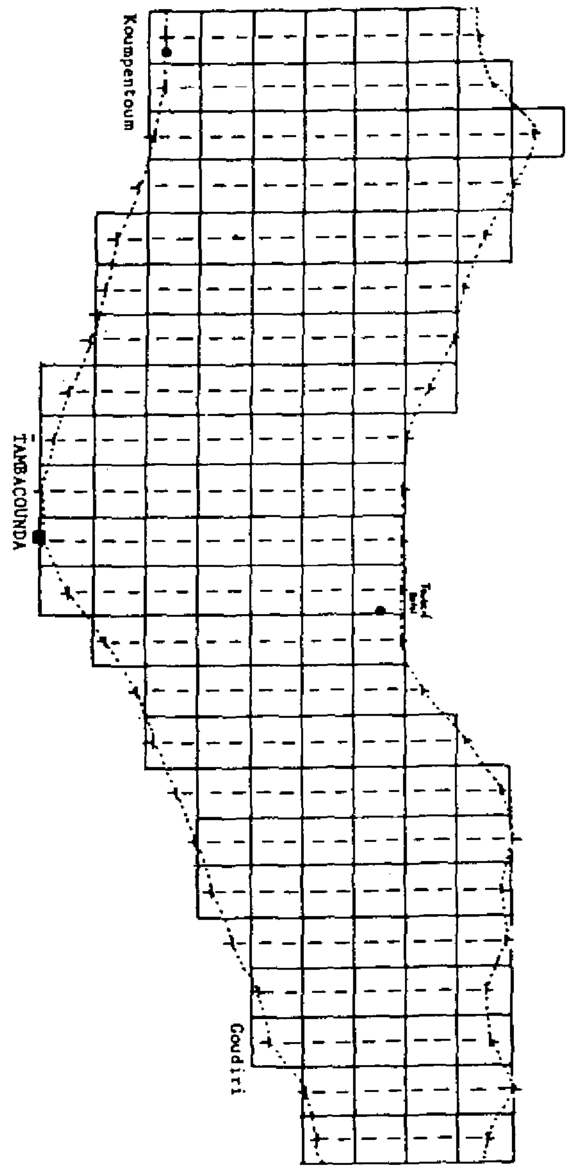
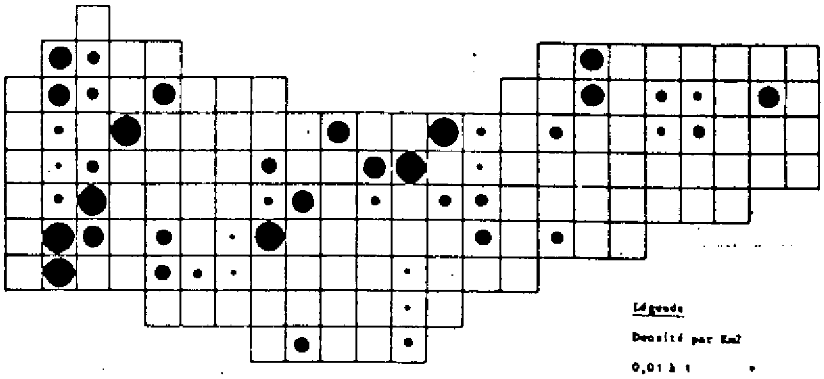


Figure 26d: Flight lines



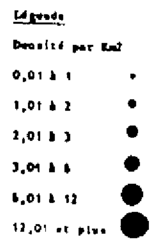
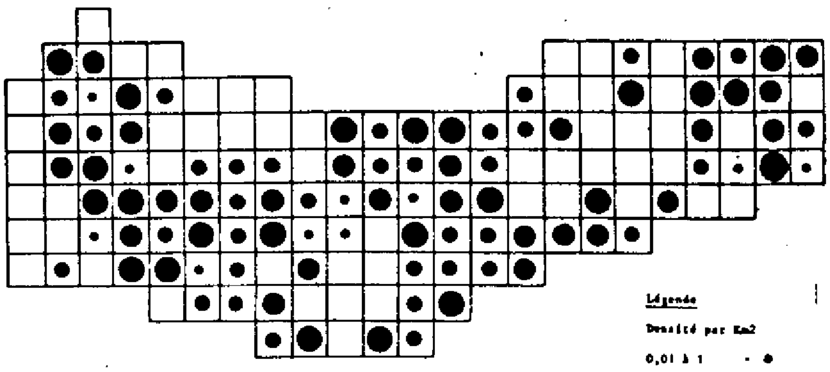


Figure 27: Distribution of smallstock (shoats) during the survey



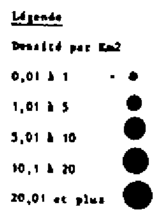


Figure 28: Distribution of cattle during the survey

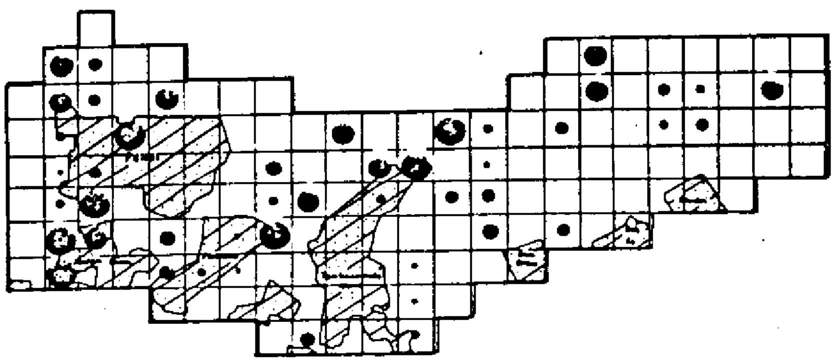


Figure 29a: Comparison of distribution of shoats with forest reserves

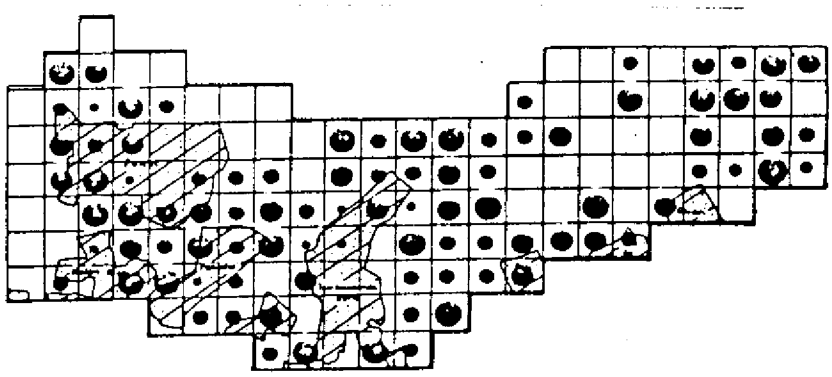


Figure 29b: Comparison of distribution of cattle with forest reserves

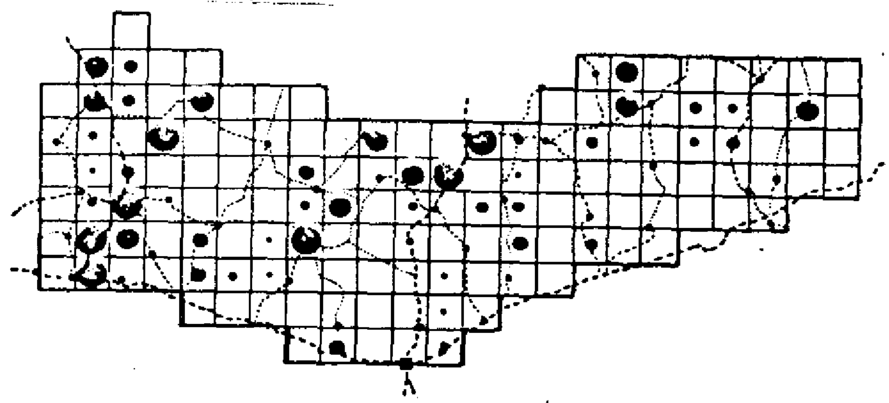


Figure 30a: Comparison of distribution of shoats with villages & tracks

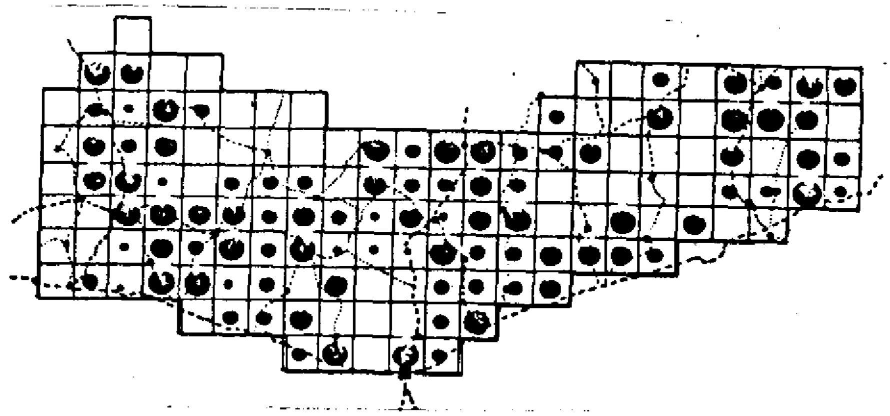


Figure 30b: Comparison of distribution of cattle with villages & tracks

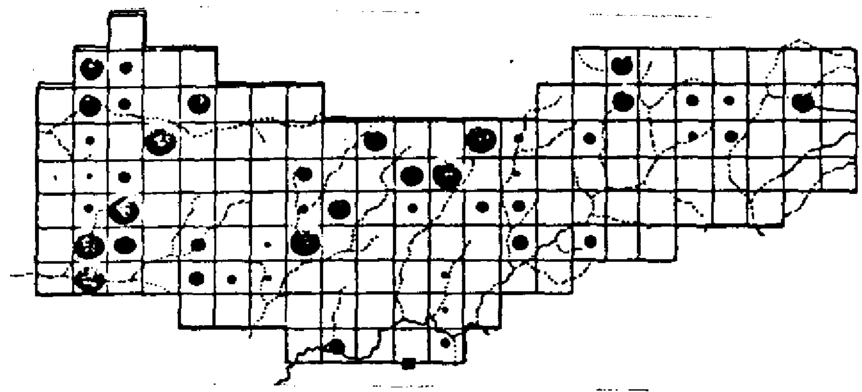


Figure 31a: Comparison of distribution of shoats with water courses

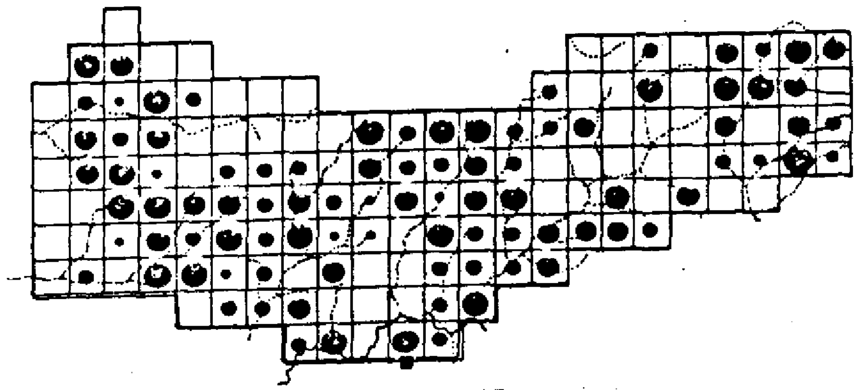


Figure 31b: Comparison of distribution of cattle with water courses

equipment. It was found difficult to use in pract ce, given the number of decisions that had to be made each minute and the number of clipboards and checksheets that had to be constantly manipulated by the observer. No doubt a large part of observer bias can be removed by correct professional training and by pre-flight refresher courses using photographs, slides and films.

Ideally training films would be made by mounting a 16mm cinecamera vertically in a light aircraft, and by shooting high quality colour film of a selection of areas to give the widest possible range of values for the ecological parameters of interest. It would be paticularly helpful to calibrate the film by use of colour slides, taken at the same time and subsequently analysed objectively. Alternatively, or in association with such an objectively calibrated film, several observers could be called on to make visual estimates from the film at preset intervals, and the consensus resulting from the estimates recorded on magnetic tape to run in synchronisation with the film. This commented film could then be used to standardise the estimates of the observers just before the flight. Although such a system would be costly to install, it would be invaluable in its effect on improving the quality and therefore the worth of the data collected.

Although the project recommends that ecological data collected by the FSO be treated with caution, it feels justified in including this data in its computerised analytic system, or proto-GIS, on the grounds that the use of data which are known to have limitations is preferable to the rejection of those data entirely. Inaccurate data may introduce noise which could mask real correlations, but they are not likely to give rise to spurious correlations. Nevertheless, for some applications the work of the FSO might be limited to technical tasks related to the functioning of the SRF, perhaps combined with recording electronically collected digital data, such as those of a radiometer.

In order to reduce the effect of observer bias to a minimum, the project recommends that values for ecological variables be integrated across as many surveys as is practical or possible, given the objectives of the surveys. Thus, for example, the project data on woody plant cover given in this case study would be averaged, so that the data used for analysis would be the mean values of the four surveys.

There is no question that the SRF is unrivalled in its ability to collect data on livestock populations in the Sahel. This powerful and efficient technique gives users a global and yet detailed view of animal distributions. Traditional field methods cannot hope to provide this information with the timeliness or economy of the systematic reconnaissance flight.

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