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ANTHROPOGENIC AND ENVIRONMENTAL CORRELATES OF LIVESTOCK DISTRIBUTION IN SUB-SAHARAN AFRICA

A Comparative Analysis of Livestock Surveys in Mali, Niger, Nigeria, Sudan and Tchad

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EXECUTIVE SUMMARY

Background

The common image of Africa is of a continent in turmoil, of civil wars, destitution and famine. Viewed from an historical perspective, however, much of Sub-Saharan Africa can be more objectively judged to be in a state of transition, undergoing a period of profound socio-economic, agricultural and environmental change. As human populations have increased, there has been a progressive expansion of agriculture and a conversion of natural vegetation to farmland, with exposure of more arid regions to the risks of over exploitation.

One consequence of these changes is the increasingly competitive land use pressures arising from potentially conflicting interests of farmers, foresters, pastoralists and conservationists. Faced with these pressures, traditional relationships between agricultural communities are obviously changing; some are becoming weaker, or breaking down altogether, whilst other new ones are being forged.

Following the Earth Summit in Rio current thinking in both international and national circles is focused on the promotion of sustainable forms of development, and how this can be achieved. Clearly for a continent in a general state of transition, the achievement of sustainable development is going to be a long term process, with different countries responding to their own particular circumstances and priorities. One reasonable certainty is that with growing human populations there will be an ever increasing demand for food; and that the achievement of greater production through the development of sustainable forms of agriculture should be a common goal and given the highest possible priority.

Given the limited success of so many agricultural development projects in the past, particularly those targeted at livestock production, there is some doubt about the best way forward. The validity of any form of development planning or policy analysis obviously depends on the reliability of information used. Unfortunately, the information about the current status of natural resources in many African countries is woefully inadequate for objective analysis and planning.

Livestock are in danger of becoming a forgotten resource, yet they represent a key element of sustainable farming systems and many rural economies. Accurate information about livestock abundance and the determinants of their distribution is essential to obtaining a better understanding of dynamic agricultural systems in a state of transition. This report presents an analysis of an unique database of livestock and land use surveys spanning thirteen years and consolidating data from Niger, Nigeria, Mali, Sudan and Tchad, covering an area equivalent in size to the whole of Europe.

Methodology and Database

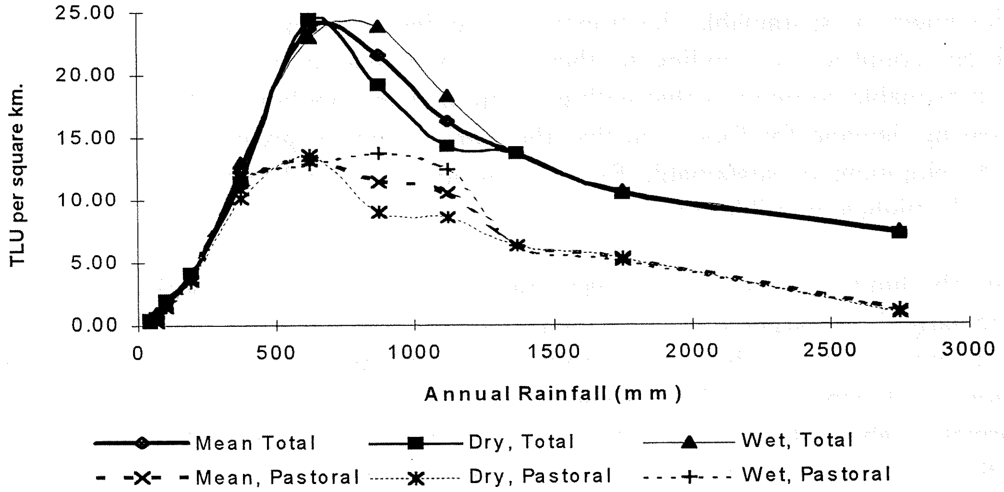
An unique feature of the ERGO database of livestock resources is that it is derived from standardised methods of information collection over a wide variety of environments across Africa, from the arid rangelands of the Sahel to the humid forest zone. The parameters included in the analysis come from three primary sources: **standard cartography,** for mean annual rainfall, agro-climatic zone, which are used for stratification purposes; **systematic low level aerial surveys,** for the direct observation of pastoral livestock, human settlement (roof tops), vegetation and land use; and **complementary ground surveys,** for enumerating village livestock numbers and local production systems. Thus, except for the stratification parameters, the analyses are based on standardised field data collection from the air and ground.

Analytical Objectives

The major foci of the analyses have been to examine livestock population levels in the four agro-climatic zones; to compare the population estimates derived from these data with earlier estimates; and to identify the primary correlates of livestock density- i.e. to establish the ecological conditions where most animals are to be found.

As well as considering simple densities (or totals) of cattle, camels, and small ruminants, total ruminant biomass has also been examined. Ruminant biomass figures exclude both equines and wild animals, but these comprise a vanishingly small fraction of the ruminant biomass in the areas surveyed. Each category of livestock is investigated for the different seasons, and for the mean annual levels. Total populations have been divided, where appropriate, into two elements: 'Pastoral' - i.e. that part of the overall population that is not closely associated with human settlement; and 'Village' - those 'backyard' livestock that are found within settlements.

Figure A: Biomass Density in Surveyed Areas: Annual Rainfall



Livestock Densities and Distribution

Figure A demonstrates the similarity in the locations of maximum animal densities for the 'Pastoral' and 'Village' livestock populations. Both peak in the 500 to 1000mm belt. The relative densities of the two elements in relation to annual rainfall are also shown, which emphasises the increasing importance of the livestock associated with human settlement in areas with more than 500mm rainfall per year. In the driest areas, the 'Pastoral' element accounts for 70 - 90% of the total, a figure which falls to 50-60% in areas with between 500 and 2000 mm annual rainfall, and then drops to 10-15% in the wettest belt.

These proportions imply that other livestock surveys, which have failed to take account of the 'Village' livestock in their estimations of animal populations, are likely to have under-estimated biomass levels very substantially in all but the driest regions.

Species Composition

Figures B and C show the relative contributions of camels, cattle and small ruminants to livestock biomass levels in the various rainfall belts. On each graph, the biomass density is also shown as a reminder that high proportions do not necessarily equate to high densities.

One of the most noticeable contrasts shown in the Figures is that between the 'Total' and 'Pastoral' biomass compositions. The latter give the strong impression that cattle are the major livestock species in all but the driest areas, where they are replaced by small ruminants and camels. This is the conventional view of livestock composition in Sub-Saharan Africa, and may account for the 'bovi-centric' basis of many development and veterinary projects.

As suggested in the discussion of the density figures, the incorporation of stock associated with settlements into the biomass figures results in a markedly different picture emerging. Whilst cattle remain the predominant species in areas with rainfall between 250 and 1250 mm per year, they only account for a half to two-thirds of the total livestock biomass. This is in contrast to the 80 - 95% levels that are implied by the 'Pastoral' composition data. In the wetter areas, it is the small ruminants (mainly goats) that are the most important element of the Total biomass, whilst in the most arid parts, it is camels and small ruminants (sheep and goats). As with biomass densities, seasonal variations in livestock compositions are slight.

Figure B: Total Biomass Composition: Rainfall

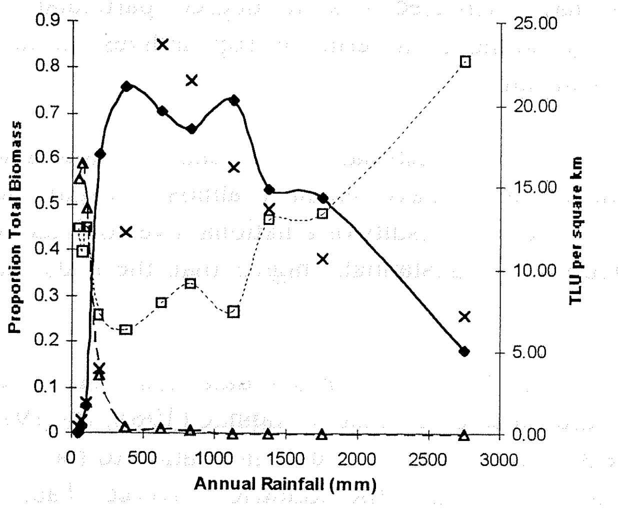
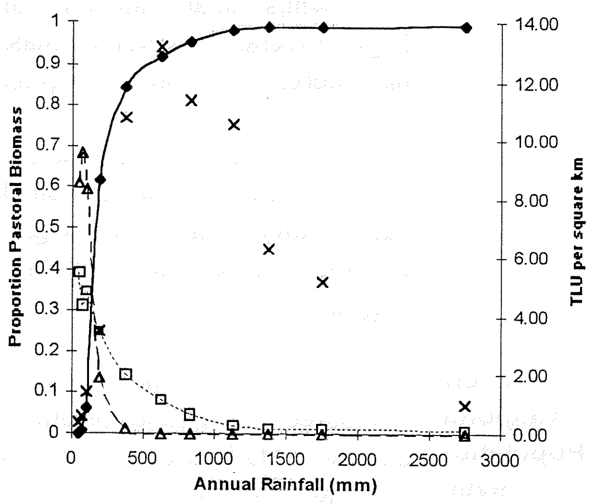


Figure C: Pastoral Biomass Composition: Rainfall



—◆— Cattle ····□···· Small Ruminants — —△— — Camels X Biomass Density

These findings suggest that the significance of backyard stock in general, and small ruminants in particular has been substantially under-estimated by previous assessments of livestock in the Sub-Saharan region. Further, the comparatively minor seasonal variations in both stock composition and density suggest that the conventional view of substantial seasonal transhumance into the Arid Zone during the wet season, and into the wetter regions during the dry season is no longer applicable to the majority of livestock within the region.

Local Population Trends

ERGO's livestock database is essentially geographical in nature, and is not well suited to the identification of temporal population trends. Nevertheless, some sites have been surveyed repeatedly over a number of years using the same methodology, and a few relevant historical records exist for others. Comparison of the information available for five arid and semi-arid sites across the Sahel, indicates a general increase in the number of small ruminants during the eighties, with cattle populations remaining stable in some areas and declining dramatically in others.

Whilst far from being conclusive evidence, this observation does at least confirm the subjective impression of many observers, that cattle have been more severely effected by droughts in the Sahel than small ruminants. The latter are generally more tolerant of arid conditions, and are not so dependant on water as cattle. Small ruminants also breed more rapidly than cattle and, because their numbers build up more quickly following a drought, are likely to be favoured by pastoralists recovering from previous stock losses.

National Population Trends

Time series data for livestock populations in Mali, Nigeria, Niger, Tchad and Sudan were compiled from statistics in the literature. Sudan stands out as having by far the largest cattle, sheep and goat populations, all of which appear to have increased progressively in size and with remarkable uniformity over the past twenty-five years. Sudan also has the largest camel population, but its size is reported to have remained relatively stable since the late seventies.

Livestock population estimates for Mali, Niger and Tchad show a general consistency over the past twenty-five years. Not only are most them of a similar size, but they also exhibit similar periodic fluctuations, corresponding to the droughts of the early seventies and early eighties. Cattle and camel populations have not grown in the long-term, whilst small ruminant numbers have increased to some degree, particularly in Niger. Overall livestock biomass in these countries, in terms of tropical livestock units has, therefore, remained surprisingly constant.

Nigeria's livestock levels, according to the FAO estimates, have changed little since the mid sixties. Camel and small ruminant levels have remained almost constant, and cattle numbers have risen slightly. However, the results of a national livestock survey in 1990 indicate that livestock numbers were substantially higher than the FAO data suggests.

Current Regional Population Levels

The regional population estimates derived from the ERGO data base have been compared to a number of other estimates, including those by Jahnke (1982) for 1979, and the FAO figures for 1990. Table A shows the present data in relation to the 1979 estimates for the various ecozones surveyed within the countries covered. Table B compares national populations from ERGO, Jahnke, and FAO.

Table A: Biomass Densities by Ecozone (Country Zones Surveyed)

	Total			Pastoral			
Ecozone	Annual Mean	Dry Season	Wet Season	Annual Mean	Dry Season	Wet Season	**Jahnke (1979)**
Arid (73)	4.4	4.2	4.6	3.9	3.7	4.1	3.5
Semi-Arid (12)	22.6	21.7	23.5	12.2	11.2	13.3	14.4
Sub-Humid (10)	14.8	14.0	15.6	8.1	7.3	8.9	6.3
Humid (5)	9.0	8.9	9.2	3.2	3.2	3.2	9.1
Total	7.9	7.6	8.3	5.3	5.0	5.7	5.59

Figures are Tropical Livestock Units (TLU) per km^2. 1 TLU = 1 Camel, 1.43 Cattle or 10 Small Ruminants.
Figures in Brackets are Percentage of Total

The comparison of biomass in the four agro-climatic zones suggest two significant conclusions. Firstly, unless livestock numbers have increased by a third between 1979 and the late eighties, then the 1979 estimates in all but the Humid Zone are too low. The ERGO estimates are most probably higher than others because they include 'Village' livestock, most especially small ruminants, and because purely ground based counts are likely to under-estimate the numbers of animals in remote areas which are assessed effectively by aerial survey. Also, ground based counts are often reliant on indicators, such as records of vaccination campaigns, which may not target entire populations and may not include all the major livestock species.

The comparison also suggests that substantially higher livestock densities occur in the Semi-Arid and Sub-Humid Zones than has previously been appreciated. This may be partly because the earlier estimates do not incorporate of 'Village' livestock into the overall population estimates. It may also be that there has been a shift in the epicentre of livestock distribution away from the Arid Zone, consequent upon the impacts of drought and land degradation, and towards the Sub-Humid Zone, where expanding human populations have opened up areas hitherto unsuited to livestock keeping.

Current National Population Levels

The national comparisons, once again, suggest that earlier estimates have underestimated livestock levels within the regions covered (Table B). It is noticeable that the greatest degree of underestimation is in those countries where the 1990 FAO figures appear to have incorporated little or no annual increment in population levels since 1979.

Table B: Comparison of National TLU Estimates

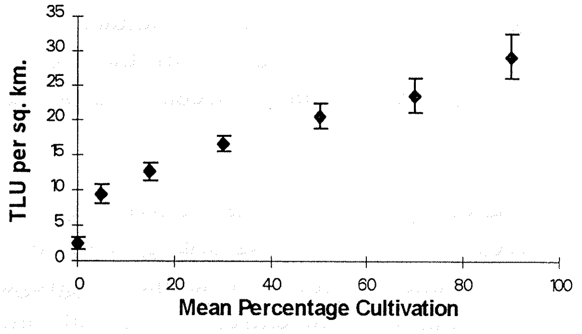
Country	Jahnke (1979)	FAO (1990)	ERGO	% Difference
Mali	4,512	4,911	5,810	18
Niger	3,407	4,062	4,347	7
Nigeria	11,718	11,518	14,399	25
Tchad	3,715	3,931	4,789	22
Sudan	17,550	21,000	23,188	10
Total	40,608	45,422	52,533	16

Figures are in Thousands

Environmental Correlates

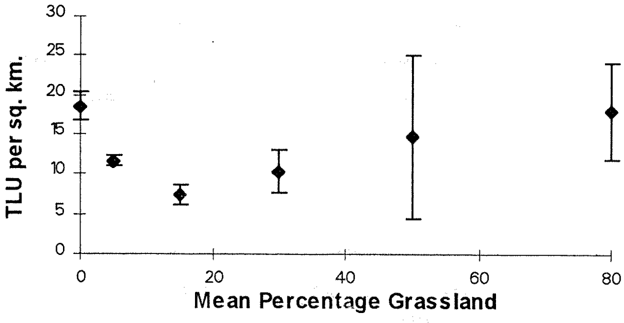
Bivariate regression analyses shows that biomass densities, are closely linked to cultivation levels, but are less strongly associated with measures of natural grazing availability (examples are shown in Figures D and E).

Figure D: Biomass Density: % Cultivation



Log10 (Y)=0.3014 + 0.5561 Log10(X).R^2=0.535; N=3663; $p < 0.0001$

Figure E: Biomass Density: % Grassland



Log10 (Y)=0.9739 - 0.2745 Log10(x).R^2=0.057; N=3273; $p < 0.0000$

Predictors of Regional Livestock Distribution

Exhaustive multivariate analyses confirm the relative strength of these relationships. Whether for annual or seasonal figures, biomass levels are much more closely associated with the consequences of human activity - either percentage cultivation or habitation density - than they are with the extent or distribution of natural grazing. This pattern also holds true for the subset of livestock that are more pastorally managed - those that have traditionally been thought to concentrate in areas where natural grazing is widespread.

The statistical validity of the relationships identified is startling given the breadth of ecological conditions covered by the surveys. Further, the similarity between the trends established for all livestock and the pastorally managed element suggest that there is little reason to view the latter as a special case, affected by factors specific to the pastoralist management system.

Cattle and small ruminant density are linked to the environmental parameters in much the same way as are biomass levels. All but two categories are most closely associated with indicators of human presence. These are the annual and wet season densities of 'Pastoral' small ruminants, which are best predicted by rainfall, though in the dry season these animals also aggregate most strongly where there is cultivation.

This general pattern does not, however, hold for camels. For this species, the primary predictors of density are either rainfall, percentage grassland or percentage grass cover. They are concentrated, as might be expected, in areas with low rainfall and relatively extensive natural grazing, and are not generally found in areas where there are resident human populations.

A question that arises from these results is whether the strong association between human activity and livestock density is locally valid. A possible scenario is that human activity is the dominant predictor in the wetter, more populated areas, but the availability of natural grazing - either grass cover or grassland - is more significant in the arid rangelands.

Predictors of Local Livestock Distribution

The correlations between livestock and environmental parameters within restricted rainfall bands show that in the most arid zones, either cultivation or habitation are consistently the primary predictors of the densities of all the livestock species, except of biomass and camels in the 125 to 250 mm rainfall band, where natural grazing is the most significant environmental correlate. The significance levels are, however, generally low when compared to the majority cited here, and so, though the relationships exist, they are relatively weak.

This implies that other factors, not included within the data, are likely to be the major determinants of animal distribution in these areas. An obvious candidate is the availability of permanent water, which would be closely associated with the presence of cultivation and human habitations, and also provide a link between livestock and human activity.

In the wetter regions with up to 1500 mm rainfall per year, human activity, again, is consistently the best predictor of total livestock numbers. Natural grazing is, in general, weakly or negatively associated with animal densities - if animals aggregate where cultivation is widespread, they are, by definition concentrated where all other forms of vegetation are scarce. The regression equations presented in the previous section suggest that if the effect of cultivation (or habitation) on animal densities is removed, then the remnant association with natural grazing is positive - suggesting that within any single intensity of cultivation, animals do tend to be found where there is more grass cover.

It is only in areas with more than 1500mm rainfall per year (corresponding to the Humid Zone) that indicators of the extent of natural grazing become generally better predictors of livestock density than either cultivation or human habitation levels, though for small ruminant density, habitation remains the dominant correlate.

Similar patterns are evident for the seasonal associations. The exceptions are, in the dry season, camels, between 75 and 500 mm rainfall, and cattle in the wetter zones with above 1250 mm rainfall per year, for which natural grazing is the dominant correlate. In the wet season, the extent of natural grazing is the most significant correlate for camel, small ruminant and biomass density in the two driest rainfall bands, and for cattle and biomass in areas with more than 1500 mm annual rainfall.

These results imply that livestock are more closely associated with natural grazing than human activity only during the wet season and at the two extremes of the rainfall spectrum. This is a pattern that fits more closely to the traditional view of livestock distribution than implied by the analyses of mean annual distributions. During the wet season, there is likely to be more grass available in the most arid areas, allowing the animals to be grazed in the open rangelands. During the dry season, the natural grazing is less extensive, and thus animals are restricted to the better watered regions, where cultivation and habitation are also concentrated.

What is perhaps less expected is the narrow range of annual rainfall levels within which these conventional interrelationships operate - in general, once there is more than 75mm precipitation per year, the influence of human activity becomes paramount, until rainfall increases beyond 1500mm. Given that densities of animals in these 'extreme' areas are comparatively low, then the proportion of the regional livestock biomass that is primarily influenced by the distribution of natural grazing is only in the region of 5 - 6%.

This conflicts with many traditional views, which hold that most livestock are managed by pastoralists who follow the best of the natural grazing in order to minimise the risk to their animals. Rather, it suggests that cultivation, or the vegetation associated with it, has become the most predictable source of livestock fodder, obviating the need to travel long distances in search of less certain natural resources.

Livestock, Human Activity and Land Degradation

If livestock and human activity are so closely associated, then it is reasonable to suppose that the increasing concentration of agricultural exploitation will have deleterious effects upon the land. Using Nigeria as a case study, a strong quantitative link was found between levels of erosion and the human activities likely to degrade environments (cultivation and livestock production), particularly in those dry areas with relatively little vegetation cover.

Development Implications

These findings have several implications for future development policy. If, as is almost inevitable, human activity continues to expand in the future, then the trend away from dependence of livestock upon extensive rangelands is likely to continue. It therefore seems essential that future development planning address the interface between livestock and cropping as a higher priority than has been the case to date.

It can be also be confidently predicted that the degree of land degradation associated with cultivation will increase in the future, and if the changes in livestock distributions continue, this process will become even more severe. Future plans designed to ameliorate or combat degradation should therefore include some elements to assess the possibility synergistic interaction between livestock, cropping and over-exploitation. This is particularly important in the light of the apparent underestimation of current livestock resources (and consequently, their potential impact on the environment) by official sources.

The significance of 'backyard' stock also appear to be seriously under-estimated at present, given that 'Village' animals, most especially small ruminants, account for a substantial proportion of total livestock biomass. This element of the livestock population can only become more abundant as human population rise, and is rarely targeted by development planners at present.

Further Studies

A number of topics are suggested that are thought worthy of further investigation. These are divided into three broad categories: those arising directly from the development implications of these analyses, particularly socio-economic and productivity studies designed to clarify our understanding of the interaction between livestock and human settlement; those, more technical, studies with the objective of broadening the applicability of the present results; and the monitoring exercises that will be needed to maintain and update our knowledge of future trends.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the assistance and support of numerous individuals and organisations, who, over the past decade, have become temporally entangled in field survey operations and the collection of information, which is the primary ingredient of this report. Specific mention should be made of the International Livestock Centre for Africa, under whose auspices many of the techniques used were tested and developed; L'Opération de Développement de l'Elevage dans la Région de Mopti in Mali; le Projet d'Elevage Intégré in Niger; le Projet National d'Elevage in Tchad; the Nigerian Federal Department of Livestock and Pest Control Services; OXFAM and the Gezira Rehabilitation Project in Sudan.

Personal thanks are also due to those who have read and commented on various drafts of this report, including: David Rogers, Mike Packer, Simon Hay, Malcolm Coe and Clive Hambler of the Department of Zoology, Oxford University; Brian Williams of the London School of Hygiene and Tropical Medicine; Richard Baker of the UK Central Science Laboratory, Harpenden; John Rowley of OXFAM; Olivia Graham; and Camilla Toulmin and Iain Scoones of the International Institute for Environment and Development, London.

The views expressed in this report are those of the authors and should not be taken necessarily to represent the views of the Overseas Development Administration. Any errors that have escaped the critical net are attributable to the authors.

UNITS AND ACRONYMS

ERGO	Environmental Research Group Oxford
FAO	Food and Agriculture Organisation
ha	hectare
IBAR	Inter-African Bureau for Animal Resources
IBRD	International Bank for Reconstruction and Development
ILCA	International Livestock Centre for Africa
km	kilometre
OAU	Organisation of African Unity
ODA	Overseas Development Administration
RIM	Resource Inventory and Management
STRC	Scientific, Technical and Research Committee
TLU	Tropical Livestock Unit
WRI	World Resources Institute

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ANTHROPOGENIC AND ENVIRONMENTAL CORRELATES OF LIVESTOCK DISTRIBUTION SUB-SAHARAN AFRICA

1. BACKGROUND

For many years now, it has been apparent that the extensive savannah regions of Africa are in a state of transition resulting from increasingly competitive land use pressures and conflicting interests of farmers, pastoralists, foresters and conservationists. The sustainable development of such areas and the achievement of an appropriate balance between crops, livestock, trees and wildlife is the subject of continuing debate and will remain a major challenge for years to come.

There is growing awareness of the progressive degradation of arid rangelands from drought and over exploitation. Until recently, the focus of attention has been on the advance of the desert and desertification of degraded areas. Toulmin (1993) has noted that the terms of the land degradation debate have changed over the past few years from "combating desertification" to "improving natural resource management in dry land regions." In her view this is more than just a change in terminology, and has helped shift attention to the institutions responsible at local and national levels for managing how natural resources are actually used.

At the same time it must also be recognised that sound management depends on reliable information, and that the current status of natural resources in many sub-Saharan countries is most uncertain. With the growth of human populations there has been an expansion of agriculture and a transformation of vegetation and land use, which has not been adequately monitored and is poorly documented. Essentially, not enough is known about the present state of affairs to be confident that any strategies designed to improve matters will have any chance of success.

Because livestock are an important element of rural economies in the Sub-Saharan region, a reliable and objective assessment of livestock abundance and composition across a wide range of environmental conditions represents a useful contribution to our knowledge of natural resources. This report follows on from a preliminary analysis prepared for OXFAM in which the environmental correlates of livestock biomass were investigated, and presents the findings of a more detailed analysis of data from systematic low level aerial surveys and complementary ground studies of livestock and land use in Mali, Niger, Nigeria, Sudan and Tchad, covering an total area of more than 1.5 million square kilometres.

It has been prepared at the request of ODA so as to:

- assess the environmental correlates of African livestock distribution and abundance across the major agro-climatic zones, from arid rangelands to humid forests;
- assess the relative importance of rainfall in determining livestock distributions;
- assess the degree to which environmental determinants of livestock distribution change with rainfall levels, particularly below 600mm;
- investigate trends in livestock populations by comparing the present data with earlier estimates;
- consider what lessons can be drawn from these findings, and what policy implications might follow from them;
- identify further studies and additional information requirements related to specific issues arising from the data analyses.

2. AN OVERVIEW OF WHAT DETERMINES LIVESTOCK NUMBERS.

In a regional study of wildlife and pastoral systems in Eastern and Southern Africa, Coe et al. (1976) established strong positive correlations between large herbivore biomass, mean annual rainfall and above ground primary production, and proposed that mean annual rainfall might be used to provide first order predictions of carrying capacity in savannah regions. The underlying thrust of their argument was that wildlife systems, having evolved over millions of years, provided as good an indication as any of the levels of animal populations that might be sustainably supported in the medium to long term.

They noted that large herbivore biomass in six pastoral areas of Kenya surveyed by Watson (1972) exceeded that of wildlife systems with equivalent rainfall. Many domestic animals died in those areas during the 1973/74 drought, and this was interpreted as an indication that previous stocking levels were above long-term carrying capacity.

Whilst acknowledging that other factors, such as soil fertility and ground water availability, also influence primary production and hence carrying capacity at the local level, Coe et al. (1976) argued that rainfall was the primary determinant of large herbivore biomass across a broad range of savannah regions receiving 160-700 mm of rain per annum.

Extending this approach to tsetse free zones of Ethiopia, Bourn (1978) showed that cattle biomass increases with human population density, rainfall; and altitude. Tsetse infested areas generally supported much lower cattle densities than those which were tsetse free. At the macro level this pattern was repeated across the continent, with national cattle biomass levels in tsetse free countries increasing with mean annual rainfall; substantially lower biomass in tsetse infested countries; and countries with significant numbers of trypanotolerant cattle populations having intermediate biomass values.

Building on these findings and incorporating additional sources of information, Bell (1982 and 1985) drew attention to the important modifying influence of soil nutrient status on the general relationship between plant and large herbivore biomass and water availability.

In a regional assessment of South American rangelands in Argentina and Uruguay, Oesterheld et al., (1992) found that domestic ungulate biomass for a given level of above-ground primary production (= rainfall) was greater than that for wild herbivores in natural ecosystems world-wide, and concluded that "elementary" (i.e. extensive) animal husbandry practices raise the carrying capacity of rangelands for large herbivores.

The general validity of this conclusion, however, has been disputed by Fritz and Duncan (1993), who were unable to find any significant difference between comparable pastoral and natural sites in savannah regions of Africa. Instead, their analysis demonstrated that, for any given rainfall level, a key determinant of large herbivore biomass in both pastoral and wildlife systems was the soil type and nutrient status, presumably reflecting the quality of available grazing.

In recent years, thinking has evolved in a number of other relevant areas, specifically those relating to the following questions:

a). Is it possible to calculate or define a maximum livestock density or 'carrying capacity' that an area can permanently support?

b). Is the idea of a fixed/constant carrying capacity applicable to pastoral (or agropastoral) systems that are driven by risk aversion strategies?

The usefulness of the conventional carrying capacity concept has been called into question (Behnke et al., 1993). Whilst it may be theoretically possible to define a maximum sustainable stocking level for an area of land, as a preliminary indicator of potential overstocking, it may be largely irrelevant to the formulation and implementation of livestock policy. This is partly because prevailing systems of communal land tenure and opportunistic pastoral management in Africa make it impractical to regulate animal numbers effectively.

Others believe that the idea of a fixed and constant sustainable stocking level is fundamentally flawed when applied to pastoral systems, because there is too much annual variation in productivity of any one area, and because livestock are not generally kept in one place for the whole year round. They argue that conventional theories and recommended management practices derived from the carrying capacity concept are increasingly inappropriate for much of Africa. In particular, they emphasise the need to establish new models of natural variability and pastoral adaptation and the importance of developing more appropriate techniques for assessing rangeland potential.

3. WHY ARE AFRICAN LIVESTOCK STATISTICS SO UNCERTAIN?

National livestock population figures are derived from various sources of information, including vaccination and dip tank records, agricultural field surveys, tax returns, slaughter, marketing and trade data. Where countries have undertaken comprehensive vaccination campaigns, against rinderpest for example, this obviously gives a good indication of population size, but rarely are all animals vaccinated and an assumption must therefore be made about the proportion which were not treated. Conversely, there is always the possibility that some animals will receive more than one treatment. Major disease control campaigns are targeted at individual species, usually cattle or small ruminants. Other species of livestock are usually excluded and estimates of their population size are most uncertain.

No standard method of assessment is used and details thus vary from country to country. The reliability of livestock population figures obviously depends on the quality of the data collected and the validity of underlying assumptions. FAO publishes an annual compilation of national livestock statistics derived from information provided by member states, but these figures are often based on assumed rates of increase applied to outdated baseline data and rarely upon objective field surveys. As a results, they are not necessarily reliable.

4. THE ERGO DATABASE

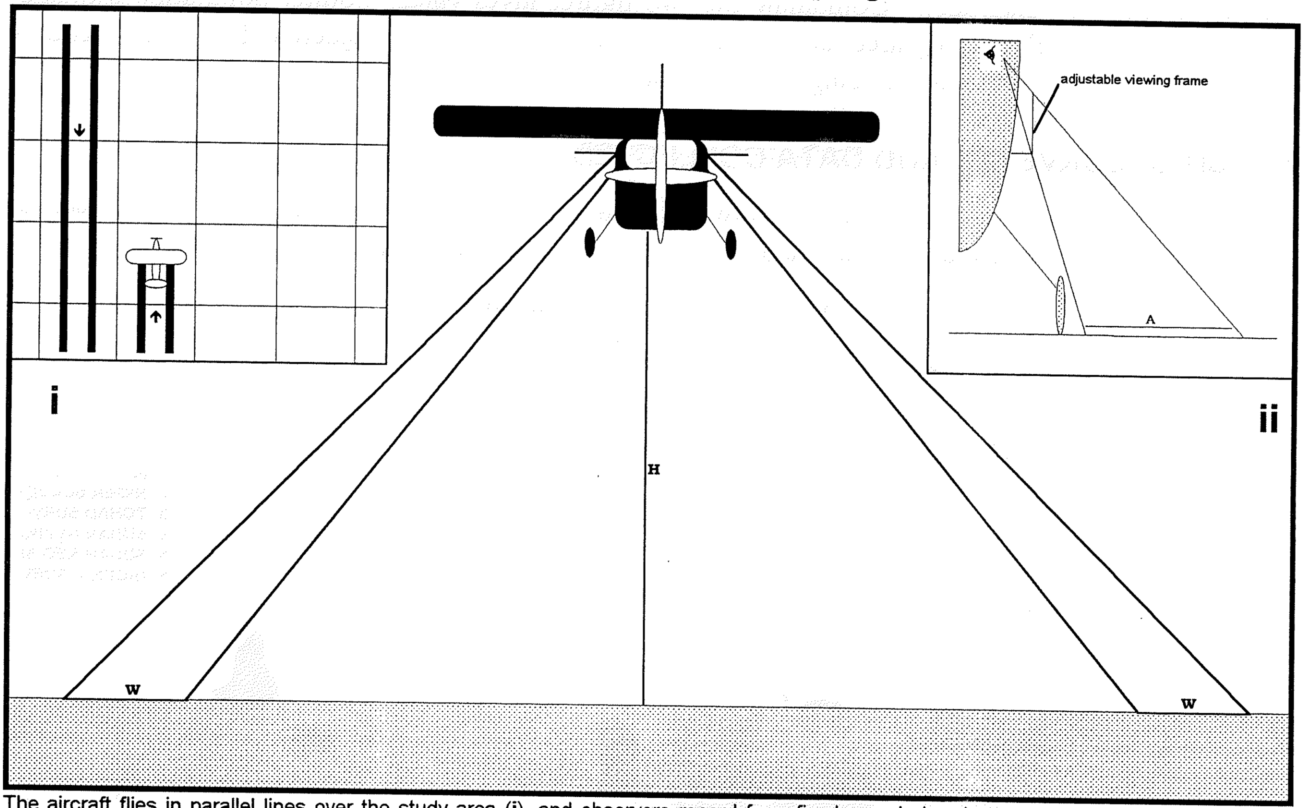
Since 1980, ERGO staff have conducted more than fifty livestock and land use surveys on behalf of the International Livestock Centre for Africa (ILCA), Resource Inventory and Management (RIM), and a variety of development agencies and national bodies. These are listed in the References preceding the Appendix. The surveys cover a total area of more than 1.5 million square kilometres, but as many were flown in both wet and dry seasons, and several have been covered in several different years, the actual area surveyed amounts to more than 3 million square kilometres - equivalent to the whole of Europe.

A unique feature of the ERGO database of livestock resources is that it is derived from standardised methods of information collection over a wide variety of environments across Africa, from the arid rangelands of the Sahel to humid forest zone. The database consolidates the records of a series of systematic low level aerial surveys and complementary ground studies conducted in Mali, Niger, Nigeria, Sudan and Tchad (Figure 2). It contains some 13,000 geographically co-ordinated sample points with records of livestock, human settlement, vegetation and land use associated with each sample point. Other encoded attributes include mean annual rainfall, and agro-climatic zone.

5. DATA COLLECTION, COVERAGE AND CONTENTS

The parameters included in the analysis come from three primary sources: **standard cartography,** for mean annual rainfall, plant growing period, soils and tsetse, which are used for stratification purposes; **systematic low level aerial surveys,** for the direct observation of pastoral livestock, human settlement (roof tops), vegetation and land use; and **complementary ground surveys,** for enumerating village livestock composition and local production systems. Thus, except for the stratification parameters, the analyses are based on standardised field data collection from the air and ground.

Figure 1: Aerial Survey Sampling



The aircraft flies in parallel lines over the study area (**i**), and observers record from fixed sample bands to each side. The flight lines are divided into equal sectors, to create a grid cell lattice, by which each record is located. Only those herds and settlements which pass through the observation strips are counted and photographed. The strip width (**W**) is directly proportional to the flying height above ground (**H**) and is defined by externally mounted viewing frames (**ii**) which are adjusted to delineate a band on the ground (A) which corresponds to the desired sample band width W at the nominal flying height. Typically, **W** is 500m at 800 ft above ground level (agl) or 625m at 1,000ft agl.

5.1. Low Level Aerial Surveys

Aerial surveys are normally flown between 400 and 2,000 feet above the ground, and are designed to collect numerical information about target populations and distributions over large, often remote areas, in a short period. The air crew consists of a co-ordinator/navigator, pilot, and two observers or photographers. The survey technique is usually based on a systematic flight pattern which provides uniform coverage of an entire region and enables a geographically co-ordinated gridded database to be established. Sample counts are taken from each grid cell. Key features of this technique are its repeatability, and that it does not rely on any previous knowledge of the area concerned. Repeat surveys at critical times of the year allow seasonal changes in distribution and abundance to be determined.

Whilst the basic methodology of the livestock surveys has changed little since the early eighties, in that they are based on aerial counts of visible animals, considerable evolution has taken place in the integration of aerial survey and ground survey techniques. From 1986 onwards, all surveys have included a ground element designed, at least partly to complement the information collected from the air and enable the estimation of populations of animals that cannot be directly enumerated from the air, such as stock kept under shelter, or in settlements, or those species which cannot be counted from a distance of 800 ft.

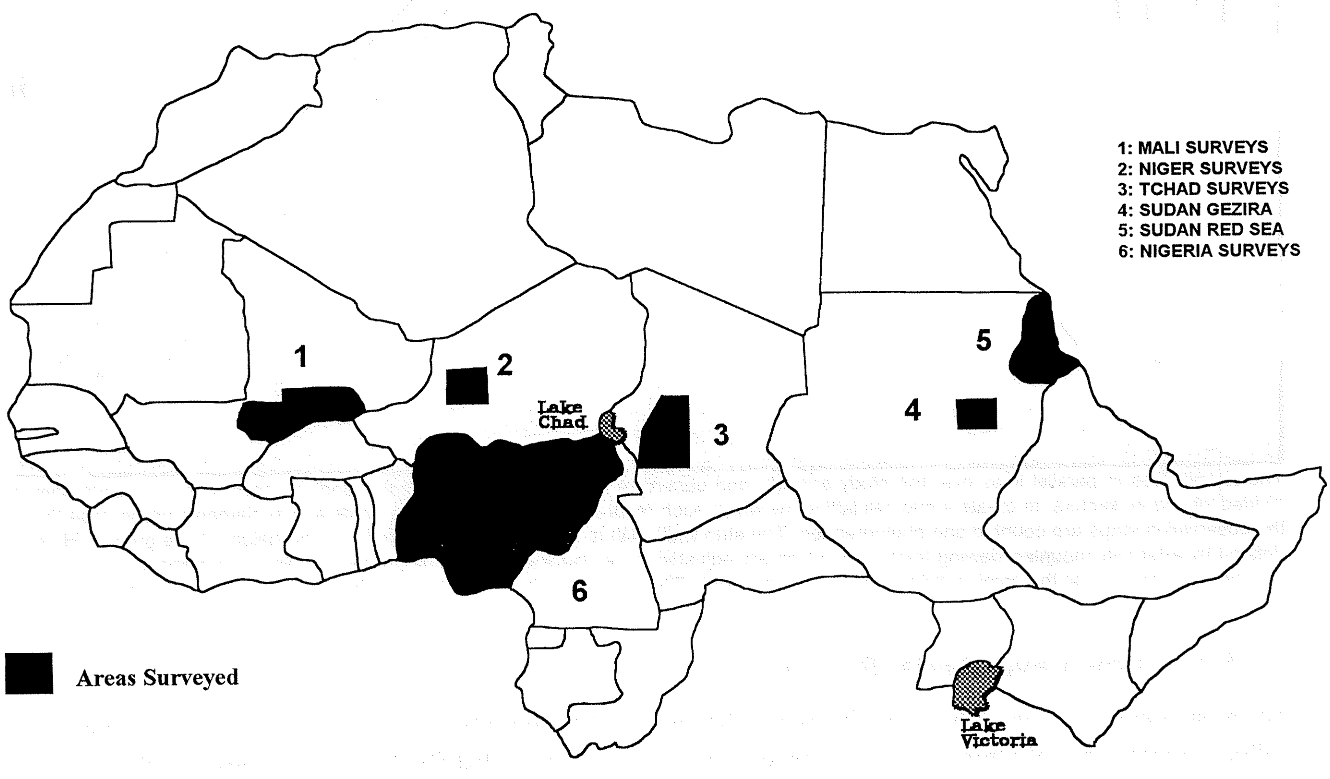
5.2. Ground Surveys

The ground surveys are designed to collect information which cannot be obtained from aerial reconnaissance, and to provide data which can be combined with aerial counts to give estimates of parameters which would otherwise be impractical. An example is the number of poultry kept in rural villages: air counts give the number of habitations in a sample grid; ground counts provide the number of birds per habitation. Combining the two figures gives village poultry population estimates and distributions. This integrated air/ground approach provides an objective basis for resource assessment and a better understanding of local production systems.

6. SITES SURVEYED AND DATA COLLECTED

The locations of the areas surveyed are shown in Figure 2. The parameters estimated in each survey and details of date, extent and funding agency are summarised in Appendix Table A1.

Figure 2: Survey Locations



6.1. Livestock

All surveys have estimated the numbers of cattle, camels and small ruminants visible from the air. Since 1986, animals have also been enumerated by complementary ground survey which provide the information needed to enumerate species that cannot be counted from the air. These surveys can also be used to differentiate between the large ruminants associated with human settlement, and those more pastorally managed animals that are found away from villages. This distinction is made by ensuring that the aerial survey observers either record animals seen within village boundaries separately from those elsewhere, or by excluding such livestock from the aerial counts altogether. If the latter course is adopted, then the estimates of total livestock numbers are calculated by adding the numbers derived from aerial counts to those derived from the ground survey and aerial habitation records. If it is assumed that the aerial counts represent pastorally managed animals, then the two sets of figures can be used to give an indication of the populations of animals managed by transhumant/nomadic pastoralists (the 'Pastoral' element) and those managed by mixed farmers, or settled agropastoralists ('Village' animals).

6.2. Habitation

All surveys have differentiated rural habitation into village and pastoral dwellings. In many cases distinctive sub-types have also been distinguished; for example, Fulani rugas and Twareg tents in West Africa, Beja tents in Sudan and Tiv huts in Nigeria. However, given the obvious linkage between pastoral livestock and pastoralists, and the limited distribution of individual pastoral groups, they have not been considered in the analysis. Thus, only established village settlements are included under the heading habitation, which is taken to be generally representative of both arable and mixed farmers, as well as agropastoralists. Major urban centres covering more than ten square kilometres and large towns with more that 5,000 roof-tops, have also been excluded from the analysis.

6.3. Vegetation and Land Use

Vegetation and land use assessments have varied to some extent from survey to survey, depending on the nature of the environment. Early surveys, which were generally of more arid pastoral zones, focused on the assessment of cultivation and measures of the availability and quality of grazing. Later surveys recorded a much greater variety of categories, which have been amalgamated into seven basic types: land within the cultivation cycle (active cropping plus fallow), bare ground, grassland, scrub, open woodland, dense woodland, and forest. In a number of surveys grass cover was also assessed. This differs from grassland in that the scrub and woodland categories, as well as grassland, support grass. Where grass cover was not measured specifically, an index has been calculated and tested in areas where grass cover was specifically assessed in order to confirm its relevance and accuracy.

7. ARE THE DATA RELIABLE ?

Vegetation parameters were usually estimated visually, rather than photographically, and available evidence suggests that they are surprisingly accurate. This can be illustrated by comparing photographic and visual estimates, or repeated measures of vegetation categories that are constant from season to season. For example, photographic and visual assessments of cultivation in northern Nigeria during 1990 produced estimates of 32.05 and 32.5% respectively. In the Bahr el Ghazal Region of Tchad, woody vegetation was assessed visually in 1991 at 14.3% and in 1993 at 13.6%. In Gongola State, Nigeria, percentage grassland was estimated in 1983 and 1984 at 14% and 17% respectively, and in Niger State, Nigeria, cultivation was estimated in 1989 and 1990 as 20 and 21% respectively. These comparisons provide reasonable grounds for assuming that these vegetation and land use parameters are sufficiently precise to be meaningful.

Livestock and habitation estimates are also made visually, but corrected for observer error by comparing visual estimates with counts from photographs, calculating a 'bias' and applying the correction factor to all observer counts over ten. Calculated observer biases are usually less than 5%, and commonly between 1% and 2%. This is reflected in repeated estimates of permanent habitation levels which should change little from year to year. For example, in the Bahr el Ghazal region of Tchad, the 1991 and 1993 estimates for permanent numbers were 79,700 and 82,800 respectively; and for Niger State, Nigeria permanent habitation estimates for 1989 and 1990 are 17.5 and 17.8 per square kilometre respectively.

8. DATA PROCESSING AND ANALYSIS

As can be seen from the table of surveys in the Appendix, most survey areas have been covered during both dry and wet seasons. Further, some have been surveyed during a particular season in more than one year. When examining information from several sites and times, two distinct analytical approaches are possible: looking at each individual survey dataset, establishing conclusions for each one, and then building a more general picture; or trying first to establish a general picture, and then investigating the degree to which the results from specific areas confirm the overall patterns.

It is the latter approach which has been adopted here, based on the assumption that any relationships strong enough to be statistically significant across the wide range of land types and ecological conditions that have been surveyed are of fundamental importance to livestock distribution. Accordingly, data from duplicate surveys have been averaged to give a single figure for each variable for each grid. This intentionally factors out any variation between years, though allows for comparison of seasonal figures.

In similar vein, it was decided that this analysis should look at livestock as a whole, as well as treating individual species separately. There are several advantages of the conversion of the various species into units of biomass. Firstly, all species can be examined in comparable terms. Secondly the results from areas with markedly different species compositions can be compared directly. Thirdly these results can be compared with figures for carrying capacities derived from different ecosystems - particularly those where wild animals form a substantial element of the grazing herbivore biomass. Livestock figures have therefore been converted into standard Tropical Livestock Units (Jahnke, 1982), where one TLU is equivalent to one camel; 1.43 cattle, two equines, or ten small ruminants.

It should be emphasised at this juncture that both wildlife and equines have been excluded from these analyses. Wild animals were counted in all the surveys carried out, but, without exception, were so infrequently recorded as to be insignificant. Horse and donkey numbers were recorded only in the later surveys, and thus their exclusion allows data from the earlier surveys to be incorporated in the analyses. It is unlikely that the exclusion of these two species has made a significant difference to the livestock biomass figures produced - even where equines are common they comprise only a small fraction of total livestock numbers and biomass.

9. LIVESTOCK POPULATIONS WITHIN AREAS SURVEYED

9.1. Biomass

Table 1 presents the calculated annual mean livestock biomass densities for different rainfall levels, together with the equivalent figures for wet and dry seasons. These data are based on all survey areas for which biomass figures are available that incorporate cattle, camels and small ruminants for both wet and dry seasons. They therefore exclude data from those surveys that were conducted in one season only. Details of their derivation are discussed in the Appendix.

Two biomass figures are considered: ‘Total’ and ‘Pastoral’. The latter exclude those animals closely associated with human habitation or settlements (‘Village animals’, see section 6). By implication, as discussed above, this part of the livestock populations is more likely to be managed by pastoralists, although not necessarily owned by them.

The pattern common to all the biomass figures is the low levels recorded in the regions with an annual rainfall of less than 250 mm, where stocking rates are between 40 and 250 hectares per TLU. Above this rainfall level, a doubling of precipitation is associated with a three to eight-fold increase in livestock densities which reach stocking rates as high as 4.2 hectares per TLU. Areas receiving between 500 and 1000 mm rainfall per annum support similar livestock densities, at or near the maximum calculated levels, whereafter biomass levels decline steadily as annual rainfall increases.

Table 1: Biomass Density in Areas Surveyed: Annual Rainfall

	Biomass Density (TLU per square kilometre)					
	Total			**Pastoral ***		
Annual Rainfall (mm)	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.41	0.49	0.34	0.36 (88)	0.45 (92)	0.27 (79)
51 - 75	0.76	0.48	1.04	0.63 (83)	0.32 (67)	0.93 (89)
76 - 125	1.86	2.04	1.68	1.44 (77)	1.51 (74)	1.37 (82)
126 - 250	3.89	4.09	3.66	3.50 (90)	3.58 (87)	3.43 (94)
251 - 500	12.24	11.49	13.00	10.79 (88)	10.16 (88)	11.42 (88)
500 - 750	23.66	24.38	22.96	13.16 (56)	13.52 (55)	12.80 (56)
751 - 1000	21.50	19.08	23.93	11.36 (53)	8.95 (47)	13.78 (58)
1001 - 1250	16.25	14.23	18.26	10.56 (65)	8.64 (61)	12.48 (68)
1251 - 1500	13.71	13.76	13.67	6.28 (46)	6.34 (46)	6.22 (46)
1501 - 2000	10.63	10.50	10.76	5.21 (49)	5.33 (51)	5.09 (47)
2001 +	7.25	7.07	7.43	1.00 (14)	0.83 (12)	1.17 (16)

* Figures in brackets are % of Total Biomass

There appears to be relatively little seasonal variation in either 'Total' or 'Pastoral' livestock levels, which implies that a high proportion of animals are either resident in, or remain within, the same rainfall belt throughout the year. The differences that are apparent suggest a slight increase in the drier areas during the dry season, and a rather more substantial increase in the wetter (750 - 1250mm) areas during the dry season. This is compatible with a shift in animals towards the more arid areas during the rains, when natural grazing is likely to be most widely available, and a simultaneous shift away from the wetter parts, where crops are being grown, and the threat of diseases like trypanosomiasis is at its greatest. This evidence suggests that whatever movements there are, however, are comparatively minor.

Figure 3: Biomass Density in Surveyed Areas: Annual Rainfall

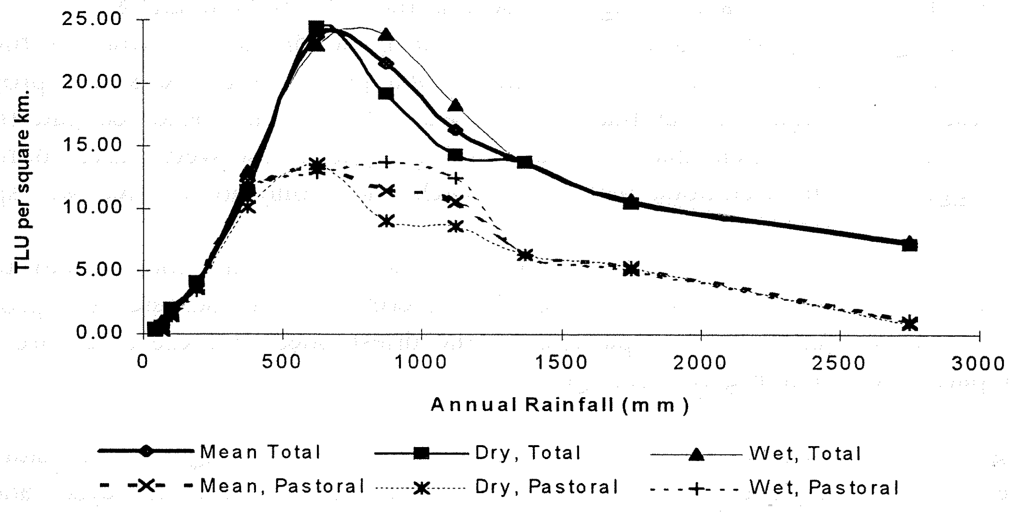
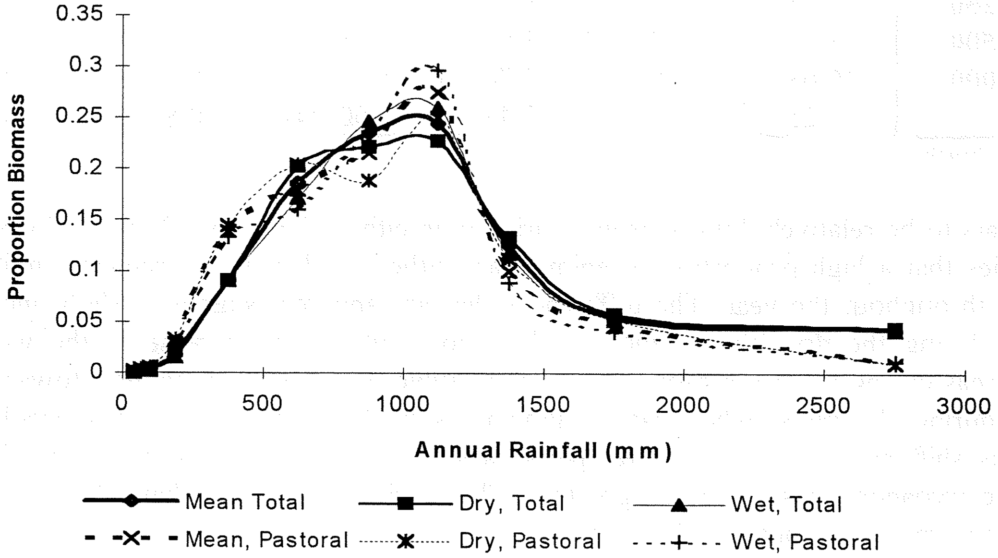


Figure 3 clearly demonstrates the relative densities of the 'Total' and 'Pastoral' elements, and emphasises the increasing importance of the livestock associated with human settlement in areas with more than 500mm rainfall per year. In the driest areas, the 'Pastoral' element accounts for 70 - 90% of the total (Table 1), a figure which falls to 50-60% in areas with between 500 and 2000 mm annual rainfall, and then drops to 10-15% in the wettest belt. One implication of these proportions is that other livestock surveys, that have failed to take account of the 'backyard' stock in their estimations of animal populations, are likely to have under-estimated biomass levels, in all but the driest regions, very substantially. Figure 3 also demonstrates the similarity in the locations of maximum animal densities for the 'Pastoral' and 'Total' livestock populations. Both peak in the 500 to 1000mm belt.

Figure 4 shows biomass data expressed as proportions of the total estimated biomass within the rainfall belts. The extent of these bands has been estimated from rainfall maps of the areas surveyed in Mali, Niger, Nigeria, Sudan and Tchad, and highlights the general trends discussed in the preceding paragraphs - most livestock are found in areas with between 250 and 1500 mm rainfall per year, whilst a relatively small proportion of the regions' livestock is found in either wetter or drier areas. There is, however, a noticeable difference between the locations of the patterns of 'Pastoral' and 'Total' livestock distribution in that more of the former are concentrated in the 250 - 750 mm rainfall belt and less in the wettest areas than there are of the latter. This reflects the distribution of human habitation with associated livestock, which is most abundant in the wetter of these two zones.

Figure 4: Biomass Distribution in Areas Surveyed: Annual Rainfall

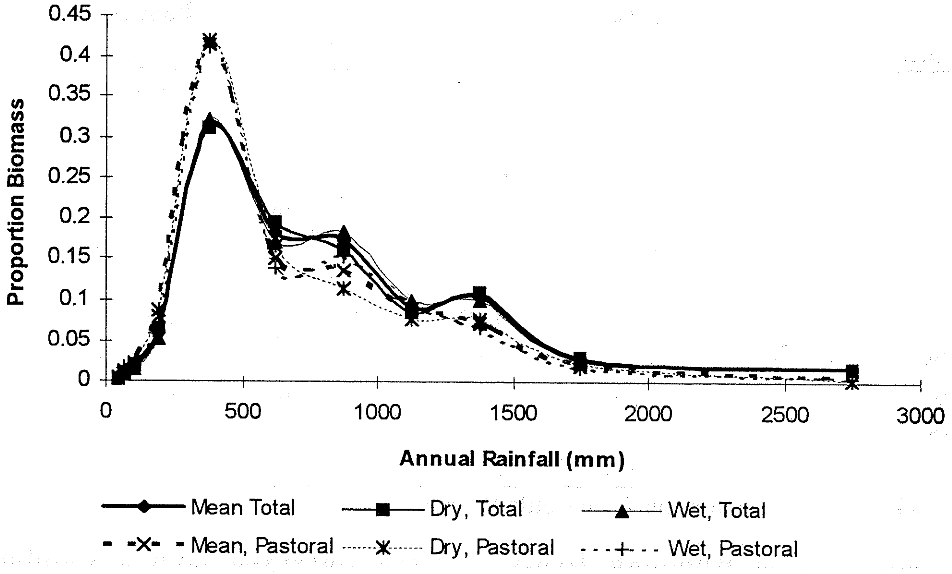


As with livestock densities, there is relatively little seasonal variation in the relative distribution of the 'regional herd'. The most noticeable changes are seen in the 375 - 625mm and 875 - 1125mm belts. In the former, a higher proportion of livestock are found in the dry season, whilst in the latter the reverse is the case. In areas with more than 1250 mm rainfall per year than wet season proportions of 'Pastoral' livestock are slightly lower than the dry season ones. This observed pattern mitigates against the conventional argument that livestock only aggregate in the wetter areas during the dry season, and suggests that the traditional patterns of transhumance only are now less widespread.

Figure 4 shows the data for the areas actually surveyed, and does not take into account the areas of the rainfall belts within the countries covered. This therefore underestimates the proportion of livestock in extensive rainfall bands - particularly the driest ones. If these areas are taken into account, the pattern shown in Figure 5 emerges.

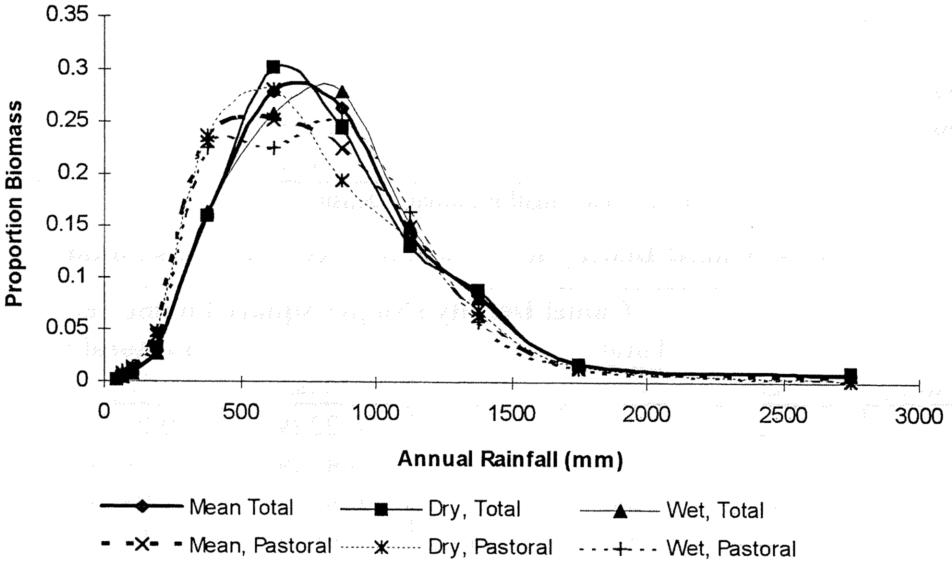
This highlights the importance of the arid areas to livestock. Though the densities may be comparatively low, the drylands are very extensive within the countries surveyed, and thus the populations of animals these regions support are substantial. The largest populations occur in the 250 - 500mm rainfall band, in contrast to the pattern shown in Figure 4. Also, Figure 5 shows a more noticeable difference in the relative distributions of the 'Pastoral' and 'Total' populations in that the former is more concentrated in the dryland areas. Seasonal variations are, however, slight.

Figure 5: Biomass Distribution: Rainfall
Corrected for Area of Rainfall Bands Sampled Within Countries Surveyed



It is emphasised, however, that whilst the Arid Zone was sampled within all the countries surveyed, the Semi-Arid, Sub-Humid and Humid Zones were not. Accordingly the pattern shown in Figure 5 is biased towards the Arid Zone (see also section 10.1 below). If this bias is removed, the pattern shown in Figure 6 is produced, which suggests a higher proportion of livestock in the Semi-Arid Zone (500 - 1000mm rainfall per year), with the 'Pastoralist' element concentrated in the drier regions.

Figure 6: Biomass Distribution: Rainfall
Corrected for Total Area of Rainfall Bands Within Countries Surveyed



9.2. Individual Livestock Species

Tables 2 to 4 show the mean annual and seasonal densities of cattle, small ruminants, and camels in the various rainfall bands within the areas surveyed. These have been calculated in the same way as the biomass figures, as detailed in the Appendix.

Table 2: Cattle Density in Areas Surveyed: Annual Rainfall

Annual Rainfall (mm)	Cattle Density (No per square kilometre)					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.00	0.00	0.00	0.00 (na)	0.00 (na)	0.00 (na)
51 - 75	0.02	0.03	0.002	0.01 (39)	0.01 (43)	0.00 (0)
76 - 125	0.16	0.15	0.17	0.13 (81)	0.10 (67)	0.15 (88)
126 - 250	3.51	4.04	3.09	3.07 (88)	3.31 (82)	2.83 (92)
251 - 500	13.63	13.04	14.23	12.97 (95)	12.47 (96)	13.46 (95)
500 - 750	22.23	22.83	21.64	17.22 (78)	17.66 (77)	16.78 (76)
751 - 1000	20.51	16.93	24.08	15.46 (75)	11.89 (70)	19.03 (79)
1001 - 1250	16.97	14.12	19.83	14.79 (87)	11.98 (85)	17.59 (89)
1251 - 1500	10.50	10.58	10.42	8.86 (84)	8.92 (84)	8.79 (84)
1501 - 2000	7.89	8.05	7.72	7.34 (93)	7.51 (93)	7.18 (93)
2001 +	1.91	1.66	2.16	1.41 (74)	1.17 (70)	1.66 (77)

* Figures in brackets are % of equivalent Total Cattle Density

Table 3: Small Ruminant Density in Areas Surveyed: Annual Rainfall

Annual Rainfall (mm)	Small Ruminant Density (No per square kilometre)					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	1.84	2.39	1.28	1.41 (77)	2.01 (84)	0.80 (63)
51 - 75	3.02	2.67	3.37	1.95 (65)	1.31 (39)	2.59 (77)
76 - 125	8.35	8.66	8.04	4.91 (59)	4.00 (46)	5.82 (72)
126 - 250	10.45	8.47	11.99	8.62 (82)	6.74 (80)	10.50 (88)
251 - 500	28.37	26.31	30.82	15.65 (55)	12.34 (47)	18.96 (62)
500 - 750	62.33	66.72	58.24	10.79 (17)	11.18 (17)	10.41 (18)
751 - 1000	70.16	70.93	69.38	5.33 (8)	6.16 (9)	4.49 (6)
1001 - 1250	43.55	43.34	43.76	2.09 (5)	2.49 (6)	1.69 (4)
1251 - 1500	64.30	64.20	64.40	0.78 (1)	0.94 (1)	0.61 (1)
1501 - 2000	51.42	49.01	53.83	0.67 (1)	0.70 (1)	0.64 (1)
2001 +	59.99	59.96	60.03	0.09 (0)	0.12 (0)	0.06 (0)

* Figures in brackets are % of equivalent Total Small Ruminant Density

Table 4: Camel Density in Areas Surveyed: Annual Rainfall

Annual Rainfall (mm)	Camel Density (No per square kilometre)					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.23	0.25	0.21	0.22 (96)	0.25 (99)	0.19 (90)
51 - 75	0.45	0.20	0.70	0.43 (96)	0.18 (90)	0.67 (96)
76 - 125	0.92	1.08	0.76	0.86 (93)	1.03 (95)	0.68 (89)
126 - 250	0.51	0.61	0.40	0.48 (95)	0.57 (93)	0.39 (98)
251 - 500	0.17	0.20	0.14	0.14 (83)	0.18 (88)	0.10 (69)
500 - 750	0.22	0.23	0.21	0.02 (10)	0.03 (15)	0.01 (6)
751 - 1000	0.13	0.13	0.13	0.01 (9)	0.01 (9)	0.01 (9)
1001 - 1250	0.01	0.01	0.01	0.00 (17)	0.00 (31)	0.00 (0)
1251 - 1500	0.00	0.00	0.00	0.00 (na)	0.00 (na)	0.00 (na)
1501 - 2000	0.00	0.00	0.00	0.00 (na)	0.00 (na)	0.00 (na)
2001 +	0.00	0.00	0.00	0.00 (na)	0.00 (na)	0.00 (na)

* Figures in brackets are % of equivalent Total Camel Density

Cattle are effectively absent from areas with less than 125 mm rainfall per year, but are found at low densities (less than 0.2 per square km.) in the 125-250 mm band. Thereafter, they increase rapidly to a peak of approximately 22 per square kilometre between 500 and 1000 mm per annum, and remain at moderate levels (15 to 20 per square kilometre) until rainfall exceeds 1500mm. The wettest areas see a rapid decline in cattle density, to a minimum of around 2 per square kilometre in the 2000+ mm belt.

The proportion of 'Village' cattle is consistently less than 30% in all but the driest regions where more than half of the population is associated with settlements, suggesting that the majority are subject to some form of transhumance. Given the comparatively minor seasonal variations in density, however, such movements are likely to be short distance, or at least limited to movements across one or two rainfall belts. What seasonal differences are evident are restricted to the 750 to 1250 mm rainfall bands, more or less equivalent to the southern part of ILCA's Semi-Arid Zone and the northern half of the Sub-Humid Zone, where wet season densities are substantially higher than those of the dry season. As discussed above, in the context of the biomass figures, this implies that the traditional movements into the wetter areas during the dry season are less widespread than previously thought, and that many cattle are resident in these wetter areas throughout the year.

Pastoral small ruminants are more abundant in the driest regions than are cattle, and peak in the 250 500 mm rainfall belt. In areas wetter than this, however, the 'Pastoral' sheep and goats become increasingly scarce, and are consistently less abundant than cattle.

Seasonal differences in small ruminant densities are slight, and unlike those of cattle, show an increase in parts of the Semi-Arid zone during the wet season, at the expense of the populations in the wetter bands. This is compatible with the traditionally held views of seasonal movements, and suggests that small stock transhumance patterns have changed less than that of cattle in recent years.

The most striking difference between cattle and small stock distribution patterns is the preponderance of 'Village' small stock, particularly in the regions receiving more than 500mm rainfall per year, where less than 1 in 5 of the animals recorded were 'Pastoral' (Table 3). Accordingly, when the total populations are compared, the small ruminant density is very substantially higher than that of cattle, reaching a maximum of 70 per square kilometre (a stocking rate of approximately 1.5 hectares per head) in the 750 to 1000 mm belt, and seasonal variations are less apparent than they are for the 'Pastoral' element of the population. Though they do decline as rainfall increases thereafter, the decrease in sheep and goat density is comparatively minor, and so even the wettest band supports substantial numbers of small stock, nearly all of which are associated with human habitation.

This pattern conflicts with the conventional view that livestock are comparatively sparse in the Humid belt, and also challenges the commonly held view that cattle are the most significant livestock species.

Camels are rare in the areas surveyed, reaching a peak of just over one per square kilometre during the dry season, in the 50 - 150 mm rainfall band. Their range extends further into the less arid belts during the dry season, when the conditions in the driest areas are at their most severe. In the arid areas, the great majority of the camels recorded were 'Pastoral', 'Village' camels forming the substantial majority of the total populations only in the Semi-Arid Zone.

This pattern is consistent with the fact that most of the surveys performed were on the southern fringes of camel distribution, and that substantial numbers of these animals only entered the region covered by the database during the dry season.

Figure 7: Total Biomass Composition: Rainfall

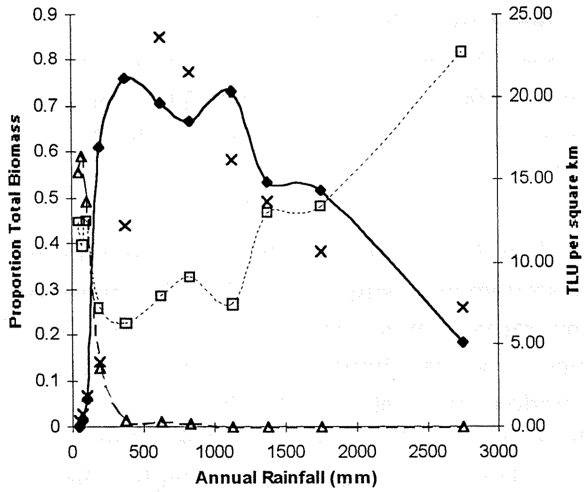


Figure 8: Pastoral Biomass Composition: Rainfall

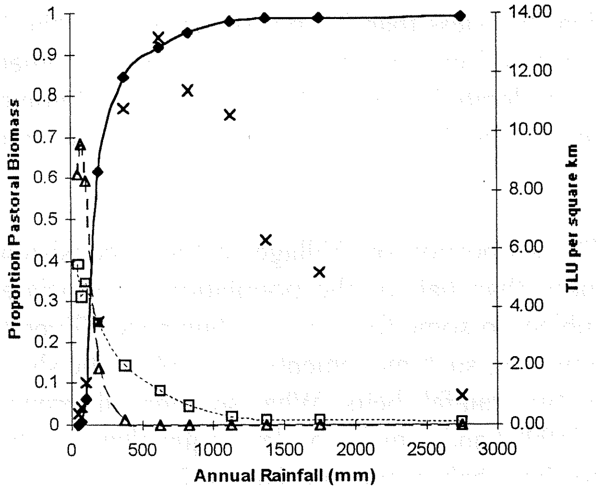


Figure 9: Total Biomass Composition: Rainfall Dry Season

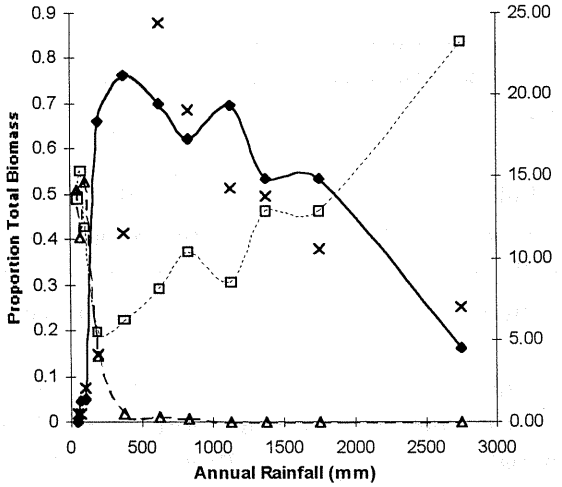


Figure 10: Pastoral Biomass Composition: Rainfall Dry Season

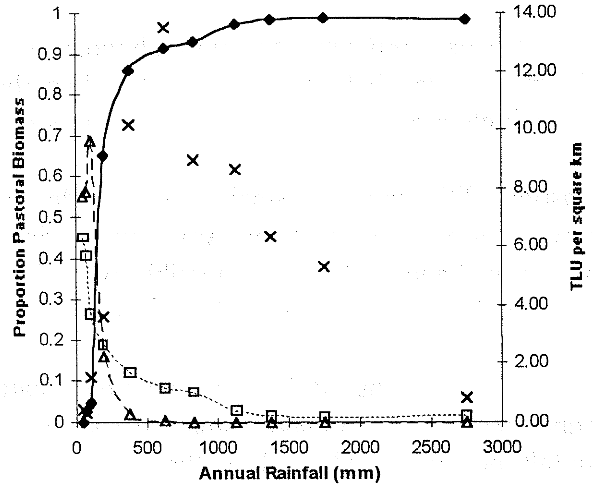


Figure 11: Total Biomass Composition: Rainfall Wet Season

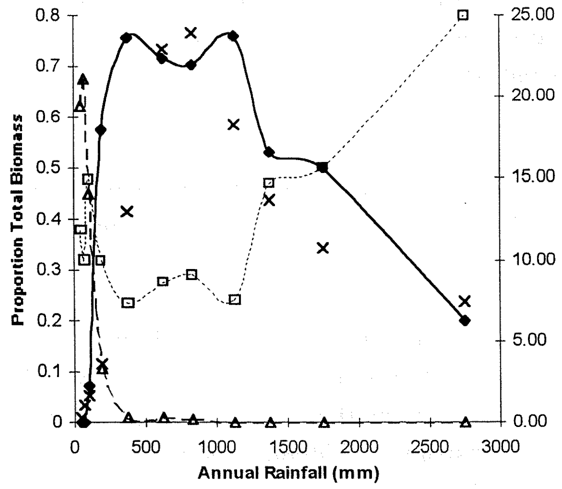
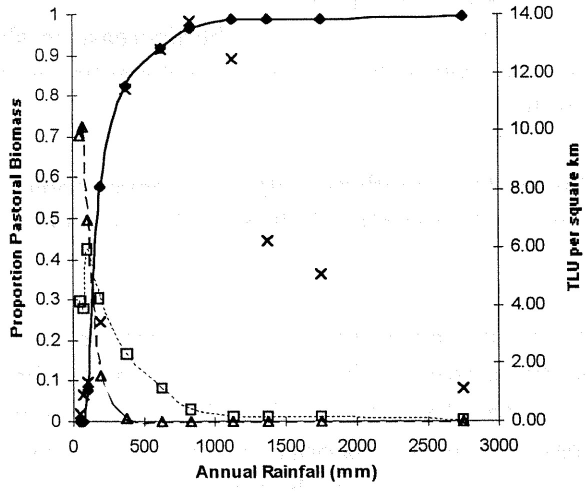


Figure 12: Pastoral Biomass Composition: Rainfall Wet Season



—◆— Cattle ····□···· Small Ruminants – –△– – Camels X Biomass Density

Figures 7 to 12 show the relative contributions of camels, cattle and small ruminants to livestock biomass levels in the various rainfall belts. On each graph, the biomass density is also shown as a reminder that high proportions do not necessarily equate to high densities.

One of the most noticeable contrasts shown is that between the 'Total' and 'Pastoral' biomass compositions. The latter give the strong impression that cattle are the major livestock species in all but the driest areas, where they are replaced by small ruminants and camels. This is the conventional view of livestock composition in Sub-Saharan Africa, and may account for the 'bovi-centric' basis of many development and veterinary projects.

As suggested in the discussion of the density figures, the incorporation of stock associated with settlements into the biomass figures results in a markedly different picture emerging. Whilst cattle remain the predominant species in areas with rainfall between 250 and 1250 mm per year, they only account for a half to two-thirds of the total livestock biomass. This is in contrast to the 80 - 95% levels that are implied by the 'Pastoral' composition data.

In the wetter areas, the small ruminants (mainly goats) replace cattle as the pre-eminent livestock species, with cattle accounting for a decreasing fraction of the total as rainfall increases. In the drier zones, the pattern for total livestock composition is close to that for the 'Pastoral' animals - as is to be expected given the limited human habitation and the small proportion of 'backyard' stock that these areas support. Hence cattle are gradually replaced by small ruminants and camels as the rainfall levels decline.

Seasonal variations in biomass compositions are minor, both for livestock as a whole and for the 'Pastoral' element. There is some indication that the proportion of camels in the 37.5 - 100mm belt is higher during the wet season than in the dry. This results more from an increase in small ruminant densities than a fall in camels numbers (see above), though the overall densities are so low that small variations in population density of one species may produce a disproportionate effect on stock composition figures.

10. COMPARISONS WITH OTHER POPULATION ESTIMATES

In the following sections, livestock populations are examined for the four major agro-ecological Zones defined by ILCA and for each country surveyed. The country data are also considered in an historical perspective, in an attempt to gain a temporal perspective on population trends.

10.1. Ecozonal Populations

The most comprehensive and widely used source of livestock populations in Africa is that produced by Jahnke in 1982, which includes summaries of the population data available for 1979. Jahnke's review also provided a broad continental perspective and strategic planning framework for establishing international research priorities (ILCA, 1987), and set the scene for a range of sectoral studies, including: investigation of crop-livestock interactions in mixed farming systems (McIntire et al., 1992), and a more general assessment of animal agriculture in sub-Saharan Africa (Winrock International, 1993).

A key element of Jahnke's review, which has been widely quoted in the literature, was his assessment of livestock resource distribution by agro-ecological zone and geographical region. That assessment was based on interpretation of information from a variety of sources, including: livestock population estimates from FAO's Production Yearbook for 1979; agro-ecological zones from FAO's World Soils Resources Report (Higgins et al. 1978); and maps of livestock distribution (World Atlas of Agriculture, 1976; and OAU/STRC/IBAR, 1976). Essentially, Jahnke apportioned national livestock populations to different agro-ecological zones as best he could on the basis of information available to him. This included the OAU/STRC/IBAR (1976) map of cattle distribution in Africa and the World Atlas of Agriculture (1976). The OAU/STRC/IBAR map was based on information from the early seventies. At the time, Jahnke commented on the "general absence of reliable statistics" and that his findings should only be taken as "rough estimates", broadly indicative of the orders of magnitude involved.

A word of two of clarification is required to explain the uncertain distribution and abundance of livestock resources in Africa. In the first place, it is important to recognise that FAO Production Yearbook figures for Africa are rarely based on comprehensive field surveys and their accuracy is, therefore, open to question. The Yearbooks are in fact no more than compilations of reported government statistics, augmented, where necessary by FAO's own estimates. Secondly, the geographical distribution of livestock within most African countries is far from uniform and is poorly documented, so the apportioning of numbers to different agro-ecological zones is a somewhat subjective process. Resource allocation is further complicated by the seasonal movement of livestock between zones.

ERGO's database provides an objective basis for comparing some of Jahnke's "rough estimates" with the findings of extensive recent field surveys in the arid, semi-arid, sub-humid and humid zones. In order to compare the present data with these 1979 estimates, the total numbers of animals or biomass units within regions used by Jahnke must be calculated. These regions are either countries or agroecological zones, the latter being defined using the correspondence of growing period with rainfall, following Jahnke's schema, as follows: Arid = less than 500mm; Semi-Arid = 500 - 1000mm; Sub-Humid = 1000 - 1500; and Humid = more than 1500mm. In the following analyses, the Highland Zone has been subsumed into the Sub-Humid Zone throughout.

With the exception of Nigeria, the regional coverage of the ERGO data is limited to one or two ecozones in each country, which precludes reliable extrapolation to the country level, unless ecozone data from one country is applied to the others. Given the importance of 'Village' livestock, and the reliance of this element upon human habitation density, such extrapolation is unlikely to be dependable. Comparison of the 'Pastoral' element might, however, be more fruitful, though again, it is likely that the numbers of small ruminants would be substantially underestimated, particularly in the wetter regions.

This problem is illustrated by the figures in Table 5 which suggests that the two sets of estimates are comparable where either 'Village' or 'Pastoral' livestock predominate, but that where there is a mixture of the two, there are marked differences between the two sets of information.

Table 5: Livestock Biomass Levels by Ecozone (Whole Countries Surveyed)

Ecozone	**Total**			**Pastoral**			**Jahnke** (1979)
	Mean	Dry	Wet	Mean	Dry	Wet	
Arid (61)	13865 (21)	13254 (21)	14465 (21)	12167 (29)	11555 (31)	12780 (29)	10903 (29)
Semi-Arid (21)	36227 (54)	34806 (54)	37652 (53)	19658 (48)	17864 (47)	17964 (48)	16751 (45)
Sub-Humid (14)	15152 (22)	13988 (22)	16316 (23)	8764 (21)	7664 (20)	9863 (22)	7751 (21)
Humid (4)	1747 (3)	1718 (3)	1745 (3)	652 (2)	652 (2)	653 (1)	1796 (5)
Total	66991	63766	70178	41241	37735	41260	37201

Figures are Thousands of TLU. Figures in Brackets are Percentage of Total

These may reflect real contrasts, or merely an incompatibility due to over-enthusiastic extrapolation of the ERGO data. It is considered that the most reliable course of action is to ensure that the two sources of data are as compatible as it is possible to make them, before comparisons are examined more closely. This means that the assumptions made in the course of extrapolation must be based on as few uncertainties as possible.

A compromise is therefore required, notably that the ERGO annual mean density data are applied only to those zones sampled within the countries surveyed. This gives figures for the Arid Zones of Mali, Tchad, Sudan and Nigeria; the Semi-Arid Zones of Mali and Nigeria; and the Sub-Humid and Humid Zone of Nigeria.

The following Tables (6 to 11) present the density and population comparisons for biomass, cattle and small ruminants. The proportions of the total populations within each Zone which are illustrated in the accompanying Figures (13 to 15).

Table 6: Biomass Densities by Ecozone (Country Zones Surveyed)

	Total			Pastoral			Jahnke
Ecozone	Mean	Dry	Wet	Mean	Dry	Wet	(1979)
Arid (73)	4.4	4.2	4.6	3.9	3.7	4.1	3.5
Semi-Arid (12)	22.6	21.7	23.5	12.2	11.2	13.3	14.4
Sub-Humid (10)	14.8	14.0	15.6	8.1	7.3	8.9	6.3
Humid (5)	9.0	8.9	9.2	3.2	3.2	3.2	9.1
Total	7.9	7.6	8.3	5.3	5.0	5.7	5.59

Figures are TLU per square kilometre. Figures in Brackets are Percentage of Total

The biomass comparisons suggest two significant conclusions: given that livestock numbers are unlikely to have increased by a third between 1979 and the late eighties, the 1979 estimates are too low, largely because they do not incorporate of 'Village' livestock into the overall population estimates; and that substantially higher densities occur in the Semi-Arid and Sub-Humid Zones than has previously been appreciated (Figure 13).

Table 7: Livestock Biomass Levels by Ecozone (Country Zones Surveyed)

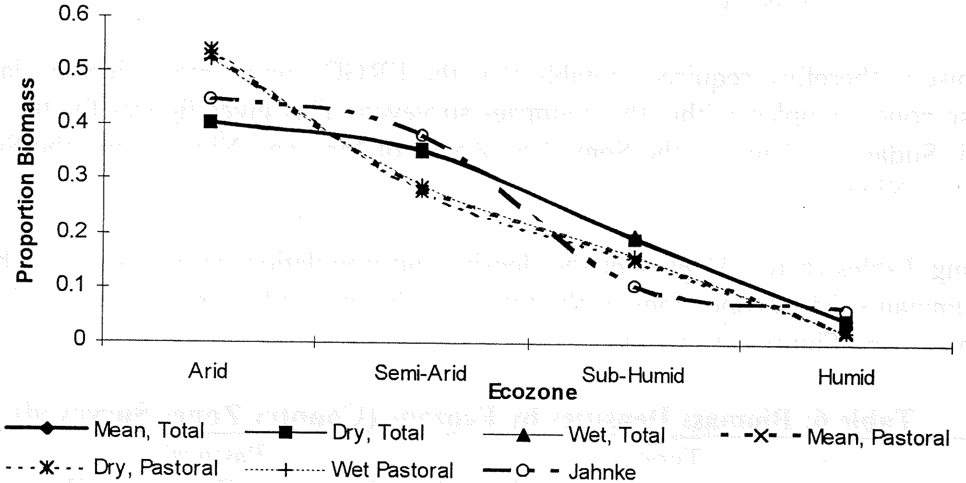
	Total			Pastoral			Jahnke
Ecozone	Mean	Dry	Wet	Mean	Dry	Wet	(1979)
Arid (73)	13865 (41)	13254 (41)	14465 (41)	12167 (53)	11555 (54)	12780 (53)	10903 (45)
Semi-Arid (12)	12085 (35)	11611 (36)	12560 (35)	6558 (29)	5993 (28)	7123 (29)	9256 (38)
Sub-Humid (10)	6642 (20)	6269 (19)	7015 (20)	3635 (16)	3285 (15)	3986 (16)	2575 (11)
Humid (5)	1519 (4)	1493 (4)	1544 (4)	541 (2)	538 (3)	544 (2)	1510 (6)
Total	34111	32627	35584	22901	21371	24433	24244

Figures are Thousands of TLU. Figures in Brackets are Percentage of Total

Whether this results from a (southward) relocation of the regional livestock herd, or an underestimate of the populations in these Zones cannot be directly ascertained from these data. Studies by Fricke (1979) and Putt *et al.* (1983), however, concluded that cattle numbers in the Semi-Arid Zone of Nigeria had already begun to decline by the early seventies, and were on the increase in the Sub-Humid Zone. These changes were not reflected in either the OAU/IBAR map or Jahnke's figures, which are therefore likely to underestimate cattle numbers in the wetter areas of the country.

Thus, within Nigeria, the contrasts between the resent data and the earlier estimates are, most probably, the result of both an underestimate of livestock populations in the less arid regions, and a southward relocation of the regional herd. Much of this relocation has been attributed to the impacts of drought in the drylands, and to human population increase, with the consequent reduction of in the threat of trypanosomiasis, in the wetter areas. Both factors are unlikely to have been restricted to the land within Nigeria's boundaries, and so it seems probable that such changes have been occurring throughout Sub-Saharan Africa in recent years.

Figure 13: Proportion of Biomass: Ecozone (Country Zones Surveyed)



Tables 8 and 9 and Figure 14 show the cattle population data, again for the whole of the ecozones within the countries with mean annual figures available. Some marked differences between the two sets of information are evident. As with the biomass data, the 1979 densities are lower than the ERGO estimates, though the difference are less marked if only the 'Pastoral' animals are considered.

Table 8: Cattle Population Densities by Ecozone (Country Zones Surveyed)

	Total			**Pastoral**			**Jahnke**
Ecozone	Mean	Dry	Wet	Mean	Dry	Wet	(1979)
Arid (73)	4.4	4.3	4.5	4.2	4.0	4.3	2.6
Semi-Arid (12)	21.4	19.8	22.9	16.3	14.7	17.9	16.8
Sub-Humid (10)	13.2	12.1	14.4	11.4	10.2	12.5	5.4
Humid (5)	5.1	5.0	5.1	4.5	4.5	4.6	5.2
Total	7.5	7.1	7.9	6.4	6.0	6.8	5.0

Figures are Cattle per square kilometre. Figures in Brackets are Percentage of Total

Both the numbers and proportions of cattle in the parts of the Sub-Humid Zone surveyed appear to have been underestimated in the earlier data. This is to be expected, given the increase in the number of cattle resident in Nigeria's Middle belt in recent years (see above).

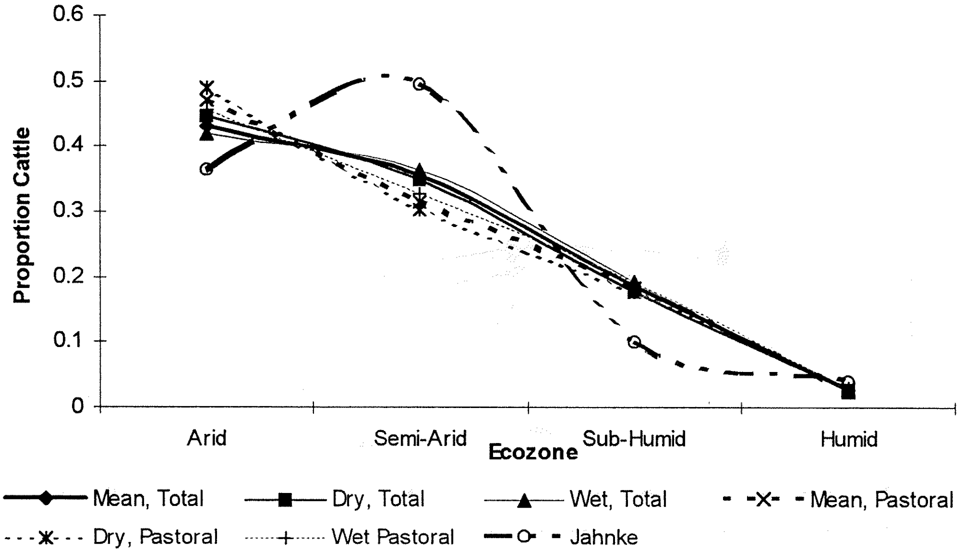
Table 9: Cattle Populations by Ecozone (Country Zones Surveyed)

	Total			**Pastoral**			**Jahnke**
Ecozone	Mean	Dry	Wet	Mean	Dry	Wet	(1979)
Arid (73)	13883 (43)	13638 (44)	14196 (42)	13061 (47)	12739 (49)	13383 (45)	7939 (36)
Semi-Arid (12)	11437 (36)	10618 (35)	12257 (36)	8741 (32)	7882 (30)	9600 (33)	10840 (50)
Sub-Humid (10)	5950 (18)	5425 (18)	6473 (19)	5108 (18)	4590 (18)	5625 (19)	2203 (10)
Humid (5)	850 (3)	845 (3)	855 (3)	763 (3)	758 (3)	767 (3)	857 (4)
Total	32120	30526	33781	27673	25969	29375	21839

Figures are Thousands of Animals. Figures in Brackets are Percentage of Total

The densities recorded by the air and ground surveys in the Arid Zone are also higher than those given for 1979 by Jahnke, though the absolute magnitude of the difference is only 1.5 to 2 animals per square kilometre. Given that the majority of the Arid Zone is remote and so unsuited to purely ground based enumeration techniques, it is quite possible that the methods of assessment used in the seventies did not adequately account for the animals in the remotest regions, thus under-estimating animal densities. The Arid Zone is, however, very extensive, and so a small increase in density translates into a very substantial rise in estimated populations within the Zone (Table 9).

Figure 14: Proportion of Cattle: Ecozone (Country Zones Surveyed)



It is the comparisons of small ruminant estimates that show the greatest differences between the two data sets (Tables 10 and 11). The 1979 figures appear to be very substantial underestimates, though there is an approximate correspondence between the two assessments of total animal numbers for the Humid Zone.

Table 10: Small Ruminant Population Densities by Ecozone (Country Zones Surveyed)

	Total			**Pastoral**			**Jahnke**
Ecozone	Mean	Dry	Wet	Mean	Dry	Wet	(1979)
Arid (73)	11.1	10.2	12.0	6.7	5.3	8.1	7.1
Semi-Arid (12)	66.3	68.9	63.9	8.0	8.6	7.4	25.9
Sub-Humid (10)	55.5	55.3	55.6	1.3	1.6	1.1	22.5
Humid (5)	55.5	54.2	56.8	0.4	0.4	0.4	54.9
Total	24.4	24.0	24.8	6.1	5.2	7.0	13.3

Figures are Small Ruminants per square kilometre. Figures in Brackets are Percentage of Total

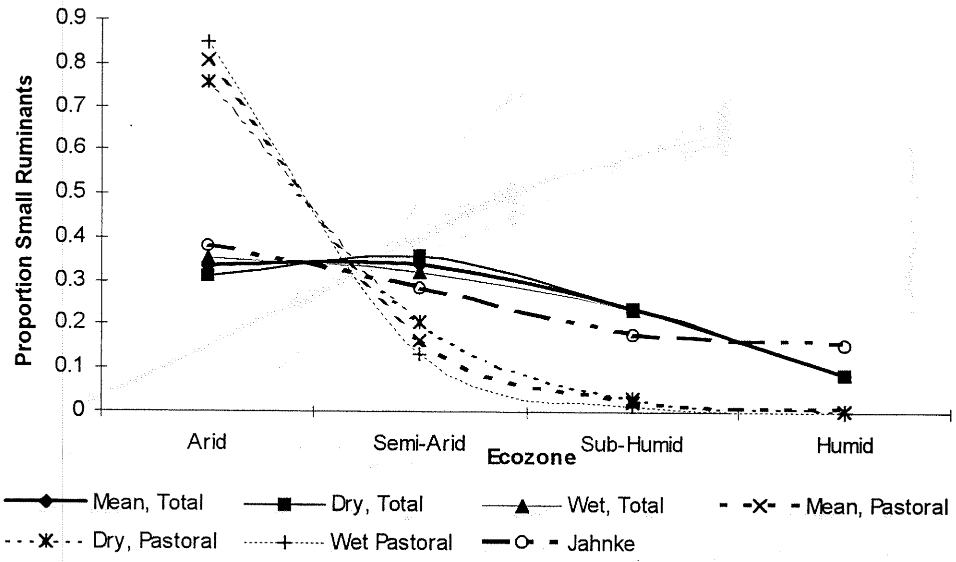
Table 11: Small Ruminant Populations by Ecozone (Country Zones Surveyed)

	Total			**Pastoral**			**Jahnke**
Ecozone	Mean	Dry	Wet	Mean	Dry	Wet	(1979)
Arid (73)	35005 (33)	32248 (31)	37872 (36)	21098 (81)	16762 (76)	25434 (85)	22097 (38)
Semi-Arid (12)	35520 (34)	36884 (36)	34233 (32)	4289 (17)	4618 (21)	3960 (13)	16707 (29)
Sub-Humid (10)	24921 (24)	24854 (24)	24988 (23)	598 (2)	717 (3)	480 (2)	10328 (18)
Humid (5)	9331 (9)	9115 (9)	9547 (9)	66 (0)	71 (0)	61 (0)	9097 (15)
Total	104777	103101	106640	26051	22168	29935	58229

Figures are Thousands of Animals. Figures in Brackets are Percentage of Total

It is not possible to determine whether the 1979 estimates have under counted the ‘Pastoral’ or ‘Village’ element of the population, though the approximate agreement of the ‘Pastoral’ and 1979 figures in the Arid Zone suggest that in areas where ‘Pastoral’ animals predominate, it is the ‘Village’ animals that the earlier estimates miss. In those areas where there are few or no pastoral animals, notably the Humid zone, the ‘Village’ animals are assessed reasonably accurately. This is fairly typical of unstandardised methodologies - where counts are targeted at specific livestock types, often to the detriment of others.

Figure 15: Proportion of Small Ruminants: Ecozone (Country Zones Surveyed)



Jahnke gives details of camel numbers only by country and assumes that all camels are found in the Arid Zone. The ERGO data indicates, however, that some 10% of the total camel population within the country zones surveyed are found in the Semi-Arid and Sub-Humid Zones (Table 4) which suggests that Jahnke's assumptions about the distribution of this species are an oversimplification. As a result, a comparison of populations is unlikely to be revealing, and has not been considered here.

10.2. Country Populations

10.2.1. Historical Perspective

The dynamics of livestock distribution and the assessment of long-term population trends in sub-Saharan Africa are subjects of general interest and much speculation. If it were not for the fact that livestock are managed by people, it might be fairly confidently predicted that they should respond just like other animal populations and increase in size until density dependant factors limit their growth, and some form of oscillating equilibrium is established. However, the reality of managed, multi-species, mobile livestock populations, ranging across agro-ecological zones and national boundaries is somewhat more complex.

10.2.2. Local Population Trends

ERGO's livestock database is essentially geographical in nature, and is not well suited to the identification of temporal population trends. Nevertheless, some sites have been surveyed repeatedly over a number of years using the same methodology, and a few relevant historical records exist for others (Hiernaux, 1993). Comparison of the information available for five arid and semi-arid sites across the Sahel, summarised in Table 12, indicates a general increase in the number of small ruminants during the eighties, with cattle populations remaining stable in some areas and declining dramatically in others.

Whilst far from being conclusive evidence, this observation does at least confirm the subjective impression of many observers, that cattle have been more severely effected by droughts in the Sahel than small ruminants. The latter are generally more tolerant of arid conditions, and are not so dependant on water as cattle. Small ruminants also breed more rapidly than cattle and, because their numbers build up more quickly following a drought, are likely to be favoured by pastoralists recovering from previous stock losses.

Table 12: Changes in Cattle and Small Ruminant Density in Areas Surveyed

Country	Date	Location	Area km²	Cattle /km²	SR /km²	Reference
Mali	11/80	Inland Delta	36,000	22.5	6.9	Milligan et al., 1982
	03/81	Inland Delta		37.9	13.7	Milligan et al., 1982
	06/82	Inland Delta		23.7	16.9	Milligan et al., 1982
	05/87	Inland Delta		23.4	22.6	RIM, 1987
	03/83	Gourma	81,300	4.5	8.7	RIM, 1987
	09/84	Gourma		8.5	15.7	RIM, 1987
	06/87	Gourma		2.2	11.2	RIM, 1987
Niger	05/81	NRL/ILP	81,555	3.5	9.6	Milligan, 1982
	10/81	NRL/ILP		4.6	14.1	Milligan, 1982
	09/82	NRL/ILP		4.1	10.2	Milligan, 1982
	09/85	NRL/ILP		0.5	28.3	Bourn and Wint, 1986
Sudan	1975	Red Sea Province	124,100	0.3	5.0	Watson et al., 1976
	1989	Red Sea Province		0.1	5.0	ERGO, 1990
Tchad	1966-70	Kanem and Batha	59,800	8.8	7.0	Cabot and Bouquet, 1973
	1970-73	Kanem and Batha		7.7	7.5	Anon, 1973
	1983	Kanem and Batha		6.1	7.8	Tchad Government, 1983
	1991-93	Bahr el Ghazal		7.3	8.6	RIM, 1991 and 1993

10.2.3. National Population Trends

An alternative approach to the assessment of livestock population trends at the local level is to examine time series data for individual countries. Nigeria is the only entire country represented in the ERGO database and that information is compared with historical records going back to 1930.

Time series data for Nigerian livestock were compiled from various sources and are illustrated in Figure 16. Cattle population estimates for the period 1930-62 are based on an assumed 50% under-declaration in Jangali tax returns (Shaw and Colvile, 1950; Glover, 1960; Annual Reports of the Department of Veterinary Services of the Northern Region of Nigeria; and Fricke, 1979). Estimates for other livestock species between 1958-62 are from Northern Nigeria Veterinary Department Annual Reports. For the period 1963-89 all population estimates are from FAO (1972) and (FAO, 1991 in WRI, 1992). Figures for 1990 are those of the National Livestock Resources Survey (RIM, 1992).

One of the more intriguing aspects of this examination of time series data is the progressive increase in Nigeria's cattle population, from just under 6 million in 1930 to almost 14 million in 1990, more than doubling over a 60 year period, with an average rate of net population growth of about 1.5% per annum. Short-term declines and subsequent recoveries in cattle numbers are also evident, following the droughts of the early seventies and eighties.

Three other features of the Nigerian time series data are worth noting. Firstly, there is the statistical discontinuity that exists between the late fifties and early sixties. This coincides with Independence and a change in reporting procedures. Before Independence, livestock statistics focused on northern Nigeria; after Independence national totals were estimated for the whole country. Then there is the remarkable constancy of small ruminant populations from the mid-sixties onwards, which is somewhat unrealistic. Finally, there is the marked upward revision of all livestock populations in 1990, representing the findings of Nigeria's first national livestock resources survey (RIM, 1992).

Figure 16: Changes in Livestock Populations: Nigeria

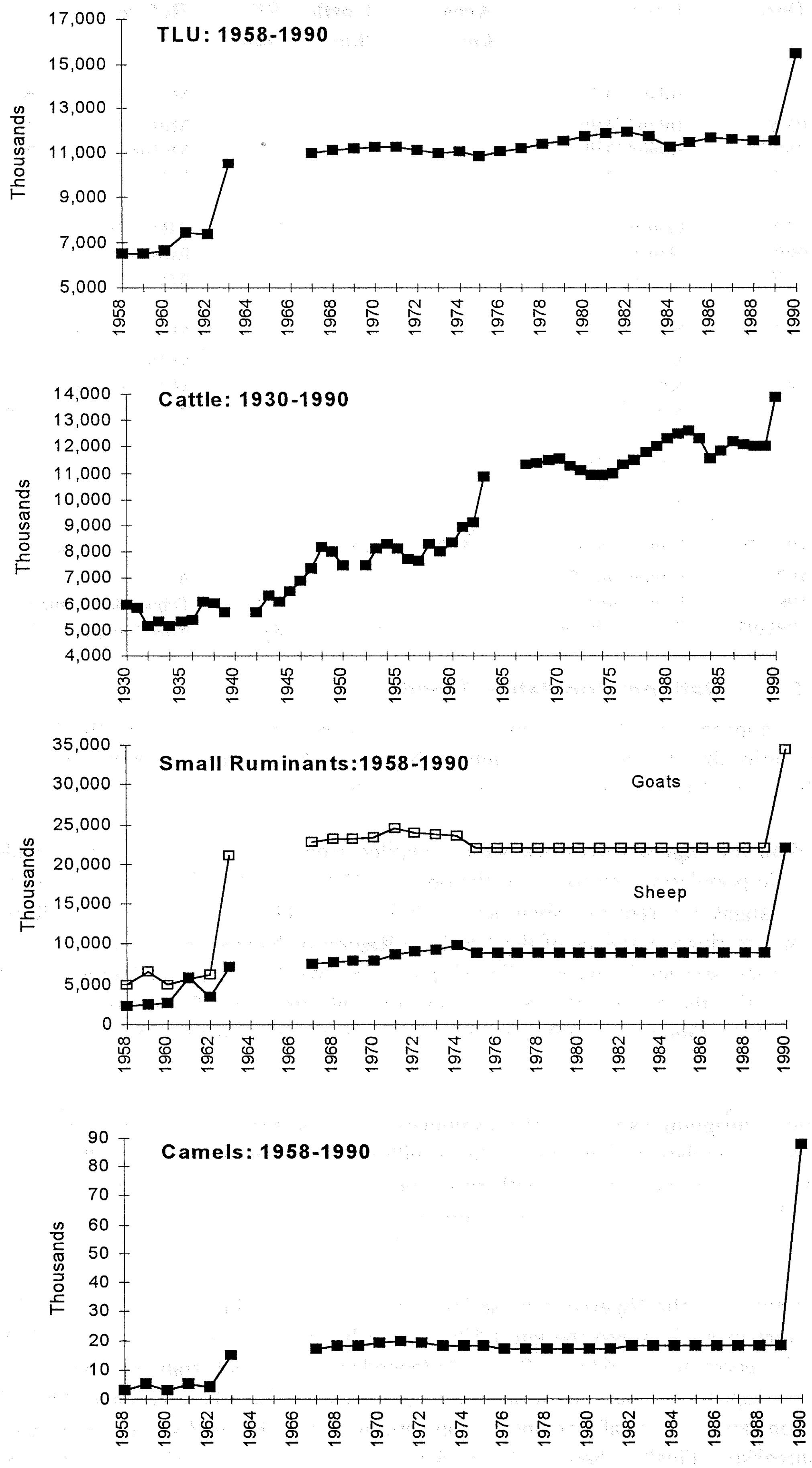
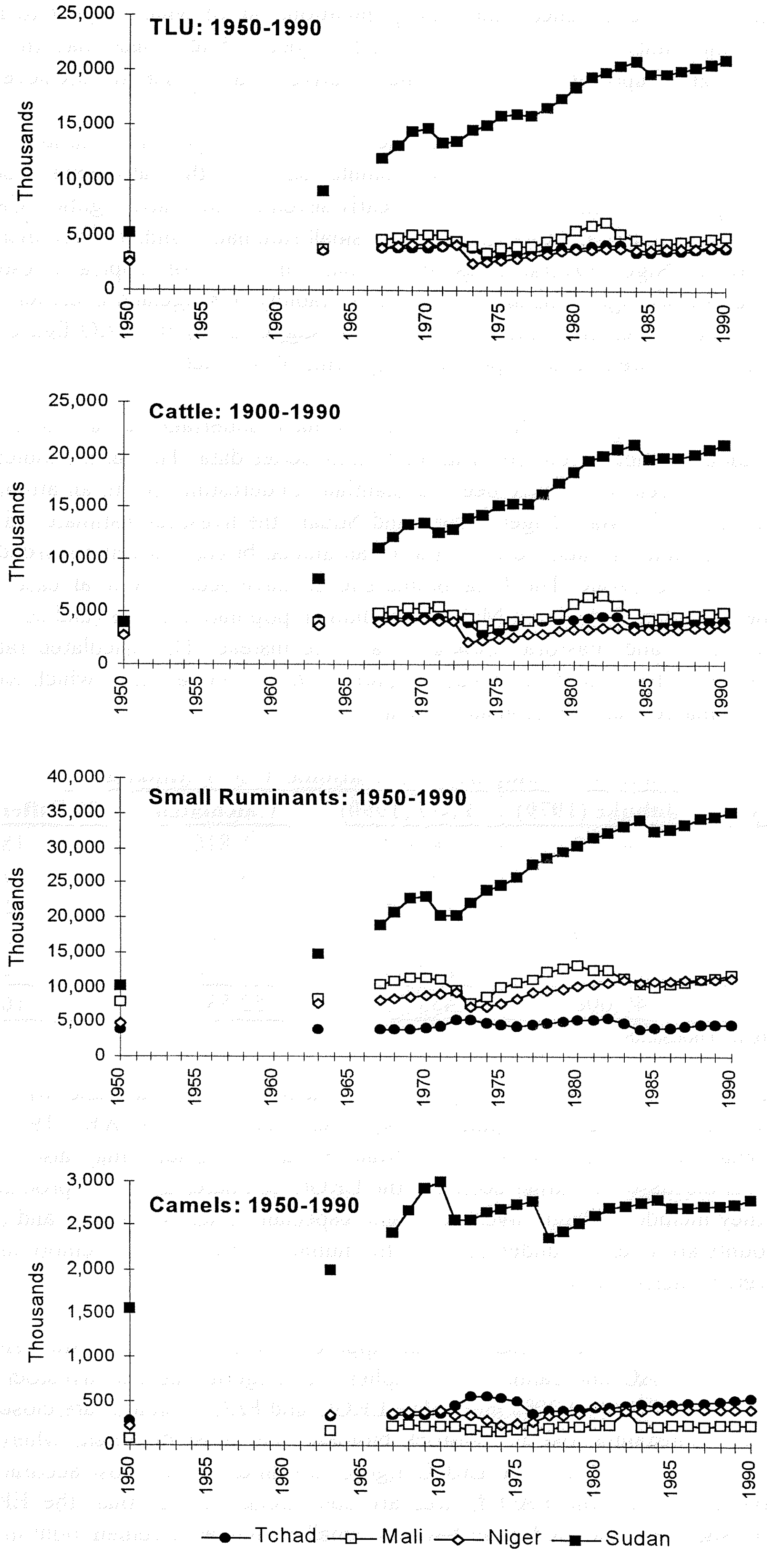


Figure 17: Livestock Populations in Mali, Niger, Sudan and Tchad, 1950-1990



Time series data for livestock populations in Mali, Niger, Tchad and Sudan were compiled from FAO (1972) and (FAO, 1991 in WRI, 1992), and are illustrated in Figure 17. Sudan stands out as having by far the largest cattle, sheep and goat populations, all of which appear to have increased with remarkable uniformity over the past twenty-five years. Sudan also has the largest camel population, but its size is reported to have remained relatively stable since the late seventies.

Livestock population estimates for Mali, Niger and Tchad show a general consistency over the past twenty-five years. Not only are most them of a similar size, but they also exhibit similar periodic fluctuations, corresponding to the droughts of the early seventies and early eighties. Cattle and camel populations have not grown in the long-term, whilst small ruminant numbers have increased to some degree, particularly in Niger. Overall livestock biomass, in terms of tropical livestock units has, therefore, remained surprisingly constant. This relative stability of rangeland livestock, contrasts with the progressive increase of chicken and pig populations suggested by the FAO figures, which are of course characteristic of more intensive, peri-urban systems of production.

As mentioned previously, Nigeria is the only country to have undertaken a national livestock survey whose findings can be compared directly with FAO time series data. The results indicate that, in the past, Nigerian livestock resources have been substantially underestimated. In an attempt to generate comparable information for Mali, Niger, Tchad and Sudan, the livestock estimates given in Table 7 have been used to calculate a ratio between the mean annual biomass levels recorded and Jahnke's 1979 estimates for each ecozone. The Total biomass levels have been used in all cases except for the Sub-Humid Zone of Sudan, Tchad and Mali, where human population levels (and so "village' animal densities) are very low, and 'Pastoral' biomass was used instead. The calculated ratios were then applied to the 1979 data for each Zone in each country to derive Zonal totals which were then added together to give estimated National biomass estimates.

Table 13: Comparison of National TLU Estimates

Country	Jahnke (1979)	FAO (1990)	Calculated	% Difference
Mali	4,512	4,911	5,810	18
Niger	3,407	4,062	4,347	7
Nigeria	11,718	11,518	14,399	25
Tchad	3,715	3,931	4,789	22
Sudan	17,550	21,000	23,188	10
Total	40,608	45,422	52,533	16

Figures are in Thousands

This "calculated" ruminant biomass is compared with Jahnke's 1979 data and with those derived from FAO's 1990 national livestock population estimates (FAO, 1991 in WRI, 1992) in Table 13, which indicates that the livestock resources in Mali, Tchad and Sudan may also be substantially underestimated. As discussed in earlier sections, the ERGO estimates are most probably higher than others because they include 'Village' livestock, most especially small ruminants, and because purely ground based counts are likely to under-estimate the numbers of animals in remote areas which are assessed effectively by aerial survey.

There is, however a second possible reason for the apparent underestimation in the FAO figures. The difference between the FAO and Jahnke data implies that Nigeria had less livestock in 1990 than 1979, whilst Sudan and Niger had 20% more. The ERGO and FAO estimates are closest where FAO have incorporated a substantial rise in livestock biomass, and most divergent where FAO figures imply a fall since 1979, (and where the ERGO figures are likely to be most accurate). A possible conclusion is, therefore, that the FAO figures are substantially lower than the ERGO ones for Nigeria, Mali and Niger because the former have too small an annual increment built into them.

11. LIVESTOCK AND THE ENVIRONMENT

11.1. Environmental Predictors of Total Livestock Distribution

The following pages present the results of an analysis of the relationships between livestock densities and the environmental parameters for which data are available. The presentation of the results has been divided into two major sections. The first overview section initially considers the simple bivariate correlations between individual livestock biomass parameters and the environment - and is intended to provide a simplified picture of the patterns identified. It then examines these relationships, using multivariate analyses, for biomass, cattle, small ruminants and camels, for each season.

The second section then considers the degree to which the relationships established for the whole of the areas surveyed also apply throughout the range of rainfall conditions covered.

11.1.1. Overview - Relationships within all Areas Surveyed

11.1.1.1. Bivariate Correlations

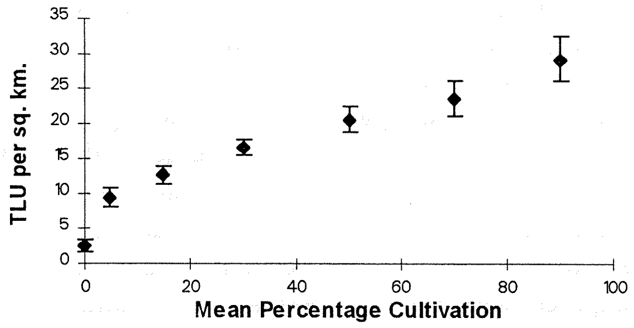
The simple (bivariate) correlations between livestock biomass and environmental parameters are shown in Appendix Table Axx. In each case, the variables have been 'linearised' to facilitate the comparison of the correlations. The four most significant relationships are indicated in ranked order, by the numbers in brackets. A description of the treatment of the data, and the procedures used to generate the graphs is given in the Appendix.

The most important relationships with total livestock biomass, expressed as mean annual TLU per km^2, are shown in Figures 18 to 19. A description procedures used to generate the graphs is provided in the Appendix. In brief, there is, for all the relationships plotted, considerably less than a one in ten thousand chance that they are false.

The strongest association is between Total Biomass and percentage cultivation. Not only is there an even rise in livestock density with cultivation levels, but the degree of variation (as shown by the bars) is quite low, and the statistical levels of significance are astonishingly high. There is therefore very little room for doubt that livestock aggregate in the greatest numbers where there is most cultivated land.

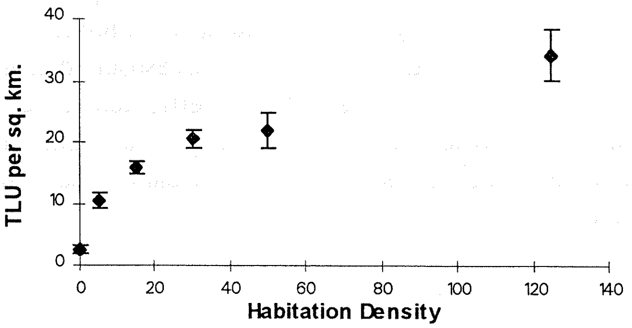
Not surprisingly, the relationship between biomass levels and the density of permanent human settlement (the number of rooftops per square kilometre) is also very strong, though marginally weaker than the association with cropping levels. It is noticeable that the rise in livestock levels with habitation numbers is rather less even than with cultivation, and the variation, particularly at the more intensely cropped categories is a little greater.

Figure 18: Total Livestock Biomass: % Cultivation



Log10 (Y)=0.3014 + 0.5561 Log10(X).R^2=0.535; N=3663; p < 0.0001

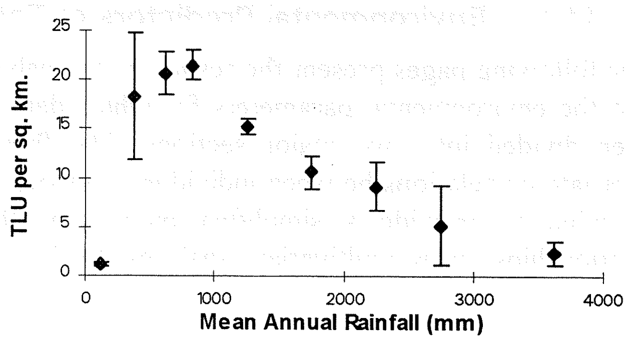
Figure 19: Total Livestock Biomass: Habitation Density



Log10 (Y)=0.3582 + 0.5897 Log10(X).R^2=0.507; N=3663; p < 0.0001

Total biomass is also strongly correlated with rainfall, though not in a straightforward linear fashion as the previous two relationships. The driest areas (with between 37.5 and 250 mm precipitation per year) support very low livestock levels - an average of 1.28 TLU (320 kg) per square kilometre. However a modest increase in rainfall of up to 250mm is associated with a fourteen fold rise in livestock levels to 18.29 TLU (approximately 4600 kg) per square kilometre. Livestock levels reach a peak at around 825 mm, and then drop fairly evenly as it gets wetter.

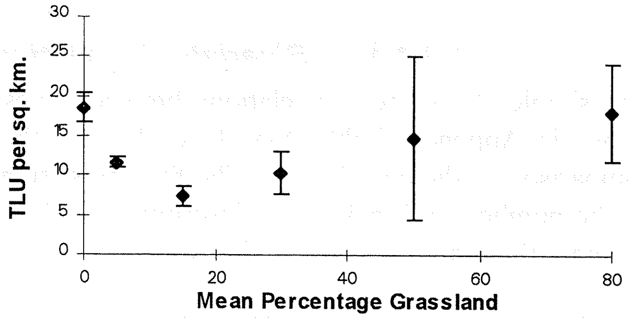
Figure 20: Total Livestock Biomass: Rainfall



$\text{Log10(y)}=1.082 - 0.00007(x) - 50.59/(x).R^2=0.3681$; N=3663; $p < 0.0000$

It is not only received wisdom, but intuitively reasonable that domestic ungulates should be concentrated where there is an abundance of natural grazing. The plot shown in Figure 21 (right) not only does not support that hypothesis, but actively suggests that higher livestock densities are found in areas with less grassland. However, though significant, the relationship is weak, and leaves room for the explanation that livestock numbers are so variable at specific levels of grassland that no real trend can be reliably discerned.

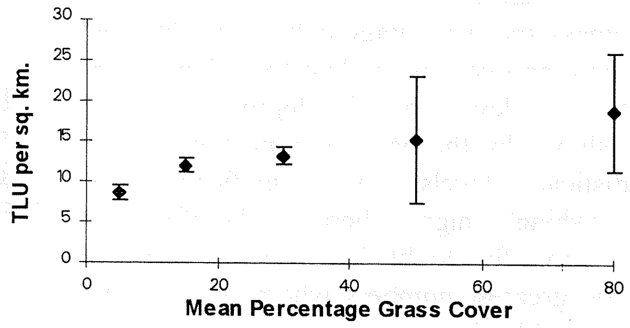
Figure 21: Total Livestock Biomass: % Grassland



$\text{Log10 (Y)}=0.9739 - 0.2745 \text{ Log10(x)}.R^2=0.057$; N=3273; $p < 0.0000$

This explanation is supported by the fact that Total Biomass does rise consistently with the levels of grass cover within all natural vegetation categories. More animals are found in areas with more grass. There is a lot of variation, however, particularly at the higher levels of grass cover, and accordingly, the relationship is comparatively weak. The variation in levels of grass cover explain only 10% of the variation in livestock density, as compared with the 50% explained by either cultivation or habitation levels.

Figure 22: Total Livestock Biomass: % Grass Cover

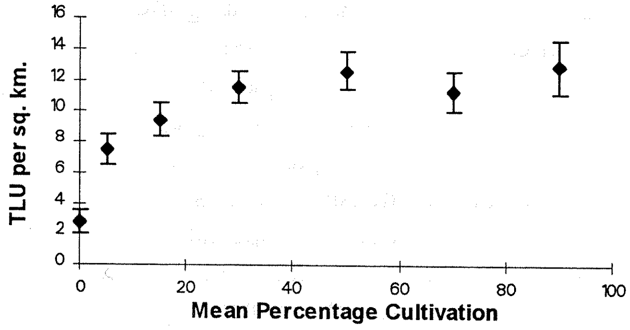


$\text{Log10 (Y)}=0.3122 + 0.4267 \text{ Log10(x)}.R^2=0.103$: N=3273; $p < 0.0000$

Given that Total Livestock Biomass incorporates both those animals that are managed pastorally, and those that are closely associated with human settlement, it can be argued that it is to be expected that the primary determinants of livestock distributions are those most closely linked to human activity - namely cultivation and settlement levels. If the traditionally held views are correct, and animals go where there is grazing, examining these same relationships for the more pastorally managed livestock should reveal weaker relationships between animals distribution patterns and human activity.

This is indeed the case, as illustrated in the data plots shown in Figures 23 and 24 (right and below). Both cultivation and habitation levels are less closely correlated with pastoral biomass densities than with total biomass density. Nevertheless, the relationship between pastoral animals and cultivation levels is still substantially the strongest of those examined. As with total biomass, pastoral animal densities rise with cropping intensity, though the increase levels off once more than half the land area is cultivated.

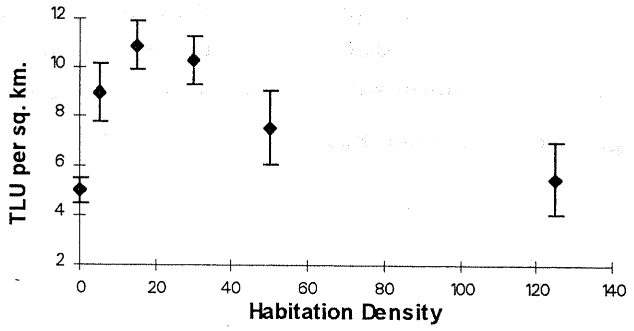
Figure 23: Pastoral Livestock Biomass: % Cultivation



Log10 (Y)=0.3105 + 0.3777Log10(X). R^2=.269; N=4403; $p < 0.0000$

However, the link between pastoral animal distribution and permanent human habitation levels appears to be more complex in form (Figure 24). Pastoral animal densities rise to a maximum at habitation densities of around 20 rooftops per square kilometre, then fall again in the more populous areas. Accordingly, despite its statistical significance, this relationship is sufficiently weak to be of little help in predicting pastoral livestock abundance.

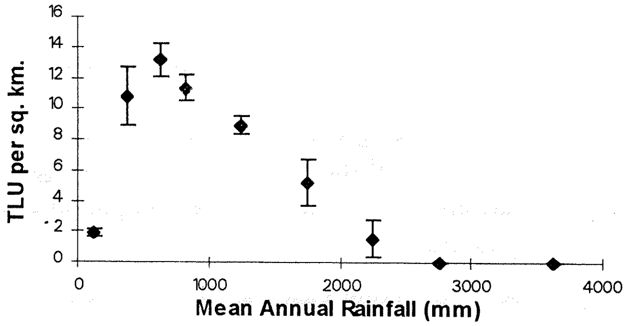
Figure 24: Pastoral Livestock Biomass: Habitation Density



Log10(Y)=0.4977 + 0.1940 Log10(X). R^2=0.060; N=5045; $p < 0.0000$

The environmental parameters most closely related to pastoral biomass are annual rainfall and percentage grass cover, as shown in Figures 25 and 26 (right and below) . Pastoral animal numbers rise to a maximum at rainfall levels of around 825 mm, and then decline to zero at about 2500 mm. This pattern is similar to that described for total biomass densities, except that pastoral livestock appear to be absent from the very wettest areas, presumably because of the threat of vector-borne and other diseases.

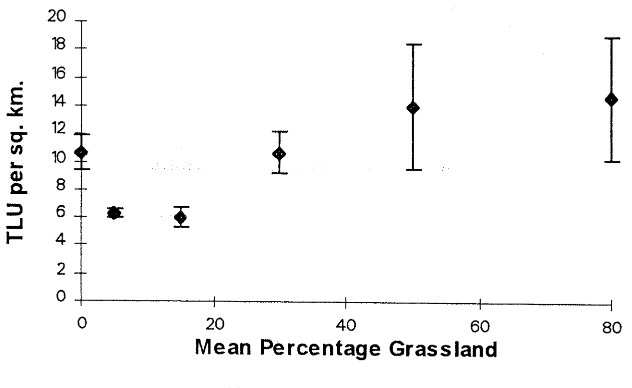
Figure 25: Pastoral Livestock Biomass: Annual Rainfall



Log10(Y)= 0.9246 - 0.0002(X) -44.972/(X). R^2=0.213; N=5058; $p < 0.0000$

The distributions of grassland and pastoral animal biomass are not significantly correlated. Given the significant, if weak, relationship between grassland and total biomass, this result is perhaps somewhat unexpected as it would seem justifiable to assume that pastoral animals are more closely linked to grassland than are village livestock. The lack of association with pastoral animal distributions argues that the one with total biomass should be viewed with some reservation.

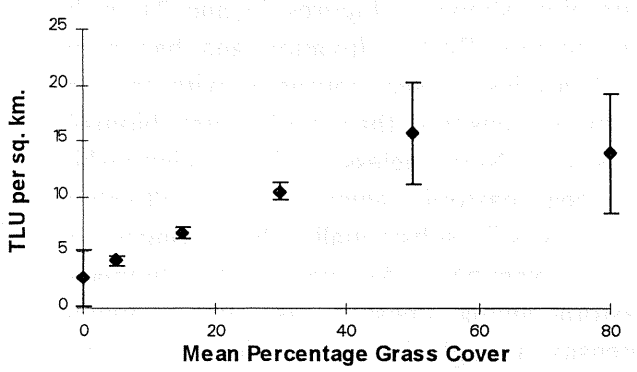
Figure 26: Pastoral Livestock Biomass: % Grassland



No significant trend

Pastoral animal biomass levels are, however, positively correlated to the presence of grass in all natural vegetation categories, as represented by grass cover. Where there is more grass, there are more pastoral animals, though an increase above 50% grass cover appears not to be accompanied by an similar increase in animal densities. Statistically, the relationship is weak, especially when compared to that with cultivation, primarily because there is a lot of variability in animal densities at both high and low levels of grass cover.

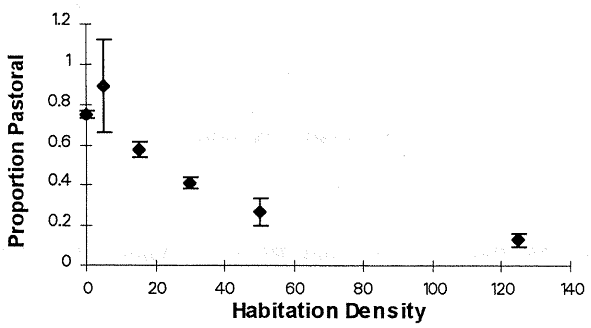
Figure 27: Pastoral Livestock Biomass: % Grass Cover



Log10 (Y)=0.2883 + 0.3284 Log10(x). R^2=0.102; N=4685; P <0.000

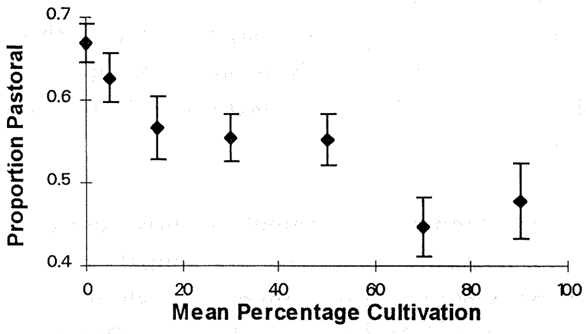
Another way of examining the influence of various parameters on the pastoral and total livestock levels is to look at the proportion of the total biomass which is pastoral. The strongest of these by far is the negative correlation with the density of human settlement. This is reflected in the weaker negative association with cultivation levels. (Figures 28 and 29, below)

Figure 28: Proportion Pastoral: Habitation Density



Log10(Y)=0.7843 - 0.2572Log10(X). R^2=0.222; N=3353; p < 0.0000

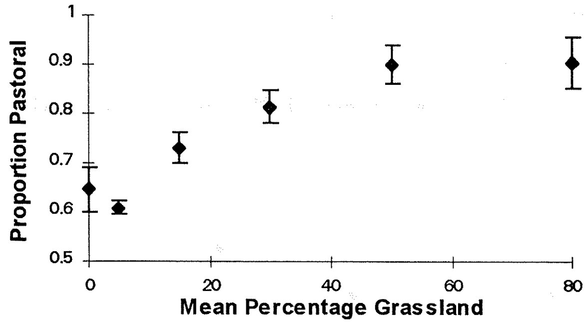
Figure 29: Proportion Pastoral: % Cultivation



Log10(Y)= 0.6803 - 0.0944Log10(X). R^2=0.035; N=3353; 0 < 0.0000

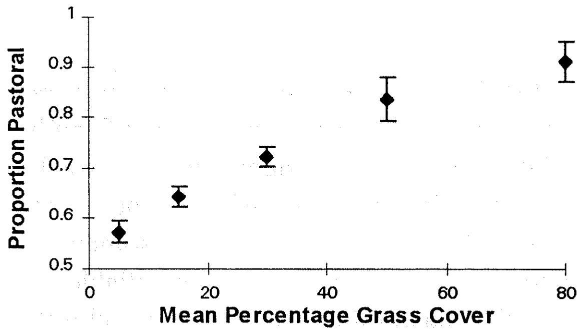
In relation to natural grazing parameters, there is a clear trend for the proportion to rise in concert with both measures of the extent of grazing (Figures 30 and 31). There is however a lot of variability and the relationships are rather weak, explaining little of the variation in the proportion of livestock which are pastoral.

Figure 30: Proportion Pastoral: % Grassland



Log10(Y)=0.5489 + 0.1543 Log10(X). R^2=0.0529; N=3042; p < 0.000

Figure 31: Proportion Pastoral: % Grass Cover



Log10(Y)=0.4743 + 0.1659 Log10(X). R^2=0.044; n=3042; p < 0.0000

11.1.1.2. Multi-variate Correlations

It is clear from the results presented above that the distributions of total livestock biomass and the pastoral element are linked in very similar ways to the extent of human activity and the abundance of natural grazing. Both livestock categories are closely linked to cultivation rather than natural grazing.

It is possible, however, that the influence of the amount natural grazing is in some way camouflaged by unknown interactions and associations between the disparate variables included in the analysis. For example, it may be the case that both cultivation and grazing availability are actually determined by rainfall, and that the apparent relationships between human activity and livestock levels are merely a by product of a stronger causal link between livestock and rainfall.

The results of the stepwise regressions are shown in Tables 14 to 17, below. A detailed example of the interpretation of the first equation shown in Table 14 is given in the Appendix. It should be noted that, because there are so many data points included within the analysis, the least significant of the relationships presented is statistically significant at the 10^{-10} level, i.e. there is approximately a 1 in ten billion probability that the relationships do not exist. The statistical significance of the stronger relationships - those with an R^2 in excess of 0.2 - is extremely high, with less than a 1 in 10^{20} likelihood that they are the result of chance. There is no room for doubt that the associations are very strong.

Table 14: Multiple Regressions of Livestock Biomass with Environmental Variables

Dependent Variable	Best Predictor	2nd Predictor	3rd Predictor	4th Predictor	Other Significant Correlates
Mean Total TLU **R^2=.7112;** DF=8,3264	**+.3600Hab(60)**	+.2997Rain (67)	+.2466Cult(69)	+.1536GrCov(71)	-Open, +GrLand, +FoWd, -Dense
Mean Pastoral TLU **R^2=0.4585;** DF=6,4029	**+.3516Cult(34)**	+.4873Rain(42)	+.1396GrLand (45)	+.1189GrCov(46)	-Open, +FoWd
Dry Total TLU **R^2=.5129;** DF=5,5991	**+.2647Cult(37)**	+..3133Hab(46)	+.3490Rain (48)	+.0872GrLand(50)	-For, +GrCov, +Open
Dry Pastoral TLU **R^2=.3129;** DF=6,5990	**+.3127Cult(22)**	+.4844Rain (27)	+.1077GrLand(30)	-.0423For(31)	+Hab, +GrCov, +FoWd
Wet Total TLU **R^2=.6608;** DF=9,3263	**+.3953Hab(54)**	+.2651Cult(59)	+.3461GrCov(63)	-.0591For(65)	+Rain,+Open.+FoWd,-Dense
Wet Pastoral TLU **R^2=.3481;** DF=6,4671	**+.3390Cult(24)**	+.2485GrCov(29)	+.4190Rain(32)	-.0784For(34)	-Open, +FoWd

Figures in brackets are percentage variance explained at each step of the regression. Variables transformed as discussed in the Appendix.

The results given in Table 14 strongly confirm the assertions put forward above that human activity, either as cultivation or habitation density are consistently the most important predictors of both total and pastoral livestock distributions. Rainfall is the second most important factor. Measures of natural grazing, either grassland or grass cover, contribute little to the explanation of animal numbers. These patterns hold true for wet and dry seasons, as well as for the mean annual biomass densities.

Tables 15 and 16 demonstrate that cattle and small ruminant density, whether for annual or seasonal figures, and for both the total populations, and the 'Pastoral' element alone, are linked to the environmental parameters in much the same way as are biomass levels. All but two categories are most closely associated with indicators of human presence. These are the annual and wet season densities of 'Pastoral' small ruminants, which are best predicted by rainfall, though in the dry season these animals also aggregate most strongly where there is cultivation.

As discussed above, it is intuitively reasonable to suppose that domestic ungulates should be concentrated where there is an abundance of natural grazing. The regression equations confirm the indications given by the bivariate correlations, namely, that this is generally not the case. Whilst an increase in grass cover is associated with a rise in cattle and small ruminant levels, this association is considerably weaker than that with human activity, and contribute little extra validity to the prediction of livestock distribution patterns. Natural grazing is therefore substantially less accurate than the presence of people as a predictor of most livestock levels.

Table 15: Multiple Regressions of Cattle Density with Environmental Variables

Dependent Variable	Best Predictor	2nd Predictor	3rd Predictor	4th Predictor	Other Significant Correlates
Mean Total Cattle **R^2 = .6445;** DF= 8,3264	**+.3969Cult(51)**	+.0168Rain (60)	+.2077GrCov(61)	+.1835Hab(62)	-For, +FoWd,
Mean Pastoral Cattle **R^2 =.5456;** DF= 8,4027	**+.3982Cult(42)**	+.6685Rain(50)	+.1202GrLand (52)	-.3674For(54)	+GrCov, -Open,
Dry Total Cattle **R^2=.4081;** DF= 7,5989	**+.3365Cult(31)**	+.1116Rain(35)	+.1309GrCov(38)	-.0616For(39)	+Hab, +GrLand, +FoWd
Dry Pastoral Cattle **R^2=.3379;** DF= 7,5589	**+.3400Cult(25)**	+.1682GrCov(30)	+.1080Rain(33)	-.0448For(34)	+FoWd, +GrLand, +Hab
Wet Total Cattle **R^2=.5611;** DF= 9,3263	**+.4267Cult(48)**	+.3995GrCov(51)	-.0888For(53)	+.0605Rain(55)	-GrLand, +Hab, -Open,
Wet Pastoral Cattle **R^2=.3978;** DF= 8,4699	**+.3923Cult(31)**	+.0957Rain(35)	+.2378GrCovW(38)	-.0849For(39)	+Dense, -Open, +FoWd,

Figures in brackets are percentage variance explained at each step of the regression. Variables transformed as discussed in the Appendix.

Table 16: Multiple Regressions of Small Ruminant Density with Environmental Variables

Dependent Variable	Best predictor	2nd Predictor	3rd Predictor	4th Predictor	Other Significant Correlates
Mean Total Small Ruminant **R^2=.7467; DF=** 8,3624	**+.8112Hab(71)**	+.1657Cult(72)	+.1433GrLand(74)	-.1676Dense(74)	+Rain, -For, -Open, +FoWd
Mean Pastoral Small Ruminant **R^2=.2564; DF=** 7,4305	**+.5984Rain(11)**	+.2370Cult(16)	+.2525GrLand(23)	-.2242For(25)	-Dense, +FoWd, -Open
Dry Total Small Ruminant **R^2=.5880; DF=** 7,5989	**.6562Hab(53)**	.2387Cult(58)	.2231Rain(58)	-.0158For(58)	-Open,-Dense,GrCovD
Dry Pastoral Small Ruminant **R^2=.2315; DF=** 7,5989	**.2576Cult(10)**	-.0562Dense(18)	.4921Rain(22)	0.0479For(23)	+GrLandD, -GrCov, +Hab
Wet Total Small Ruminant **R^2=.7348;** DF= 7,3265	**.8555Hab(69)**	.1435GrCov(71)	.1838Cult(72)	-.0350Dense(73)	+Rain,-For,+GrLand
Wet Pastoral Small Ruminant **R^2=.1306;** DF= 6,4671	**.4900Rain(6)**	.2016GrCov(9)	-.0597For(11)	.1281Cult(12)	-Dense,-Hab

Figures in brackets are percentage variance explained at each step of the regression. Variables transformed as discussed in the Appendix.

Table 17: Multiple Regressions of Camel Density with Environmental Variables

Dependent Variable	Best Predictor	2nd Predictor	3rd Predictor	4th Predictor	Other Significant Correlates
Mean Total Camel Density **R^2=.1433;** DF= 5,3627	**+.0299GrLand(10)**	+.0621GrCov(13)	+.0279Rain(14)	-.0406Dense(14)	- 0pen
Mean Pastoral Camel Density **R^2=.1336;** DF= 7,4028	**-.0483Rain(8)**	+.0221GrLand(11)	-.0140Open(12)	-.0305GrCov(13)	-Cult, +For, -FoWd
Dry Total Camel Density **R^2=.0535;** DF= 5,5991	**-.0527Rain(3)**	+.0352GrCov(5)	-.0089Dense(5)	-.0080Open(5)	+Cult
Dry Pastoral Camel Density **R^2=.0568;** DF= 8,5988	**-.0537Rain(4)**	-.0155GrLand(5)	-.0069Open(5)	+.0115Cult(5)	-Dense,+GrCov, -Hab, +For
Wet Total Camel Density **R^2=.1114;** DF= 6,3266	**+.0310GrLand(8)**	-.0101Dense(10)	-.0109FoWd(10)	+.0625GrCov(11)	-Rain, +Hab
Wet Pastoral Camel Density **R^2=.0873;** DF= 4,4673	**-.0544Rain(6)**	+.0381GrCov(8)	+.0155GrLand(8)	-.0116Cult(9)	-FoWd

Figures in brackets are percentage variance explained at each step of the regression. Variables transformed as discussed in the Appendix.

However, this general pattern does not hold for camels. For this species, the primary predictors of density are either rainfall, percentage grassland or percentage grass cover. An increase in natural grazing, or a decrease in rainfall levels are associated with a fall in camel densities - they are therefore concentrated, as expected, in areas with low rainfall and relatively extensive natural grazing, and are not generally concentrated in areas where there are resident human populations.

Table 18 shows the multiple regression equations relating to livestock composition and environmental parameters. These show that the relative contributions of each species to the overall biomass is predicted most often by rainfall levels, followed by the correlates of human activity. Even for the proportion of the Total biomass that is 'Pastoral', the addition of rainfall as a second predictor adds substantially to the significance of the equation. This strong influence of rainfall on stock composition is consistent with the clear patterns shown in Figures 7 to 12 above.

Table 18: Multiple Regressions of Livestock Composition with Environmental Variables

Dependent Variable	Best Predictor	2nd Predictor	3rd Predictor	4th Predictor	Other Significant Correlat s
Biomass					
Mean Proportion Pastoral **R^2=.3090**; DF=7,2545	-.3470Hab(18)	+.1453Rain(26)	+.1295GrCov(28)	+.1255Cult(31)	+GrLand, -Open,+FoWd
Cattle					
Proportion of Pastoral Biomass **R^2=.7006**; DF= 7,2450	+.8165Rain(62)	+.1404Cult(67)	+.0615Dense(68)	+.0965GrCov (70)	+Hab,+FoWd
Proportion of Total Biomass **R^2=.5280**; DF= 8,2544	+.0164Rain(31)	+.2529Cult(39)	+.2680GrCov(43)	-.1489Hab(46)	-GrLand, -For,
Small Ruminants					
Proportion of Pastoral Biomass **R^2=.3323**; DF= 7,2453	-.0943Cult (21)	-.0618Dense (27)	-.1460GrCov (31)	-.0664Hab (33)	+Open, +GrLand, -For
Proportion of Total Biomass **R^2=.3217**; DF= 8,2544	-.1652GrCov (9)	-.0061Rain(13)	+.2484For(20)	+.2169Hab(30)	-Cult, +Open, -For, +Dense
Camels					
Proportion of Pastoral Biomass **R^2=.4925**; DF= 7,2449	-.3394Rain (46)	-.0777Cul (47)	-.0447GrLand(49)	-.0590FoWd (49)	+Dense, +For, +Hab
Proportion of Total Biomass **R^2=.4778**; DF= 4,2548	-.1600Rain(44)	-.0698Cul(46)	-.0537FoWd(48)	-.0253Hab(48)	

Figures in brackets are percentage variance explained at each step of the regression. Variables transformed as discussed in the Appendix.

The relative importance of rainfall as a determinant as opposed to a predictor of livestock biomass levels is moot. Though cultivation, habitation and natural grazing generally outrank rainfall as predictors of livestock densities (though not camels), it can be argued that their distributions are determined to a substantial degree by the amount of water available, at least in those areas where plant growth is markedly seasonal. As a result, it is reasonable to suppose that it is rainfall that drives the system, through its effect on human distribution patterns. However, given that there is a stronger proximate link between animals and human activity than with rainfall, the statement that the ultimate determinant of livestock numbers is rainfall becomes little more than a truism.

11.1.2. Relationships Between Livestock and the Environment in Different Rainfall Bands

One of the questions arising from the results just discussed is whether the strong association between human activity and livestock density is locally valid. A possible scenario is that human activity is the dominant predictor in the more populated areas, but the availability of natural grazing - either grass cover or grassland - is more significant in the arid rangelands.

Testing this hypothesis involves assessing the relative strength of the relationships between livestock and the environmental parameters within the different rainfall bands. This process has the added advantage of factoring out the influence of rainfall on livestock distribution patterns - if rainfall is indeed the ultimate determinant of livestock densities, then it is desirable to investigate the role of the other environmental parameters having first removed its potentially confounding effect.

Given the number of rainfall bands into which the data have been divided (eleven), the presentation of regression equations analogous to Tables 14 to 17 becomes not only a complex task, but also one which is difficult to evaluate. With four livestock categories (biomass, cattle, small ruminants and camels), each with three temporal divisions (annual, dry and wet season), 132 separate equations would need to be tabulated.

Accordingly, a graphical display of the results has been devised to simplify the process of interpretation and evaluation. The diagrams shown are intended to demonstrate the relative importance of the association between the four major predictor variables identified in the preceding section (Cultivation, Habitation, Grassland and Grass Cover) and livestock density. They plot a statistical significance index of the best bivariate curve fits for biomass or animal density and each of the four predictor variables in different rainfall belts.

The transformations tested were linear, log, power, quadratic, inverse, cubic, and exponential. The index is actually Log10 (1/p), where p is the significance level calculated from the F statistic, and the relevant degrees of freedom. If the slope of the fitted curve was found to be negative, then the index is plotted as a negative value. *The plots thus indicate the relative significance of each bivariate association in each rainfall belt, which is in effect the criterion used to determine the order in which the variables are ranked in multiple stepwise regression analyses.*

Because the strength of the relationships in the driest rainfall bands tends to be less than those in the wetter areas, two of the diagrams have been split into two sections (left and right) representing the driest (less than 250mm) and wetter (more than 250mm) respectively, so that the plots for the driest areas can be seen more clearly. *It should be noted that the value of the index equivalent to the threshold statistical significance levels of 5% and 1% is 1.3 and 2 respectively. Thus, any value between -1.3 and + 1.3 is not statistically significant.*

Figure 32 presents the significance index diagrams for the relationships between annual mean livestock densities and the four predictor variables. They show that, in the most arid zones, either cultivation or habitation are consistently the primary predictors of the densities of all the livestock species, except of biomass and camels in the 125 to 250 mm rainfall band, where natural grazing is the most significant environmental correlate. The significance indices are, however, generally low, and so, though the relationships exist, they are relatively weak. This implies that other factors, not included within the data, are likely to be the major determinants of animal distribution in these areas.

An obvious candidate is the availability of permanent water, which would be closely associated with the presence of cultivation and human habitations, and also provide a link between livestock and human activity. Permanent water is likely to be less closely linked with the extent natural rangelands, though it may determine the quality of the grazing available, which would tend to obscure any association between the amount of grass available and the number of animals present.

In the wetter regions with up to 1500 mm rainfall per year, human activity, again, is consistently the best predictor of total livestock numbers. Natural grazing is, in general, weakly or negatively associated with animal densities. This apparently active avoidance of grassland by livestock may be the result of the inevitable correlation between high cultivation levels and low natural grazing availability - where there is, for example, 90% cultivation, there can only be 10% grass cover or grassland. Hence, if animals aggregate where cultivation is widespread, they are, by definition concentrated where all other forms of vegetation are scarce. The regression equations presented in the previous section suggest that if the effect of cultivation (or habitation) on animal densities is removed, then the remnant association with natural grazing is positive - suggesting that within any single intensity of cultivation, animals do tend to be found where there is more grass cover.

It is only in areas with more than 1500mm rainfall per year (corresponding to the Humid Zone) that indicators of the extent of natural grazing become generally better predictors of livestock density than either cultivation or human habitation levels, though for small ruminant density, habitation remains the dominant correlate. This link between grazing and overall biomass levels is due to an association between cattle density and percentage grassland or grass cover.

Though initially counter-intuitive, this result may be rationalised by considering that the amount of open grazing available in these more wooded or forested areas is likely to be very limited. As cattle are essentially grazing animals, and may be unable to find suitable food in or around the relatively intensive types of cultivation found in the humid areas, they are likely to be restricted to areas of open grazing.

Figure 32: Significance of Environmental Variables to Mean Livestock Density (Best Fit)

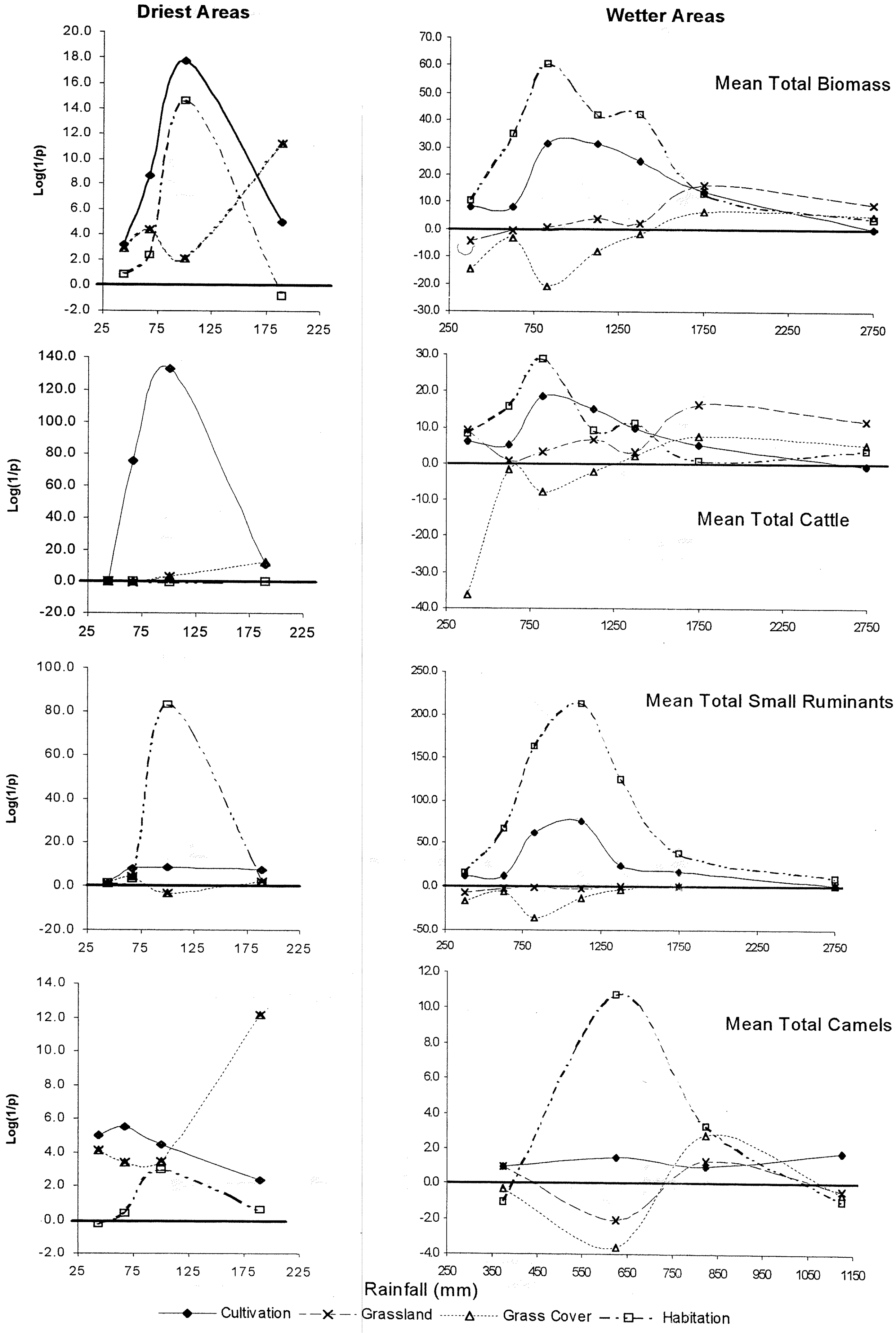


Figure 33: Significance of Environmental Variables to Dry Season Livestock Density (Best Fit)

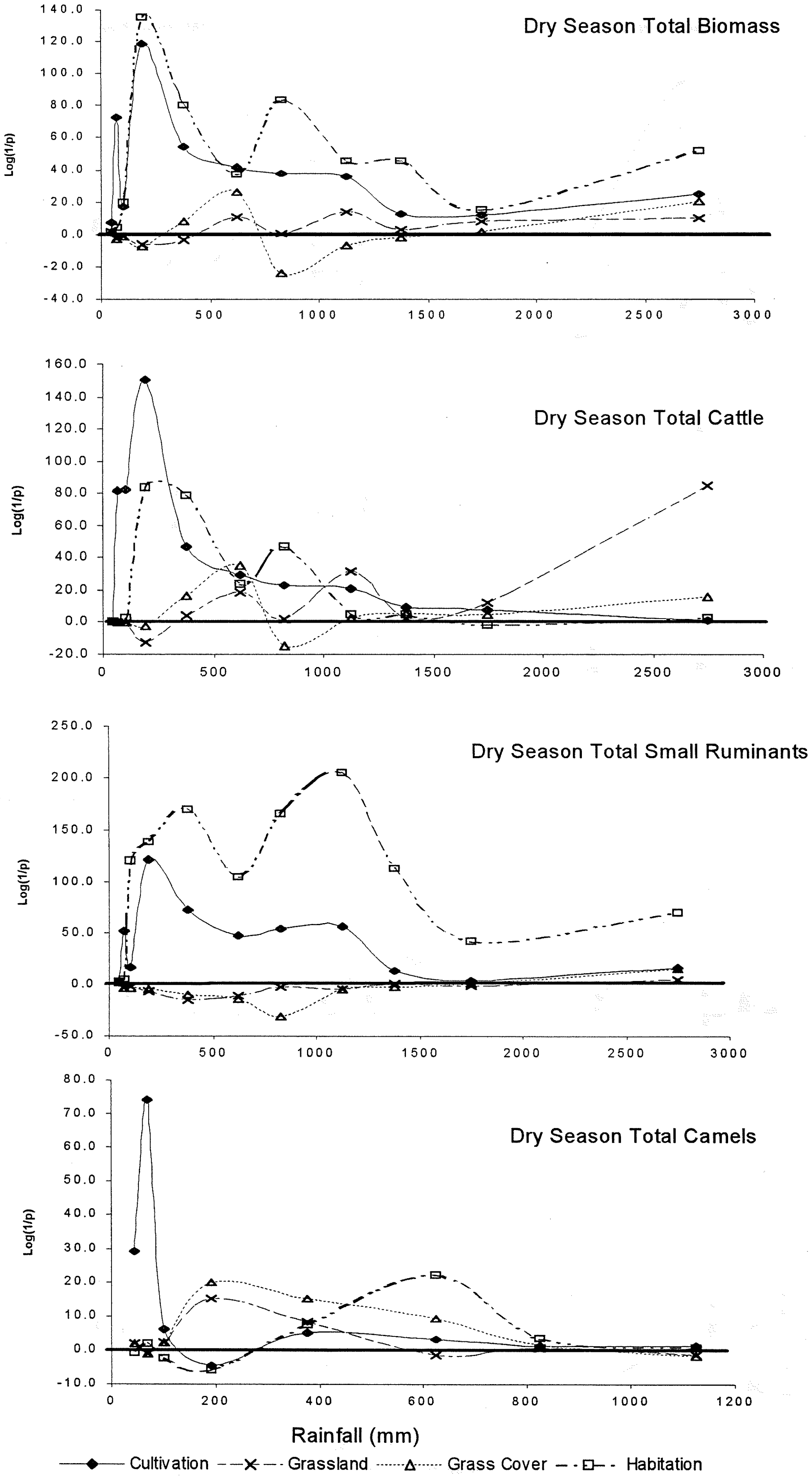
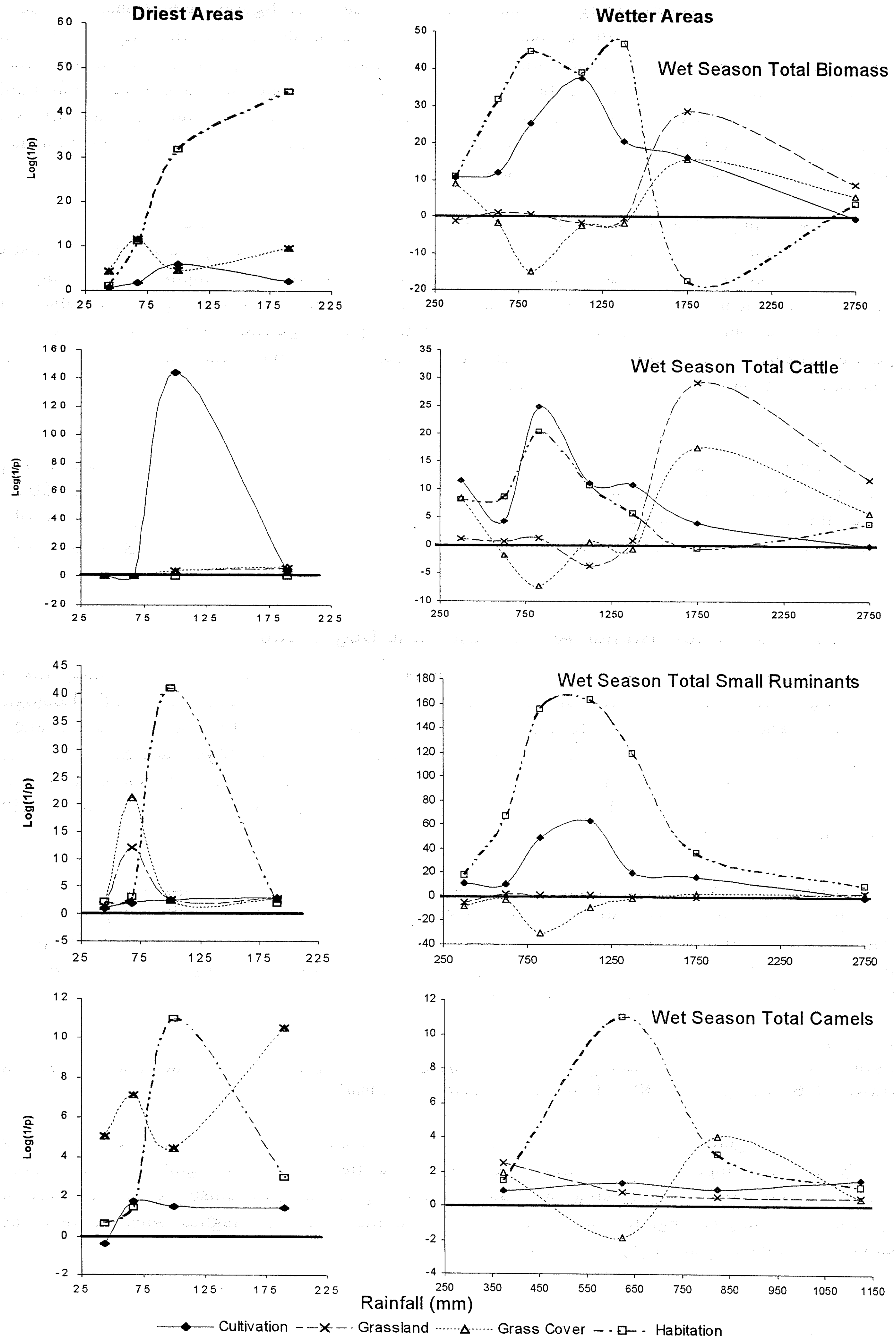


Figure 34: Significance of Environmental Variables to Wet Season Livestock Density (Best Fit)



When the environmental correlates of seasonal livestock densities are examined (Figures 33 and 34), an essentially similar pattern emerges to that found for annual mean figures - either habitation density or percentage cultivation are the primary predictors of animal density for the majority of animal categories and rainfall bands, during both wet and dry seasons. The exceptions are, in the dry season, camels, between 75 and 500 mm rainfall, and cattle in the wetter zones with above 1250 mm rainfall per year. In the wet season, the extent of natural grazing is the most significant correlate for camel, small ruminant and biomass density in the two driest rainfall bands, and for cattle and biomass in areas with more than 1500 mm annual rainfall.

These results imply that livestock are more closely associated with natural grazing than human activity only during the wet season and at the two extremes of the rainfall spectrum. This is a pattern that fits more closely to the traditional view of livestock distribution than implied by the analyses of mean annual distributions. During the wet season, there is likely to be more grass available in the most arid areas, allowing the animals to be grazed in the open rangelands. During the dry season, the natural grazing is less extensive, and thus animals are restricted to the better watered regions, where cultivation and habitation are also concentrated.

What is perhaps less expected is the narrow range of annual rainfall levels within which these conventional interrelationships operate - in general, once there is more than 75mm precipitation per year, the influence of human activity becomes paramount, until rainfall increases beyond 1500mm. Given the densities of animals in these 'extreme' areas, (Tables 4 to 7), then the proportion of the regional livestock biomass that is primarily influenced by the distribution of natural grazing is only in the region of 5 - 6%.

11.2. Livestock, Human Activity and Land Degradation

Given the link established between livestock, habitation and cultivation, then it is likely that the increasing concentration of agricultural exploitation will adversely affect the land. Ecologists, economists and others have long debated the linkage between the size of human populations and the degradation of their environment (Erlich, 1971; Erlich and Erlich, 1990; Myers and Simon, in press). Population densities *per se*, or population growth, have not been correlated with soil erosion, water impurity, deforestation and other major ecological changes (Tiffen et al, 1994; Mortimore 1989; Clarke and Rhind, 1992).

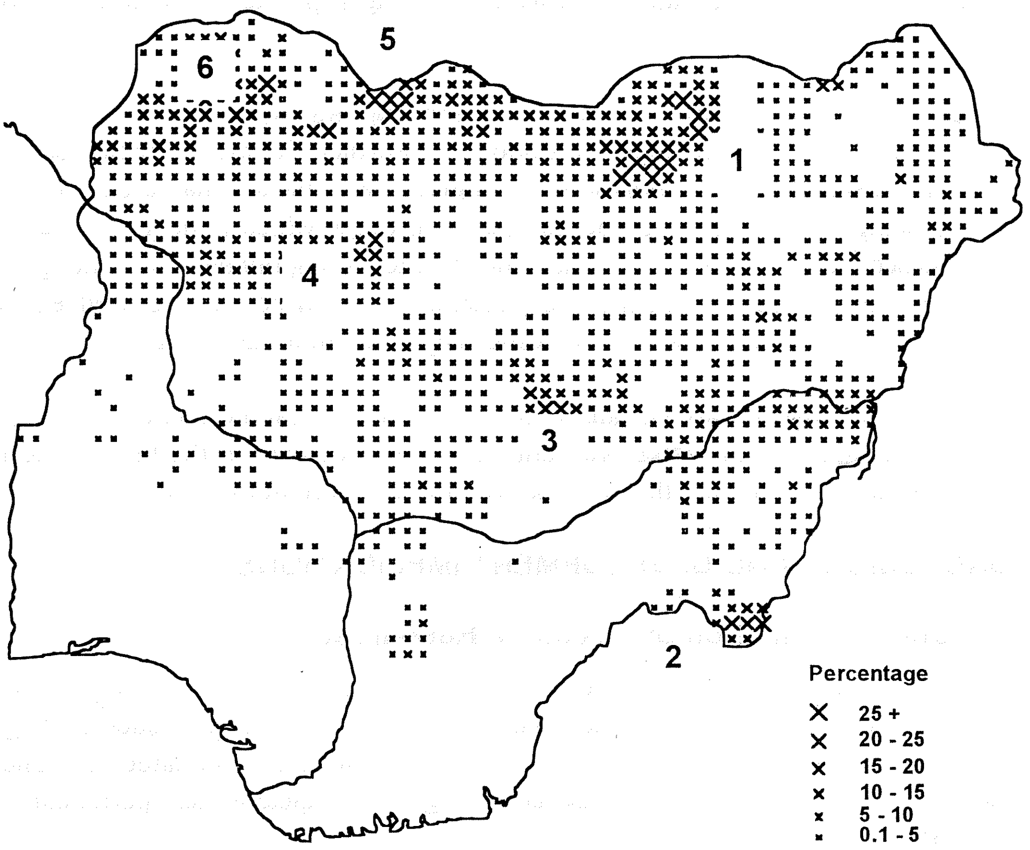
The ERGO data set includes measures of percentage erosion only for Nigeria during 1990and demonstrates a striking association between erosion and three predictor variables. Stepwise multiple regression (Equation 1) reveals that the extent of bare ground in a survey grid is the primary predictor of erosion levels. The next strongest predictor is the percentage of active cultivation (excluding fallow), followed by livestock biomass per km^2.

Equation 1
Lg10 (% Erosion) = -1.03 + 0.265Lg10 (% Bare Ground) + 0.198 Lg10 (% Active Cultivation) + 0.216 Lg10 (Livestock Biomass per km^2) R$^{2=}$ = 0.206; DF = 3, 1916; $p << 0.0001$

The statistical significance of the relationship is overwhelming - R^2 is 0.54 with in excess of 1,900 data points, as compared to a threshold value of 0.02 at the 1% level of significance. The level of erosion is thus most severe in areas with little natural vegetation - presumably those more arid and agriculturally marginal regions - and its incidence within these regions is highest where there are both extensive cultivation and high livestock numbers.

Figure 35 shows six areas of severe erosion, all of which are situated at the edges of dense settlement or cultivation. Area 1, at the apex of Bauchi, Jigawa and Yobe States, and Area 5 between Sokoto and Katsina States, represent the major stock routes into Niger. These routes go around the margins of the heavily cultivated 'Close Settled Zone' which large migrating herds of livestock tend to avoid. As a result, animal traffic is heavy, and can trigger the start of erosion. It is noticeable that the region between Areas 1 and 5, along the northern borders of the country has also sustained significant erosion. This is all extensively, rather than intensively, cropped land and the observed degradation probably reflects over-cultivation rather than animal induced erosion.

Figure 35: Distribution of Erosion, Nigeria, 1990



Areas 2 and 3 are the highlands of Mambila and Jos Plateaux, respectively. Both locations attract livestock in the wet season as they are free of tsetse and so are refuges from trypanosomiasis. The Jos Plateau is also extensively cultivated, and was heavily mined for its tin. The land degradation in these two areas thus results from both arable farming, livestock, and mining. Whilst mining operations on the Jos Plateau have now virtually ceased, land degradation is likely to become more severe, particularly on the Mambila, which is now seriously at risk from gully erosion initiated by livestock movements.

Area 4, in Kaduna State, is also on the edge of a region of heavy cultivation, and again is a traditional livestock corridor for movements between the north and the grazing in the south.

Area 6, in Sokoto and Kebbi States lies close to the Sokoto Rima river which is characterised by substantial areas of wetland or riverine cultivation, and is relatively heavily populated. Again, the erosion recorded is on the edges of a centre of comparatively dense arable farming.

An implication of this distribution pattern is that human habitation levels may also be linked to the severity of erosion. The levels of cultivation are significantly associated with human habitation density (Equation 2).

Equation 2
$\text{Lg10 (\%Cultivation)} = 0.743 + 0.472\ \text{Lg10 (Habitation Density)}\ R^2 = 0.21$; DF 2,1918; $p << 0.0001$

This relationship is considerably stronger ($R^2 = 0.48$,. N = 4404) if the composite Nigerian and Sahelian data-set is used, suggesting that, on a wider perspective, habitation (and by implication, population) may be more directly associated with erosion levels than is implied by the multiple regression equation given in Equation 1. It is the contrast between areas of extensive and intensive cropping that masks human habitation density from being a primary predictor of erosion levels in Nigeria.

There is thus a strong association between erosion and the human activities likely to degrade environments (cultivation and livestock production). Further, human activities spread with rising populations. Increasing human populations in Nigeria have meant that areas of hitherto natural vegetation are being opened up by arable farmers, a process which is likely to lead in the medium term to increased degradation. This may be further compounded by changes in livestock distributions, like those seen in Nigeria (see Section 10.2), which, if repeated elsewhere, will to hasten the spread of human induced erosion, especially in the more arid areas.

Given that human populations are certain to continue rising, it can be confidently predicted that the degree of land degradation associated with cultivation will increase in the future, and if the changes in livestock distributions continue, this process will become even more severe.

12. CONCLUSIONS AND DEVELOPMENT IMPLICATIONS

12.1. Under-Estimation of Livestock Resources

An important observation arising from this study is that official statistics appear to substantially under-estimate African livestock resources. This is evident for a country such as Nigeria, where a recent national survey indicates 25% more livestock than officially estimated; but under-estimation also appears to be more generally the case across agro-ecological zones, particularly in the Semi-Arid and Sub-Humid zones.

There are various possible explanations for this state of affairs, but the scenario preferred by the authors is that there is a pastoral bias in most reported livestock statistics. Historically, this is perhaps understandable because the great majority of livestock were kept by pastoralists, and few, if any, were kept by arable farmers. However, with the sedentarisation of pastoralists, the uptake of animal husbandry by arable farmers and generally increasing human population levels, there is bound to have been a significant increase in village livestock over time. It is this growth of village livestock populations that national statistics have failed to capture, and in particular the large number of non-pastoral small ruminants.

Clearly, this conclusion has some bearing on the validity and interpretation of livestock population estimates disseminated by international agencies, such as ILCA (1993), FAO (1991) and WRI (1992). The formal publication of such figures and the easy access of computer databases fosters a spurious sense of reality, and gives credibility to estimates which is not always justified. To emphasise this point, it is perhaps worth noting that recent censuses in Nigeria indicate not only 25% more livestock, but 25% fewer people than previously thought. This has obviously made nonsense of earlier per capita indicators of Africa's most populous country. (For those interested in trivial pursuits and who said: "There are three kinds of lies - lies, damn lies and statistics;" it was in fact Samuel Langhorne Clemens (1835-1910), American writer and humorist, otherwise known as Mark Twain.)

12.2. Livestock and the Environment

The regression analyses suggest that livestock numbers are more closely associated with the consequences of human activity - either cultivation or habitation levels - than they are with any of the environmental characteristics available in the ERGO database. In particular, the extent or distribution of natural grazing, either expressed as grassland, or as grass cover, is shown to be of limited relevance to livestock numbers. Only for some elements of the regional livestock population - notably 'Pastoral' small ruminants and camels, at some rainfall levels, and for most livestock in the wettest regions, has grazing been shown to be the primary predictor of animal densities.

This pattern of relationships also holds true for pastorally managed livestock, and indeed, the analyses suggest that for these animals, it is cultivation rather than habitation levels that are of primary significance.

The strength of the relationships, in statistical terms, is startling, given the breadth of ecological and geographical coverage and the variety of land use types from which the data are drawn, and leaves very little room for doubt that the links exist, and are real. Further, the similarity between the trends established for both pastoral and non-pastoral livestock do not suggest that there are any major differential responses, or that either should be treated as a special case.

These observations are in direct conflict with traditional and somewhat romantic views of pastoralists and their animals roaming across wide open rangelands, moving with the seasons from pasture to pasture, and water point to water point, avoiding settlements and areas of cultivation for much of the year, except for limited periods when crop residues may be utilised.

This discrepancy has several possible, and not necessarily contradictory, explanations:

a) *The traditional theories are, and always have been, wrong.*

   This is unlikely to be the case, not least because at some point in the past, human population and the attendant cultivation levels were substantially lower than they are at present, and thus were unlikely to be widespread enough to be a significant resource for livestock.

b) *The current results are wrong because they are concerned with large areas, and cover a wide range of ecological regions. They therefore conceal the fact that pastoralism and natural grazing may be linked in some areas but not others.*

   This idea is also difficult to support, given the statistical evidence. The analyses of the relationships between livestock densities and environmental parameters for each of the rainfall bands confirms the overall pattern, and only reveals a few interactions where grazing is the primary correlate of animal numbers.

c) *Although traditional views were once correct, times have changed appreciably, and they are no longer generally valid.*

   There is little doubt that livestock production systems have changed over the last two decades and continue to be in a state of transition. There have been repeated and extensive droughts in the more arid regions covered by this study - and as a result, livestock ownership patterns have changed so that many previously nomadic pastoralists no longer own the stock they look after. Further, there is mounting, if circumstantial, evidence of increasing degradation in the drier parts of the Sahel, resulting from overgrazing and the effects of an expansion of cultivation that is the inevitable consequence of increasing human populations. It is important to remember that most, if not all, of that expansion of cultivation in these drier areas will have been at the expense of natural grazing, as both are determined by the availability of water.

It is generally accepted that human populations have also expanded into previously unpopulated areas, particularly into the wetter areas, thereby clearing the natural vegetation for cultivation. As a result, regions that were originally suitable for livestock only during the dry season, when, for example, the risk of trypanosomiasis was lower, have now been opened up for occupancy throughout the year to livestock in general, and cattle in particular. Animals that used to migrate in and out of the wetter areas on a seasonal basis are now as likely to remain permanently in the more southern locations, rather than move north, if only because the predictability of either natural grazing or cultivation is greater in the wetter areas than it is in the drier ones. This has resulted in a southward redistribution of livestock in general and a more southerly dispersal of cattle in particular, away from the arid northern grasslands; a drift induced, perhaps, by a period of protracted drought and degradation of natural dry land grazing resources.

The southward relocation has had two consequences - firstly an increase in livestock populations within ecological zones that are less seasonally deficient in natural grazing than are the arid lands to the north; and secondly a reduction in the need for long distance transhumance between wet and dry season grazing areas. Thus the traditional distinction between livestock management systems used by pastoralists and agropastoralists has become increasingly blurred - pastoralists are settling and growing crops; and agropastoralists are acquiring livestock and sending them on transhumance, though generally for relatively short distances.

This trend has led to a closer involvement of stock owners with the cash economy, and thus an increase in the number of settled pastoralists - or, conversely, a decline in nomadic ones.

d) *A fourth possibility is that the links between livestock and cultivation established by the current analyses are misleading, and there is an unknown factor related to cultivation that determines livestock distributions.*

Given that regression analyses can only identify associations and cannot, without experimental manipulation, confirm causal relationships, it is not possible to state with any certainty that it is cultivation *per se* that attracts livestock. It is possible, indeed likely, that where there is cultivation, there will also be patches of grazing or browse that are suitable for livestock. This is particularly true in areas in areas where ecological conditions restrict cultivation to specific areas- such as Wadis - the presence of cropping and high quality grazing are likely to coincide. Also, land which is extensively (as opposed to intensively) cultivated often includes large amounts of marginal fallow or recently cultivated land. It may therefore be the case that the livestock are not concentrating where the cultivation is, but rather where the edges of the cultivation are.

Root and tree crop based farming systems, characteristic of the Humid Zone, have far fewer marginal resources and residues suitable for ruminant consumption and, as consequence, the links between livestock and cultivation are not so strong.

Whatever the explanation, grasslands support relatively few livestock and the great majority of animals are concentrated where cropping levels are highest.

Whether it is the actual cultivation, or the marginal resources associated with it that are the attraction is debatable, and in the current context unresolvable. To a some extent, this is irrelevant as far as the development implications are concerned. The fact that animals are found in the largest numbers in or near human settlement, rather than in remote grasslands, means that the major factor affecting livestock, both pastoralist and otherwise, is their interaction with permanent human settlement.

With the continued growth of human population and further expansion of agricultural land in years to come, the interface between livestock and cultivation will become even more important than it is at the moment. As cultivation levels rise, crop residues and associated feed resources will become the most predictable resource available to livestock, thus reducing need for long distance transhumance in search of uncertain natural grazing. *In other words, if the expansion of cultivation provides a relatively secure source of livestock grazing throughout the year, why go elsewhere ?*

12.3. Implications for the Future

12.3.1. The Interface Between Livestock and Human Settlement

The extent of cultivation varies considerably both within and between countries. Some areas are already densely populated and heavily cultivated, others much less so. With increased competition for limited land resources, the survival of growing human populations depends on the production of more food. This can be achieved either through the expansion of existing agricultural practices into new areas, or increasing the productivity of existing farmland Where land resources are relatively abundant, agricultural expansion obviously remains a possibility, but where land is in short supply, intensification the only viable option. It is in the areas where competition for limited land resources is greatest, such as the Machakos region of Kenya (Tiffin et al., 1993); or the "close settled zone" around Kano in Nigeria (Mortimore, 1988), that people see the need for change and are prepared to experiment with agricultural innovations, and adopt those measures and practices most appropriate to their local circumstances.

Viewed from that perspective, the greater abundance of livestock at increased levels of cultivation is perhaps not altogether surprising. The coincidence of livestock and cultivation can be seen as part of the overall intensification process, with obvious potential for the utilisation of draught power, manure, crop residues and otherwise unproductive land, all of which contribute to a greater overall productivity. The integration of crop and livestock production is already well advanced over much of sub-Saharan Africa (FAO, 1983; von Kaufmann and Blench, 1987; McIntire et al., 1992.), and the general promotion of mixed farming systems is considered a priority for the future development and intensification of agricultural production across the continent (ILCA, 1987; Winrock International, 1992).

An obvious conclusion to be drawn from this synthesis is that future development planning should pay particular attention to the interface between livestock and cropping. There are many topics of possible relevance in this context, some of which are already on many development agenda. The potential for conflict between pastoralists and arable farmers over, for example, crop damage or disputed access to water sources have received some attention. What is it that attracts livestock to areas of cultivation and human settlement?. Are crop residues the primary attraction, or is it the predictability of feed resources associated with cultivation, the fallow grazing and the availability of browse? Is it perhaps the reduced risk of trypanosomiasis associated with the clearance of vegetation? How important is the proximity of markets, and amenities such as schools and clinics?

Such issues are obviously relevant to all areas that are cultivated, but are likely to be particularly important in regions where cultivation is limited to, for example, the riverine *(fadama)* cropping common in the Semi Arid regions; the Wadi and Khor, in floodplain cropping in the very dry areas; or in irrigated cultivation. In all such systems, the areas of human activity are likely to act as islands, or even oases, and any interaction between farmers and pastoralists will be intensified. This will especially be the case if arable farmers themselves own animals, and their crops attract livestock from elsewhere.

In this context, the aggregation of animals in or around extensively cultivated areas may also compound the risks of over-exploitation and land degradation, particularly in the more fragile or ecologically marginal regions, characteristic of the Arid Zones. This is yet another reason to ensure that significant efforts are made in future to more fully understand the increasing interdependence of livestock and human activity; and one that should be viewed with some urgency, given the under-estimation of livestock numbers by official sources. A further consequence of this link is that future plans to combat desertification/degradation should take into account the potential, and possibly synergistic interaction between human population, livestock and over-exploitation.

12.3.2. Inter-Dependence of Livestock and People

There is mounting evidence, endorsed by this study, that conventional distinctions between pastoralists and arable farmers in Africa have become less clear-cut over the years. Whilst such specialist producers are likely to persist in many regions, there is a more general tendency for pastoralists to settle and start growing crops, and for arable farmers to take up animal husbandry. This convergence is indicative of a widespread trend towards the development of mixed farming systems, which is well established across both Semi-Arid and Sub-Humid Zones.

If, as this analysis suggests, there is little distinction between the factors that are associated with pastoralist and village (i.e. farmers') livestock, the question arises as to whether development planners should treat pastoralists as separate from farmers. In regions where livestock numbers are high, such distinctions seem unnecessary, as the undeniable trend is away from pastoralism towards agropastoralism and mixed farming. Adhering to a distinction of decreasing relevance, either through a reluctance to abandon familiar concepts, or perhaps through a distrust of regional overviews, may result in development resources being devoted to denying the inevitable.

Of particular significance is the increasing and widespread importance of 'backyard' livestock, including small ruminants, pigs and chickens. Even if only a few animals are kept by each household, the cumulative effect on abundance in densely populated areas is such that 'backyard' stock can account for a very substantial proportion of total livestock biomass. The size and variety of village livestock populations has gone largely unrecognised by many livestock departments, and their major contribution to household economies is not fully appreciated. As a result, village livestock production has tended to be overlooked in the allocation development resources, in favour of larger and more prestigious livestock species. This imbalance needs to be redressed.

Whilst the trend in the Semi-Arid and Sub-Humid zones is clearly toward the establishment of agro-pastoral and mixed farming systems, this can obviously only happen where it is possible for crops to be grown, either as rainfed, wetland or irrigated agriculture. There are of course very large areas of the arid zone where it is simply too dry for arable agriculture, and animal husbandry is the only productive and sustainable activity possible. These arid rangelands are the preserve of pastoralism, and are likely to remain so for the foreseeable future.

There is no exact boundary between rangeland and farmland, but the limit of rainfed agriculture is generally considered to be around 300mm. The Arid Zone extends to the 500mm isohyet, and thus includes substantial areas of actual or potential arable farmland, as well of extensive areas of pastoral rangelands. It constitutes 73% of the land surveyed in the five countries considered in this study, and accounted for an estimated 41% of total livestock biomass, most of which was under pastoral management (see Table 7). Nevertheless, the primary predictors of distribution and abundance of most livestock populations were cultivation and human activity. Thus, even in the Arid Zone livestock are closely associated with arable land and villages, which implies the existence of some form of inter-dependent linkage between pastoralists and farmers.

13. RECOMMENDATIONS FOR FURTHER WORK

The preliminary analyses presented to OXFAM in ERGO (1994) deliberately adopted an overview approach as the least complex way of exploring the data available, on the basis that if significant results were forthcoming, despite the diversity of areas and conditions covered, then the relationships revealed would be robust enough to have broad applicability.

The present, more detailed, analyses have confirmed the strength of the relationships identified earlier, and demonstrated that they apply for most livestock categories, across all but the most extreme rainfall zones, in both wet and dry seasons.

As is typical of such analyses, though they may answer a number of questions, they raise many more. Various broad issues have been discussed, and suggestions for relevant investigation have been put forward in the previous section. However, there are also a series of more technical topics that are worthy of attention. For example:

i) Does the close link between livestock and human activity apply equally to other livestock producing regions of Africa, particularly those with significant wildlife populations, which may influence the distribution of livestock, or those where management systems have traditionally been less reliant on transhumance as a risk aversion strategy? Is the implied transition towards mixed farming peculiar to the region studied, or is it occurring across the continent?.

ii) What are the consequences of the transition towards mixed farming in terms of livestock productivity, marketing and potential rates of increase?

iii) What are the socio-economic consequences of these changes, particularly in terms of access rights to water, or fodder? Which groups are being most affected?

iv) Are the trends established a temporary consequence of, for example, the droughts that have occurred during the last thirty years, which will eventually reverse as populations recover, or are they a permanent result of increasing human populations?

v) Given that the strength of the relationships identified between livestock and environmental parameters is comparatively weak in the most arid regions, what are the other determinants of livestock distribution in these areas?

vi) Can other sources of environmental information, particularly satellite derived vegetation data be used to predict livestock populations, using the relationships identified here?

vii) Is the suggested under-estimation of livestock resources typical of statistics for other parts of Africa?

viii)What is the economic significance of 'Village' as opposed to 'Pastoral' livestock?

The further studies required to address these questions relate to monitoring, modelling, information collection and analysis, which can be conveniently split into four categories:

a) **To expand the present analyses further, incorporating additional information** - perhaps from other areas for which comparable data are available, such as Senegal, Zimbabwe, Botswana or Kenya, where aerial surveys have been in use for some time; or describing more environmental parameters such as soil type, tsetse, water and topography. It would also be possible to incorporate economic or animal productivity parameters into the dataset as alternatives to biomass.

b) **Sensitivity analysis on identified relationships and development of a livestock and land use model.** For example, what would be the likely consequences of a 10% increase in human population on the numbers of livestock? It should also be feasible to identify regions that are particularly heavily stocked, and thus at risk of over-exploitation.

c) **To initiate socio-economic, economic and livestock productivity studies** specifically designed to investigate the interface between livestock and dense human settlement, to establish the economic importance of 'Village' livestock that appear to have been ignored by earlier assessments, and to establish the transitional impact of mixed farming on pastoral groups who resist the trend.

d) **To initiate a series of monitoring exercises** in key areas to establish whether livestock populations continue to move into areas where natural vegetation is being cleared by expanding cultivation and human settlement. As these would need to be regional in scope, and capable of covering large areas in a way that is repeatable, some sort of remote sensing technique would be required - either low intensity aerial survey, or, perhaps acquisition of satellite imagery to assess percentage cultivation, which could then be translated into livestock densities using the relationships identified in this study.

If the former, it would be appropriate to establish a series of long distance, low intensity sample transects covering all agro-ecological zones across the sub-region. If the latter, then some preliminary work would be required to 'train' the satellite data to the ERGO dataset, as well as some ground truthing to confirm the results. In addition, given the importance of 'Village' animals, some ground truthing would have to be included within the basic monitoring scheme, to allow for the enumeration of this element of the livestock population.

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APPENDIX

1. ERGO DATASET

Details of the ERGO dataset are shown in Table A1, below.

Table A1: Survey Zones included within the ERGO Dataset

Country	Locality**	Agency*	Date	Area Km^2	Grid Area	Livestock[1]		Habitation[2]	Vegetation Cover[3]
						Past	Vill		
Mali	Delta	ILCA	10-80	34,944	83	Ct,Sr,Cm			
	Delta	ILCA	03-81	34,944	83	Ct,Sr,Cm			
	Delta	ILCA	06-82	34,944	83	Ct,Sr,Cm			Ct,Gr,Ow
	Gourma	ILCA	03-83	81,640	82.3	Cm,Ct,Sr			Gr
	Gourma	ILCA	08-84	81,640	82.3	Cm,Ct,Sr		Pa, Vil	All
	Fifth Region	IBRD	07-87	102,137	81.7	All	All	Pa, Vil	All
Niger	NRL	USAID	09-82	81,550	82.3	Cm,Ct,Sr,			
	NRL	USAID	09-85	81,550	82.3	Cm,Ct,Sr		Pa,Vil	All
Sudan	Gezira	IBRD	02-86	50,569	56.3	All	All	Pa, Vil	All
	Gezira	IBRD	03-86	37,969	56.3	All	All	Pa, Vil	All
	Red Sea	OXFAM	03-89	119,900	100	All	All	Pa, Vil	All
	Red Sea	OXFAM	09-89	119,900	100	All	All	Pa, Vil	All
Tchad	Bahr. El Ghazal	IBRD	08-91	59,800	100	All	All	Pa, Vil	All
	ZOP	IBRD	03-93	147,600	400	All	All	Pa, Vil	All
Nigeria	Gongola State	IBRD	07-83	43,875	25	Ct,Sh,Cm	Gt	Pa, Vil	All
	Gongola State	IBRD	03-84	43,875	25	Ct,Sh,Cm	Gt	Pa, Vil	All
	Anambra State	IBRD	05-89	17,675	25	All	All	Pa, Vil	All
	Niger State	IBRD	05-89	59,600	25	All	All	Pa, Vil	All
	National	IBRD	03-90	924,000	400	All	All	Pa, Vil	All
	National	IBRD	09-90	924,000	400	All	All	Pa, Vil	All

[1] Cm = Camels; Ct = Cattle; Sr = Small Ruminants; Sh = Sheep; Gt = Goats; All = Includes Equines

[2] Pa = Pastoralist; Vil = Village

[3] Ct = Cultivation; Gr = Grassland/Grass Cover; Ow = Open Woodland;
All = Bare Ground, Grassland/Grass Cover; Scrub, Open and Dense Woodland; Forest, Cultivation.

* ILCA: International Livestock Centre for Africa. IBRD: International Bank for Reconstruction and Development
USAID: United States Agency for International Development.

** ZOP: Zone d'Organisation Pastorale. NRL: Niger Rangelands Project

2. CALCULATION OF POPULATION DATA

The following tables present density data for Cattle, Small Ruminants, Camels and Livestock Biomass in various rainfall belts. Biomass is calculated using the following conversions: camels = 1 TLU; Zebu cattle = 0.7 TLU; Muturu and Keteku cattle = 0.5 TLU; and small ruminants = 0.1 TLU. Each table contains estimates for wet and dry seasons, and for the calculated annual means. Each table also considers two elements of the populations: 'Total' and 'Pastoral'. The latter represents those animals counted from the air, whilst the former incorporates 'Village' livestock as well as the 'Pastoral' animals.

'Village' livestock are assessed by a combination of air and ground survey techniques which together provide the number of animals per rooftop observed from the air, as well as the number of rooftops counted from the air. These two figures are then combined to give estimates of the number of animals associated with human settlement. Where such 'Village' livestock were estimated, the ground survey data was collected only after any animals had left the settlements for their grazing areas, where they could be counted by the aerial survey teams. Aerial survey teams did not count the animals in settlements, thus avoiding double counting.

Not all surveys included estimates of 'Village' livestock, nor did all surveys count all the species, nor was each area surveyed in both wet and dry seasons. Therefore, within the whole data set, there are different sample sizes (i.e. numbers of grids with information) for each season, species, and element Pastoral' or Village' of the population. Out of the total of 7656 grids contained within the database, 3633 contain data for every livestock parameter, and 5058 contain every 'Pastoral' parameter. Further details of sample sizes are given in Table A2

Table A2: Sample Sizes for Livestock Data

	Numbers of Grids with Data					
Livestock Parameter	**Total**			**Pastoral***		
	Mean	Dry	Wet	Mean	Dry	Wet
Cattle	3633	5977	3633	5058	6666	6055
Small Ruminants	3633	5977	3633	5058	6666	6055
Camels	3633	6024	3633	5058	6666	6055
Biomass	3633	5977	3633	5058	6666	6055

There are thus three tables presented for each livestock species:

a). Unmatched data tables which contain figures representing the means for all the data available for each cell within the table;

b). Matched data tables which contain the mean data from the 3633 survey grid cells for which every parameter is available. These tables thus exclude data from those surveys that were not performed for each season, and which did not include estimates of 'Village' animals;

b). Calculated data tables which contain the 'Pastoral' livestock data for the 5058 grid cells from surveys which assessed all animal numbers in both seasons. The 'Total' livestock element of these tables has been calculated from the proportion of the 'Total' livestock which were 'Pastoral' in each rainfall band of the matched dataset, which was then applied to the observed 'Pastoral' densities.

It is the data from the third of these tables ('Calculated') that have been used in the main body of the report.

Table A3: Cattle Densities by Rainfall Band

Annual Rainfall (mm)	**Cattle Density (No per square kilometre) Unmatched Data**					
	Total			**Pastoral ***		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.00	0.00	0.00	0.00	0.00	0.42
51 - 75	0.02	0.03	0.00	0.01	0.01	0.00
76 - 125	0.16	0.15	0.17	0.13	0.10	0.15
126 - 250	0.79	5.45	0.92	3.07	4.32	3.09
251 - 500	21.10	12.81	20.12	12.97	10.95	13.46
500 - 750	18.78	14.76	18.85	17.22	13.35	16.78
751 - 1000	20.51	16.87	24.08	15.46	11.85	19.03
1001 - 1250	16.97	14.12	19.83	14.79	11.98	17.59
1251 - 1500	10.50	10.58	10.42	8.86	8.92	8.79
1501 - 2000	7.89	8.05	7.72	7.34	7.51	7.18
2001 +	1.91	1.66	2.16	1.41	1.17	1.66

Annual Rainfall (mm)	**Cattle Density (No per square kilometre) Matched data**					
	Total			**Pastoral ***		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.00	0.00	0.00	0.00	0.00	0.00
51 - 75	0.02	0.03	0.00	0.01	0.01	0.00
76 - 125	0.16	0.15	0.17	0.13	0.10	0.15
126 - 250	0.79	0.67	0.92	0.69	0.55	0.84
251 - 500	21.10	22.08	20.12	20.08	21.11	19.05
500 - 750	18.78	18.71	18.85	14.55	14.47	14.62
751 - 1000	20.51	16.93	24.08	15.46	11.89	19.03
1001 - 1250	16.97	14.12	19.83	14.79	11.98	17.59
1251 - 1500	10.50	10.58	10.42	8.86	8.92	8.79
1501 - 2000	7.89	8.05	7.72	7.34	7.51	7.18
2001 +	1.91	1.66	2.16	1.41	1.17	1.66

Annual Rainfall (mm)	**Cattle Density (No per square kilometre) Calculated data**					
	Total			**Pastoral ***		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.00	0.00	0.00	0.00 (na)	0.00 (na)	0.00 (na)
51 - 75	0.02	0.03	0.002	0.01 (39)	0.01 (43)	0.00 (0)
76 - 125	0.16	0.15	0.17	0.13 (81)	0.10 (67)	0.15 (88)
126 - 250	3.51	4.04	3.09	3.07 (88)	3.31 (82)	2.83 (92)
251 - 500	13.63	13.04	14.23	12.97 (95)	12.47 (96)	13.46 (95)
500 - 750	22.23	22.83	21.64	17.22 (78)	17.66 (77)	16.78 (76)
751 - 1000	20.51	16.93	24.08	15.46 (75)	11.89 (70)	19.03 (79)
1001 - 1250	16.97	14.12	19.83	14.79 (87)	11.98 (85)	17.59 (89)
1251 - 1500	10.50	10.58	10.42	8.86 (84)	8.92 (84)	8.79 (84)
1501 - 2000	7.89	8.05	7.72	7.34 (93)	7.51 (93)	7.18 (93)
2001 +	1.91	1.66	2.16	1.41 (74)	1.17 (70)	1.66 (77)

* Figures in brackets are % of equivalent Total Cattle Density, taken from Matched Data (see text)

Table A4: Small Ruminant Densities by Rainfall Band

Annual Rainfall (mm)	Small Ruminant Density (No per square kilometre) Unmatched Data					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	1.84	2.39	1.28	1.41	2.01	3.19
51 - 75	3.02	2.67	3.37	1.95	1.31	2.59
76 - 125	8.35	8.66	8.04	4.91	4.00	5.82
126 - 250	6.35	27.19	4.54	8.62	12.15	9.57
251 - 500	30.71	26.75	34.70	15.65	17.18	18.96
500 - 750	69.06	30.12	69.52	10.79	9.43	10.41
751 - 1000	70.16	70.64	69.38	5.33	6.15	4.49
1001 - 1250	43.55	43.34	43.76	2.09	2.49	1.69
1251 - 1500	64.30	64.20	64.40	0.78	0.94	0.61
1501 - 2000	51.42	49.01	53.83	0.67	0.70	0.64
2001 +	59.99	59.96	60.03	0.09	0.12	0.06

Annual Rainfall (mm)	Small Ruminant Density (No per square kilometre) Matched data					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	1.84	2.39	1.28	1.41	2.01	0.80
51 - 75	3.02	2.67	3.37	1.95	1.31	2.59
76 - 125	8.35	8.66	8.04	4.91	4.00	5.82
126 - 250	6.35	8.16	4.54	5.24	6.49	3.98
251 - 500	30.71	26.71	34.70	16.94	12.53	21.36
500 - 750	69.06	68.59	69.52	11.96	11.50	12.42
751 - 1000	70.16	70.93	69.38	5.33	6.16	4.49
1001 - 1250	43.55	43.34	43.76	2.09	2.49	1.69
1251 - 1500	64.30	64.20	64.40	0.78	0.94	0.61
1501 - 2000	51.42	49.01	53.83	0.67	0.70	0.64
2001 +	59.99	59.96	60.03	0.09	0.12	0.06

Annual Rainfall (mm)	Small Ruminant Density (No per square kilometre) Calculated data					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	1.84	2.39	1.28	1.41 (77)	2.01 (84)	0.80 (63)
51 - 75	3.02	2.67	3.37	1.95 (65)	1.31 (39)	2.59 (77)
76 - 125	8.35	8.66	8.04	4.91 (59)	4.00 (46)	5.82 (72)
126 - 250	10.45	8.47	11.99	8.62 (82)	6.74 (80)	10.50 (88)
251 - 500	28.37	26.31	30.82	15.65 (55)	12.34 (47)	18.96 (62)
500 - 750	62.33	66.72	58.24	10.79 (17)	11.18 (17)	10.41 (18)
751 - 1000	70.16	70.93	69.38	5.33 (8)	6.16 (9)	4.49 (6)
1001 - 1250	43.55	43.34	43.76	2.09 (5)	2.49 (6)	1.69 (4)
1251 - 1500	64.30	64.20	64.40	0.78 (1)	0.94 (1)	0.61 (1)
1501 - 2000	51.42	49.01	53.83	0.67 (1)	0.70 (1)	0.64 (1)
2001 +	59.99	59.96	60.03	0.09 (0)	0.12 (0)	0.06 (0)

* Figures in brackets are % of equivalent Total Small Ruminant Density, taken from Matched Data (see text)

Table A5: Camel Densities by Rainfall Band

Annual Rainfall (mm)	Camel Density (No per square kilometre) Unmatched Data					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.23	0.25	0.21	0.22	0.25	1.50
51 - 75	0.45	0.20	0.70	0.43	0.18	0.67
76 - 125	0.92	1.08	0.76	0.86	1.03	0.68
126 - 250	1.30	0.84	0.93	0.48	0.46	0.44
251 - 500	0.45	0.56	0.24	0.14	0.50	0.10
500 - 750	0.50	0.17	0.48	0.02	0.04	0.01
751 - 1000	0.13	0.13	0.13	0.01	0.01	0.01
1001 - 1250	0.01	0.01	0.01	0.00	0.00	0.00
1251 - 1500	0.00	0.00	0.00	0.00	0.00	0.00
1501 - 2000	0.00	0.00	0.00	0.00	0.00	0.00
2001 +	0.00	0.00	0.00	0.00	0.00	0.00

Annual Rainfall (mm)	Camel Density (No per square kilometre) Matched data					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.23	0.25	0.21	0.22	0.25	0.19
51 - 75	0.45	0.20	0.70	0.43	0.18	0.67
76 - 125	0.92	1.08	0.76	0.86	1.03	0.68
126 - 250	1.30	1.68	0.93	1.24	1.56	0.91
251 - 500	0.45	0.67	0.24	0.38	0.59	0.16
500 - 750	0.50	0.53	0.48	0.05	0.08	0.03
751 - 1000	0.13	0.13	0.13	0.01	0.01	0.01
1001 - 1250	0.01	0.01	0.01	0.00	0.00	0.00
1251 - 1500	0.00	0.00	0.00	0.00	0.00	0.00
1501 - 2000	0.00	0.00	0.00	0.00	0.00	0.00
2001 +	0.00	0.00	0.00	0.00	0.00	0.00

Annual Rainfall (mm)	Camel Density (No per square kilometre) Calculated data					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.23	0.25	0.21	0.22 (96)	0.25 (99)	0.19 (90)
51 - 75	0.45	0.20	0.70	0.43 (96)	0.18 (90)	0.67 (96)
76 - 125	0.92	1.08	0.76	0.86 (93)	1.03 (95)	0.68 (89)
126 - 250	0.51	0.61	0.40	0.48 (95)	0.57 (93)	0.39 (98)
251 - 500	0.17	0.20	0.14	0.14 (83)	0.18 (88)	0.10 (69)
500 - 750	0.22	0.23	0.21	0.02 (10)	0.03 (15)	0.01 (6)
751 - 1000	0.13	0.13	0.13	0.01 (9)	0.01 (9)	0.01 (9)
1001 - 1250	0.01	0.01	0.01	0.00 (17)	0.00 (31)	0.00 (0)
1251 - 1500	0.00	0.00	0.00	0.00 (na)	0.00 (na)	0.00 (na)
1501 - 2000	0.00	0.00	0.00	0.00 (na)	0.00 (na)	0.00 (na)
2001 +	0.00	0.00	0.00	0.00 (na)	0.00 (na)	0.00 (na)

* Figures in brackets are % of equivalent Total Camel Density, taken from Matched Data (see text)

Table A6: Livestock Biomass Densities by Rainfall Band

Annual Rainfall (mm)	Biomass Density (TLU per square kilometre) Unmatched Data					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.41	0.49	0.34	0.36	0.45	2.11
51 - 75	0.76	0.48	1.04	0.63	0.32	0.93
76 - 125	1.86	2.04	1.68	1.44	1.51	1.37
126 - 250	2.50	7.37	2.02	3.50	4.72	3.56
251 - 500	18.30	12.21	17.79	10.79	9.89	11.42
500 - 750	20.56	13.52	20.63	13.16	10.33	12.80
751 - 1000	21.50	19.01	23.93	11.36	8.92	13.78
1001 - 1250	16.25	14.23	18.26	10.56	8.64	12.48
1251 - 1500	13.71	13.76	13.67	6.28	6.34	6.22
1501 - 2000	10.63	10.50	10.76	5.21	5.33	5.09
2001 +	7.25	7.07	7.43	1.00	0.83	1.17

Annual Rainfall (mm)	Biomass Density (TLU per square kilometre) Matched data					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.41	0.49	0.34	0.36	0.45	0.27
51 - 75	0.76	0.48	1.04	0.63	0.32	0.93
76 - 125	1.86	2.04	1.68	1.44	1.51	1.37
126 - 250	2.50	2.97	2.02	2.25	2.60	1.89
251 - 500	18.30	18.80	17.79	16.13	16.62	15.63
500 - 750	20.56	20.49	20.63	11.43	11.36	11.50
751 - 1000	21.50	19.08	23.93	11.36	8.95	13.78
1001 - 1250	16.25	14.23	18.26	10.56	8.64	12.48
1251 - 1500	13.71	13.76	13.67	6.28	6.34	6.22
1501 - 2000	10.63	10.50	10.76	5.21	5.33	5.09
2001 +	7.25	7.07	7.43	1.00	0.83	1.17

Annual Rainfall (mm)	Biomass Density (TLU per square kilometre) Calculated data					
	Total			Pastoral *		
	Mean	Dry	Wet	Mean	Dry	Wet
37.5 - 50	0.41	0.49	0.34	0.36 (88)	0.45 (92)	0.27 (79)
51 - 75	0.76	0.48	1.04	0.63 (83)	0.32 (67)	0.93 (89)
76 - 125	1.86	2.04	1.68	1.44 (77)	1.51 (74)	1.37 (82)
126 - 250	3.89	4.09	3.66	3.50 (90)	3.58 (87)	3.43 (94)
251 - 500	12.24	11.49	13.00	10.79 (88)	10.16 (88)	11.42 (88)
500 - 750	23.66	24.38	22.96	13.16 (56)	13.52 (55)	12.80 (56)
751 - 1000	21.50	19.08	23.93	11.36 (53)	8.95 (47)	13.78 (58)
1001 - 1250	16.25	14.23	18.26	10.56 (65)	8.64 (61)	12.48 (68)
1251 - 1500	13.71	13.76	13.67	6.28 (46)	6.34 (46)	6.22 (46)
1501 - 2000	10.63	10.50	10.76	5.21 (49)	5.33 (51)	5.09 (47)
2001 +	7.25	7.07	7.43	1.00 (14)	0.83 (12)	1.17 (16)

* Figures in brackets are % of equivalent Total Biomass Density, taken from Matched Data (see text)

3. REGRESSION AND CORRELATION ANALYSES

3.1. Graphical Plots

In each case, the data plotted in Section 11.1.1.1. have been 'binned' or grouped into a number of categories, and plotted as means for each category, plus or minus two Standard Errors. This eliminates the confusion that a scatter plot of several thousand points would cause, and gives a preliminary indication of the variability of the livestock data within each category. The calculated regression lines, together with the proportion of variance explained, the sample size and the statistical significance levels are shown at the bottom of each plot.

3.2. Linearised Transformations of Parameters Included in the Analyses

When the livestock biomass data are plotted against environmental or human settlement variables, the lines produced are not necessarily straight, but may be curved in various ways. As the multivariate analysis techniques assume linearity, incorporating some linear and some curvilinear relationships is likely to under estimate the relevance of the curvilinear associations. Thus, in order to assess the statistical relationships between the variables, these curves must first be straightened or 'linearised'.

For all bivariate correlations (between a single livestock parameter and each environmental parameter, a series of curve fitting analyses were run to asses which transformations which gave the best fits. The transformations tested were: Linear, Logarithmic, Power, Inverse, Exponential, Cubic and Quadratic. In all cases, except for rainfall, the Power transformation gave either the best fits, or sufficiently close to them that the disadvantage of using the Power fits were considered to be outweighed by the problems of interpreting either the form or the coefficients (particularly for Quadratic or Cubic equations) of the transformation that gave the best fit.

Accordingly, all parameters in the main analysis except annual rainfall have been logged (Log_{10}). Using the logarithm of annual rainfall did not improve the degree of linearity, because the basic relationship is in the form of an upside down U. This can be straightened by an equation of the form $y=a + bx + c/x$. The constants a,b, and c were calculated using an iterative model provided by the statistical software package used.

3.3. Bivariate Correlations

The bivariate correlations between the various livestock parameters are shown in Table A7 below. The four independent (i.e. predictor) variables most closely related are indicated by the figures in brackets. The significance of each relationship is determined by the value of the correlation coefficient R.

It should be emphasised that nearly all the relationships are highly significant in statistical terms, largely because there are so many points - the threshold value of R at the 1% level is 0.115, with only 1000 points. Theoretically, therefore, in all the relationships plotted, there is considerably less than a one in ten thousand chance that they are false.

In ecological terms, a more intuitively useful measure of significance is the proportion of variance in the dependent parameter explained by variation in the environmental one (R^2). In the authors' view, if this value exceeds 0.2 then the relationship is one that demands serious attention. A value of more than a third suggest a very strong association between the two sets of figures.

Table A7: Bivariate Correlation Coefficients

Independent Variable (x)		Total Biomass (Log TLU/km^2)	Pastoral Biomass (Log TLU/km^2)	Proportion of Biomass which is Pastoral
% Cultivation	R	.7313 (1)	.5183 (1)	-.1875 (4)
(Log Annual Mean)	N	3633	4403	3353
% Grassland	R	-.2402	-.0153	.2308 (3)
(Log Annual Mean)	N	3273	4685	3042
% Grass Cover	R	.3202	.3197 (3)	.2105
(Log Annual Mean)	N	3273	4678	3042
Permanent Habitation	R	.7120 (2)	.2454 (4)	-.4718 (1)
(Log No/km^2)	N	3633	5045	3353
Annual Rainfall (mm)	R	.3283	.0555	-.4033 (2)
(Untransformed)	N	3633	5058	3353
Rainfall	R	.6067 (3)	.4364	-.0531
Linearised for Total Biomass	N	3633	5058	3353
Rainfall	R	.5770	.4615 (2)	.0859
Linearised for Pastoral Biomass	N	3633	5058	3353
% Forest & Woodland	R	.2171	.0455	-.0756
(Log)	N	3633	5065	3353
% Open Woodland	R	.1616	.0772	.0781
(Log)	N	3633	5065	3353
% Forest	R	.2171	.0455	-.0756
(Log)	N	3633	5065	3353
% Dense Woodland	R	.4184 (4)	.1374	-.1424
(Log)	N	3633	5065	3353

Figures in Brackets represent ranked order of correlation. Significance levels all $p << 0.00001$

3.4. Interpretation of the Stepwise Multiple Regression Results - an Example

Two criteria should be noted when assessing these results. The first is the value of R squared, which shows the percentage of the variation in the dependent variable that is explained by the variations in the predictor variables. The threshold value of R squared for statistical significance at the 1% level is 0.0132, assuming 1000 data points. Thus in all the equations shown below, the level of statistical significance is at least 0.001%, and where R squared exceeds 0.03, it is more than 0.00001%. This means that there is less than a one in at least ten thousand chance that these relationships are false.

The second criterion for evaluating the results is the degree to which the R squared value changes with each step in the regression (the figures shown in brackets). If the change is large, then the importance of the added predictor variable is substantial; if it is small, then the added variable contributes little to the explanation of the dependent (i.e. livestock) parameter.

To take the example of the first equation shown in Table 12:

Dependent Variable	Best predictor	2nd Predictor	3rd Predictor	4th Predictor	Other Significant Correlates
Mean Total TLU **R^2=.7112: DF=8,3264**	**+.3600Hab(60)**	+.2997Rain (67)	+.2466Cult(t69)	+.1536GrCov(71)	-Open, +GrLand, +FoWd, -Dense

This shows that the mean annual number of Tropical Livestock Units is best predicted by the number of habitations per square kilometre, which explains 60% of the variation in TLU density. Annual rainfall is the next most significant predictor of TLU per square kilometre, followed by % Cultivation and then % Grass Cover. Biomass density is also positively correlated to % Grassland and % Forest and Woodland, but negatively correlated to % Dense and % Open Woodland, though these are less closely linked to the animal numbers than are the first four predictor variables.

In this example, the addition of rainfall into the equation, after habitation density, adds 7% to the variance in TLU density explained. This suggests that it is quite an important addition, and that rainfall has a reasonably substantial effect on animal number. The addition of % Cultivation, and % Grass Cover, however add little to the explanation of animal distribution as they contribute only a further 2% to the R squared value.

The R squared value of 0.7112 shows that 71% of the variation in TLU densities is explained by the predictor variables within the equation. By implication, therefore, 29% is unaccounted for, and is associated with parameters that are not included within the analyses. The overall significance of this equation, in statistical terms, is, however, astonishingly high, given the number of points (3633) included within the analysis, and is well beyond the range quoted in standard statistical references. There is a probability of one in 10 followed by approximately 300 zeros that this relationship is the result of chance. This should be compared to the 1 in 20 probability that is universally taken to be the threshold at which relationships are 'real'.