MAASAI IMPACT ON KENYA SAVANNA VEGETATION: A REMOTE SENSING APPROACH

A thesis presented by Richard Hugh Lamprey in accordance with the regulations governing the award of the degree of Doctor of Philosophy of the University of Aston in Birmingham.

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To my parents

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SUMMARY

The Serengeti-Mara ecosystem of northern Tanzania and southern Kenya suffered severe losses in woodland cover over the period 1959-1974, caused by fire and elephant destruction. Part of this ecosystem is used extensively by Maasai pastoralists. A number of studies have shown that 'bush encroachment' frequently takes place in areas that are heavily grazed by livestock. The aim of this study has been to examine the relationship between vegetation change, livestock distributions and settlement distributions in a study area of 2750 km^2 in the Mara region. To this end, the study has focused on the integration of data from aerial photography, LANDSAT imagery, systematic reconnaissance flights and ground sampling.

It was found that *Acacia*-*Commiphora* woodlands, and the tsetse flies associated with these woodlands, declined rapidly in the study area over the period 1950-1974 as a result of Maasai burning. However, after the Maasai occupied these areas the woodland cover stabilised and has increased in some places through the regeneration of *Acacia gerrardii*. Tsetse flies are now returning. The implications of these changes are discussed.

The results of LANDSAT digital analysis indicate that grassland cover and greenness decreased along a gradient of increasing cattle density. However, the pattern of grass biomass distribution is affected by the dry season use of the Mara by the Serengeti wildebeest migration. Nevertheless, the use of remote sensing and other methods has proved successful in mapping grazing patterns for the simple rangeland system of the Mara.

It is shown that the Maasai population of the study area is increasing at the rate of 7.5% per annum through immigration resulting from agricultural expansion in Narok District. Increasing pressure is being placed on the Maasai Mara National Reserve and it is suggested that the Maasai range areas cannot support the further influx of Maasai and their stock.

KEY WORDS: MAASAI, VEGETATION, KENYA, REMOTE SENSING.

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CHAPTER 1: INTRODUCTION

1:1 Background

In the 1960s and 1970s many conservation areas in East Africa suffered declines in their woodland areas that were usually attributed to the activities of elephants (e.g. Buechner and Dawkins 1961; Glover 1963; Wing and Buss 1970; Laws 1970; Field 1971; Caughley 1976). The Serengeti-Mara ecosystem of northern Tanzania and southern Kenya was no exception (Lamprey _et al_ 1967; Watson and Bell 1969; Croze 1974a and b), and Norton-Griffiths (1979) has shown that woodland losses in the Serengeti were most pronounced in the northern areas adjacent to the Kenya-Tanzania border and the Maasai Mara National Reserve. Woodland cover in these areas declined by 50% between 1959 and 1972. Norton-Griffiths' analysis of long term monitoring data gathered by the Serengeti Research Institute indicated that these cover losses were closely correlated with the distribution of fire and secondarily related to the dry season use of the area by elephants.

In the Mara an important additional environmental factor is present, namely the Maasai and their livestock. The primary aim of this study is to test the hypothesis that over the past 30 years the woodland cover in the Maasai areas has not declined, or has even increased, through 'bush encroachment' following heavy grazing (Heady 1960; Walter 1964; Werger 1977; Barkham and Rainy 1976; Huntley 1982). Bush encroachment is considered to be a response of woodland to the lower fire frequency associated with increased herbivore offtake (Daubenmire 1968a; Vesey-Fitzgerald 1972; Vogl 1974; Lock and Milburn 1971; Norton-Griffiths 1979).

With the removal of fire, tree survival is further promoted by a reduction in water and nutrient competition from herbaceous species (Werger 1964; Strang 1973; Walker and Noy-Meir 1982; Walker in Pellew 1983). On the basis of this mechanism Pellew (1981) tentatively attributes the presence of mature _Acacia tortilis_ trees in the Seronera area of the Serengeti to a temporary suppression of fire by Maasai livestock grazing several decades before the Serengeti was gazetted as a National Park. In the Mondoro region of Zimbabwe bush encroachment has been associated with an increase in human and cattle populations (Williamson and Keech 1983). Similarly, Skovlin and Williamson (1978) have used aerial photographs to demonstrate that bushland cover is increasing in heavily grazed East African coastal savannas.

In this project changes in woody vegetation, herbaceous cover, livestock grazing intensities and human population have been studied using the three-tier approach to environmental monitoring suggested by Gwynne and Croze (1975). This approach involves the integration of data obtained on the ground (tier 1) with data gathered by systematic reconnaissance flights (SRFs) (tier 2) and information derived from remote sensing techniques (tier 3). By applying this approach, this investigation of the impact of pastoral practices on the Mara woodlands can be split into the testing of two distinct hypotheses.

Hypothesis 1: that woodland losses are confined to areas from which livestock have been excluded and that bush encroachment is taking place in areas of high livestock stocking densities.

Hypothesis 2: that those areas utilized by livestock have a significantly lower herbaceous cover and biomass throughout the year than areas from which livestock are excluded.

According to Naveh (1966) "bush encroachment is without doubt the most serious threat to the productivity of East African ranges". A number of studies have revealed that once bushland becomes established there may be a marked decline in grassland productivity (Pratt and Knight 1971; Breman 1982; Barnes 1982), but there appears to be some confusion in recognizing whether the decrease in productivity is due to the heavy grazing or to the increased woody vegetation cover. There remains no doubt, however, that once bushland is removed grassland productivity will increase as a result of the reduced competition from woody vegetation (Pratt and Gwynne 1977). Bush encroachment is often followed by an invasion of tsetse flies that render these areas unsuitable for livestock (Ford and Clifford 1968; Skovlin and Williamson 1978). At a time of increasing land use pressure from pastoralists, the understanding of bush encroachment is therefore of vital importance to the conservation of grazing resources. It is hoped that this study will shed light on some of the mechanisms involved and on the complex dynamics of savanna woodland communities that are grazed and browsed by both domestic and wild herbivores.

For this project a study area has been selected within the Serengeti-Mara ecosystem that shows a well defined livestock stocking gradient. The physical characteristics of the study area, and the ecological pressures acting on the woodlands, are described in Sections 1:2-1:4. In Section 1:5 an inventory of all available remote sensing and aerial survey data is presented, with reference to which the testing of the hypotheses above is explained in Section 1:6.

1:2 The Study Area

The Serengeti-Mara ecosystem, for which a general description has been given by Sinclair (1979a), comprises approximately 30,000 km^2 of woodland and grassland savanna straddling the Kenya-Tanzania border and lying just to the west of the Great Rift Valley (see Fig. 1:1). It encompasses the renowned Serengeti National Park of Tanzania and the Maasai Mara National Reserve of Kenya. The ecosystem boundaries delimit the yearly movement patterns of the largest biomass component, the migratory wildebeest (Pennycuick 1975). On the basis of this definition (Gwynne and Croze 1975) the ecosystem extends into the Maswa Game controlled area (of 'Sukumaland'), the Ngorongoro Game Conservation area of Tanzania, and the western Loita plains of Kenya. Sinclair defines the northern boundary as the Talek river of the Kenya Mara but technically this border lies further to the north (see Fig. 1:1), since the Serengeti wildebeest 'migration' spills over into this area every dry season, from early July until late October (Pennycuick 1975; Stelfox et al 1980).

For this project a study area has been selected that lies within this northern portion of the ecosystem (Fig. 1:2, Plate 1:1). A pronounced gradient of grazing intensity runs from the heavily utilized north-eastern quarter of the study area to the south-western quarter lying within the Maasai Mara National Reserve, from which livestock are excluded. During the course of the study it became clear that the greatest human pressure on the game reserve originates from this area, and it has been possible to make some tentative predictions concerning the future integrity of the Maasai Mara National Reserve as an effective conservation unit.

The study area of 2750 km^2 forms a rectangle with corner co-ordinates at (35°00'E, 1°02'S), (35°31'E,1°02'S), (35°00'E,1°30'S) and (35°31'E, 1°30'S). This area represents a self-contained Maasai grazing system. To the north it is bordered by the land unit of the agricultural Kipsigis tribe, to the east by the comparatively waterless Loita plains and recent wheat development schemes, to the west by the physical barrier of the Siria escarpment and to the south by the Maasai Mara National Reserve. The study area is shown in the context of its immediate surroundings in Fig. 1:2 and Plate 1:1.

1:3 The Physical Environment of the Study Area

1:3:i Geology, Topography and Soils

The geology of the area has been described by Williams (1964) and although no detailed soil maps exist, an exploratory map has been prepared by Glover (1966). The soils of the area are currently being mapped by the Kenya Soil Survey (Weeda, pers. comm.).

The topography and drainage of the area are shown in Fig. 1:3. This 3-dimensional representation has been prepared using the GINO-SURF graphics option available on the University of Oxford VAX computer. Details of the construction of this figure are given in Appendix B. Reference should be made to this figure in the following discussion, and the place-names shown will be referred to throughout this thesis.

The north-eastern quarter of the study area is dominated by the quartzite hills Aitong (2060 m), Kipleleo (2190 m), Bardamat (2120 m), Ol Kinyie (2270 m), Ol Doinyo Lalagalesho (2220 m) and Ol Doinyo Olenabala (2010 m), which rest on residual hill masses in the surrounding peneplain. The Lemek valley, with its high concentration of Maasai settlements, runs ENE-WSW through this range, Ol Doinyo Lalagalesho and Ol Doinyo Olenabala forming the northern wall of the valley, and Ol Kinyie the southern. In this study this complete range of hills will be referred to as the 'Lemek hills'. The soils of this area are shallow, sandy and rocky. From this quarter the study area gently slopes south-west at a gradient of approximately 1:100, and the drainage follows this direction. The central plains are composed of a weakly alkaline volcanic phonolitic tuff, derived from tertiary-recent volcanic activity in the Mau range to the north east of the study area. These poorly-drained tuffs ('black cotton soils') cover a sub-miocene surface. To the south of the Talek river the basement system of quartzites, gneisses and schists is exposed. This area is also shallowly overlain by phonolitic black cotton soil. The most dominant physical feature to the west is the Siria escarpment, rising to 200-300 m above the Mara plains, which represents a fault in the basement system. The erosion of the escarpment and the 'trans-Mara' country to the west has been retarded by a thick mantle of precambrian intrusive granite of the 'Nyanzian system' (Saggerson 1972). This region in the north-west corner of the study area has the appearance of a high plateaux. Finally, to the south-eastern corner of the study area lies the northern tip of the Siana range of hills, which are in effect the foothills of the Loita hills. Kaitapini (2010 m) and

Ropile (1980 m) are the only individual hills of this range that fall within the study area, and like the Lemek hills, they are quartzite in composition.

1:3:ii Hydrology and Drainage

A useful description of the drainage is given by Glover (1966). The study area drains to the south west and all watercourses eventually join the Mara river, which itself discharges into Lake Victoria 100 km to the west of the Maasai Mara National Reserve. The Mara river originates as the Amala and Nyankoris to the north which are fed by numerous small tributaries from the Mau range and Kipsigis area. The Mara flows south westwards along the base of the Siria escarpment but breaks away to the south at the position of the upper Mara bridge on the western edge of the study area. The area delimited by the Siria escarpment, Mara river and the Tanzania border is termed the 'Mara Triangle'. Reference to this important area will be made throughout this thesis. The Mara region is the most easterly catchment area of the Lake Victoria basin. The Loita plains are drained via the Uaso Ngyiro river into swamps to the north of Lake Natron in the Rift Valley.

In the Mara area the largest tributary of the Mara river is the Talek river, which drains the northern Siana hills and western Loita plains through two tributaries, the Kaimurunya and Ol Sabukiai. Closer to the confluence of the Talek to the Mara (altitude 1500 m) two branches of the Talek, the Olare Orok and the Jagartiek drain the Lemek valley and central plains.

The availability of water has been a major factor in determining the distribution of the Maasai. All of the watercourses described above held water throughout the year of the fieldwork studies, although in the Olare Orok, Jagartiek, Kaimurunya and Ol Sabukiai rivers this water was confined to stagnant pools in the dry season. According to the Maasai these tributaries dried up completely in drought years.

Aside from the Mara river and the Talek river, the most important source of permanent freshwater in the study area has been the series of springs arising from the bases of the Lemek hills, and it was to this area that, for the greater part of this century, the Maasai were confined. Until the early 1960s the Maasai Mara National Reserve and the bushlands lying along the Mara and Talek rivers were infested by tsetse-flies (Glossina spp) which prevented the use of these water supplies by livestock (Lewis E.A. 1935; Beaumont 1945; Darling 1960).

1:3:iii Climate of the Serengeti-Mara Ecosystem

The seasonal climatic changes in East Africa are loosely associated with the north and south movement of the Intertropical Convergence Zone (ITCZ), a zone of low pressure which lags six weeks behind the zenith sun as it moves across the equator (Brown and Cocheme 1973). The ITCZ reaches its northern limit in the Sudan in late July and its southern limit in Zimbabwe in late January. In its southward movement the zone crosses the Serengeti-Mara ecosystem in November bringing the 'short rains', which may continue and merge into the 'long rains' of March-May associated with the northern movement of the ITCZ (Norton-Griffiths et al 1975; Sinclair 1979; Epp and Agatsiva 1980). The rainfall distribution is therefore weakly bimodal, and the seasonal year is considered to begin in November (Sinclair 1979b).

The rainfall pattern in the Serengeti-Mara ecosystem is strongly influenced by the modifying effects of the Ngorongoro Crater highlands, which impose a rain-shadow on the south-eastern plains of the Serengeti. The pattern is also influenced by the local weather systems associated with Lake Victoria which markedly increases wet and dry season precipitation in the northern Serengeti and the Mara. It is this differential rainfall within the ecosystem that is responsible for the northward movement of the migratory herbivores in the dry season as they seek fresh herbaceous growth.

The Maasai Mara National Reserve and the study area lie within Eco-climatic Zone IV (or Ecozone IV), the semi-arid to sub-humid zone of Pratt and Gwynne's (1977) rangeland classification, and the vegetation closely matches their description of vegetation for this zone. Although Sombroek _et al_ (1980) also classify the Mara as belonging to Ecozone IV they draw attention to the fact that the use of the climatic index of Thornthwaite (1948) to classify rangeland areas has caused some confusion because Thornthwaite changed his method of calculation soon after his 1948 publication (e.g. Thornthwaite and Mather 1957). According to Sombroek _et al_ (1980) "in many cases the boundaries of the ecological maps ... do not correspond with the moisture indices given in the legend", and they therefore use the rainfall/potential evaporation ratio as the climatic index for their Eco-climatic Zone map (Brown 1977). Using the 1948 Thornthwaite index, Norton-Griffiths _et al_ (1975) place the Mara firmly in Ecozone III, the sub-humid zone, but for the purpose of this study an Ecozone IV classification appears more appropriate. The use of the correct classification is important for estimating the carrying capacity of the area (see Chapter 10).

A weakly pronounced rainfall gradient extends east-west across the study area. The Loita plains to the east (lying in Ecozone V) receive approximately 700-800 mm per annum. The western areas, more strongly influenced by the Lake Victoria weather system and the orographic effect of the Siria escarpment, receive about 1000 mm per annum. Rainfall isohyet maps for the area have been produced by Norton-Griffiths _et al_ (1975), Glover (1966), Ministry of Agriculture (1977) and Epp and Agatsiva (1980), all of which show this gradient although the positions of the isohyets vary considerably from one report to another.

Reliable rainfall records have been kept at the district administrative centre of Narok, located 50 km to the east of the study area, since 1914 and at the tourist centre of Keekorok, 20 km to the south, since 1968. Additional often incomplete records covering periods from the 1950s to the 1970s are available from seven other stations in the area; Lemek (1968-81), Kipleleo (1955-60), Mara Serena (1974-78), Governer's Camp (1974-81), Aitong (1971-present), Emarti (1974-75) and Ololunga (1973-present). Potential evaporation data are available from Narok only. The mean monthly rainfalls for Aitong, Keekorok, Lemek, Ololunga, Governor's Camp and Mara Serena are shown in Figs. 1:4a)-c). These data are also presented in Appendix C. A climatogram for Narok, showing the level of soil water available for plant growth is presented in Fig. 1:5; the potential evaporation figures are provided by Woodhead (1968) and have been converted to potential evapotranspiration (PET) according to the method of Brown and Cocheme (1973). The growing season is assumed to start when the rainfall exceeds 0.5 PET (FAO 1978).

1:4 The Biotic Environmental - Woodland Dynamics in the Serengeti-Mara Ecosystem

The woodlands of the Serengeti-Mara ecosystem are adjusting to two major and relatively recent ecological perturbations:

1) The immigration of elephants into the ecosystem: in the early 1960s widespread agricultural expansion in the areas to the north and west of the Serengeti and Mara forced large numbers of elephants into the ecosystem (Norton-Griffiths 1979; Glover and Trump 1970) resulting in severe woodland destruction in the northern areas (Lamprey *et al* 1967). Similar agricultural expansion has been taking place in Sukumaland to the south-west (Kurji 1976).

2) The eradication of rinderpest: following the eradication of the ruminant disease rinderpest in 1963 the wildebeest population of the Serengeti has increased six-fold, from 250,000 to the present 1.4 million (Sinclair 1979c). This has been a direct result of an extensive and successful programme of livestock immunization against rinderpest in areas surrounding the ecosystem (Atang and Plowright 1969). Rinderpest had become endemic in the wildebeest population since the rinderpest panzootic of the 1890s and became known as 'yearling disease', since yearling calves often succumbed in the dry season having lost the immunity acquired from

their mothers (Talbot and Talbot 1963). Until 1969 the Serengeti wildebeest migration was entirely confined within the Serengeti. However, the increase in the Serengeti wildebeest population has led to an expansion of their northern dry season range such that, after 1969, the migration spilled over into the Mara of Kenya (Pennycuick 1975). The Mara area has its own separate population that moves between the game reserve in the dry season and the northern Loita plains in the wet season (see Chapter 10). This population has also increased, from approximately 20,000 in the early 1960s (Darling 1960; Stewart and Talbot 1962) to about 100,000 in 1979 (Stelfox _et_ _al_ 1980). Another factor contributing to the 'eruption' of the wildebeest population has been the increase in dry season rainfall over the 1970s (Sinclair 1979c), which stimulated additional grass production over the period of the year when the wildebeest population is limited by its food supply. This increase of the wildebeest population has resulted in a lower fire frequency through the 1970s leading to a rapid regeneration of _Acacia_ species in some areas (Pellew 1981).

Norton-Griffiths (1979) and Pellew (1981) have presented models to clarify the relationship between grazers, browsers and woodland in the Serengeti. The processes can be described thus. In the Seronera test area in the Serengeti, bull elephants have been destroying mature _Acacia tortilis_ trees (Croze 1974a). The decrease in fire frequency through heavy grazing offtake by wildebeest has led to extensive _A. tortilis_ regeneration. However, none of these young trees are being recruited into fire-resistant height classes (> 3 m tall) because of high browsing pressure by giraffe. They are therefore trapped in a fire susceptible phase.

The research of Dublin and myself indicates that there are some marked differences in the way the woodlands of the Mara and Seronera area are responding to increased wild herbivore grazing. Nevertheless the models and observations described above form a useful base from which to investigate the impact of Maasai livestock on the vegetation.

1:5 Systematic Reconnaissance Flight and Remote Sensing Data of the Study Area

1:5:i Systematic Reconnaissance Flights (SRFs)

The importance of the Maasai Mara as an extension of the Serengeti was recognized by the Serengeti Research Institute in the 1960s, and their reconnaissance flights were extended across the Kenya-Tanzania border as far north as Aitong. With the exception of those results which have been published (e.g. Pennycuick 1975) none of these data have been available for this study; following the closure of the Tanzania-Kenya border in 1977, there has been no opportunity to visit the Research Institute. Furthermore, the Institute has been in a state of hibernation since the mid-1970s for lack of funding. It is also probable that, even had these data been available, the 10 x 10 km UTM grid-system employed by the Serengeti Ecological Monitoring Unit would have proved too 'coarse' to reveal any but the largest scale ecological trends in the 2750 km^2 study area.

In 1977 the Kenya Rangeland Ecological Monitoring Unit (KREMU), a monitoring branch of the Kenya Government, began a programme of systematic reconnaissance flights in Narok District (Stelfox _et al_ 1981). Data were gathered on a 5 km UTM grid base, which has proved ideal for a detailed analysis of wild and domestic herbivore distributions.

The aerial counting methods follow the systematic procedures derived by Jolly (1969) and described by Norton-Griffiths (1978). Initially the area was surveyed every three months but in 1979 these 'recce flights' were undertaken every month (Stelfox _et al_ 1980). The SRF information from 1979 has proved invaluable in this study, and a detailed account of the data acquisition and analysis procedure is given in Chapter 5.

1:5:ii Aerial Photography

The paucity of long term SRF data has been compensated for by the abundance of commercially available aerial photography of the Mara area. Details of this photography are given in Table 1:1. With the exception of the 1983 photography, which was obtained for this project, these sets of complete stereocoverage photography were contracted by the Directorate of Overseas Surveys and the Survey of Kenya for the construction and updating of the 1:50,000 scale topographic maps of southern Kenya.

1:5:iii 1983 Aerial Photography

The 1983 photography of 15% systematic strip coverage was acquired for this study in August 1983. Funding for this photography was kindly provided by the New York Zoological

Society and the survey was conducted and generously subsidized by the Kenya Rangeland Ecological Monitoring Unit as a photographic equipment-testing exercise. The aircraft, a twin-engined Partenavia P-68B carried 4 cameras as detailed in Table 1:1. The photographic interval was determined using a 'driftmeter' mounted in the floor of the aircraft below the forward passenger seat and very accurate navigation was achieved with the aid of a Global Navigation System continuously referenced to prominent ground-features along the flight lines. A flying height of 2460 m a.s.l (8000') was maintained throughout the flight to give photographic image scales ranging from 1:5000 to 1:25,000. These scales were considered to give the optimum combination of detail and coverage. Complete photo overlap has not been achieved for all flight lines for all cameras, but the use of 4 cameras has ensured that the flight lines have no gaps, and that much of the photography can be examined stereoscopically. The flight diagram fot this photography is shown in Fig. 7:1.

Two additional aerial surveys were carried out. The first in June 1982, funded by the Regional Remote Sensing Facility was a reconnaissance exercise to familiarize my fellow passenger Dr Dean Graetz and myself with the study area. A Cessna 210 light aircraft was hired for this purpose. The second survey was undertaken in October 1983 to obtain 35 mm oblique aerial photographs along systematically positioned flight lines. The photographs were taken through the window of a Cessna 182 flying at 500 m a.g.1. The information obtained from these oblique photographs was used to update the vegetation map of the study area produced by stereo-interpretation of the 1974 photography. Further details of this survey are given in Chapter 6.

1:5:iv Maps

The area has been topographically mapped at a scale of 1:50,000 by the Directorate of Overseas Surveys. Two series are available, compiled from the 1950 and 1974 photography respectively. The latter series is of excellent quality, with a 20 m contour interval. The 1 km UTM projection on these maps was used as a data store for the settlement distribution exercise. The study area is very conveniently covered by 4 of these map sheets, series Y731, numbers 145/1,2,3 and 4, although a 2 km strip along the eastern edge lies within 146/1 and 3.

A map of 1:250,000 scale has been prepared for Narok District, using 1961 and 1974 photography (Series Y503 No. SA-36-8). The contour interval is 200 m. This map was used for navigation during the aerial surveys.

A number of other unpublished maps have been produced for the Mara by workers of the Kenya Veterinary Department and the Tsetse Survey and Control Organization operating in the Mara in the 1950s and 1960s. Although the tsetse distribution maps obtained from the Kenya Veterinary Department have proved very useful, the other maps do not provide any additional information to that which can be obtained from the 1950 and 1961 aerial photography.

1:5:v Satellite Imagery

The launch of the first LANDSAT satellite (originally called ERTS-1) by NASA in 1972 heralded the arrival of a powerful new tool for ecological monitoring (Carneggie et al 1974), and the 18 day repetitive coverage of LANDSAT has been described as one of the systems main advantages (NAS 1978). However, the acquisition of closely sequential imagery of Eastern Africa has not been possible for two reasons - (Gwynne 1977):

a) As for most areas of the world high cloud cover tends to render a large proportion of the imagery relatively useless,

b) LANDSAT satellites passing over eastern Africa are not within range of a receiving station. In order to conserve the life of the onboard tape-recorder on which imagery was stored for later transmission to earth, the satellites were 'switched on' by NASA only at intermittent intervals.

A detailed description of the operation of the LANDSAT system is given in Chapter 9.

The LANDSAT satellites 1, 2 and 3, operational throughout the 1970s each followed a sun-synchronous orbit with a repeat interval of 18 days. The imaging of a 185 km x 185 km scene took 29 seconds at approximately 9.30 a.m. local time, and each area of the earth's surface has a corresponding row and path number associated with it.

The Mara lies in the overlap zone between row 61, paths 182 and 181. Frames from 181/61 effectively cut off much of the Maasai Mara National Reserve and therefore scenes from 182/61 were selected. Although a small south-east portion of the study area was excised by this selection, this was not considered drastic. Only Maasai movements and livestock distributions to the west of Bardamat hill, in the 1000 km^2 area corresponding to the Maasai

Koyake Group Ranch (see Chapter 2), have been considered in the LANDSAT rangeland evaluation.

Of the five cloud-free scenes from 182/61 immediately available as computer compatible tapes from the EROS Data Centre in America, three, dated 24/6/75, 17/8/75 and 21/12/75 were considered suitable for digital analysis for this study. It was felt that the digital analysis of sequential imagery from a single year was a much more useful exercise than attempting to interpret trends over a wider time-span. Thus the fate of herbaceous green biomass with respect to herbivore distribution could be traced through that year and the 1974 aerial photography could be used as photo-based 'ground-truth' for settlement and woodland distribution.

There are major difficulties in using data that have not been gathered synchronously. Without a continuous and regular sequence of data concerning the distribution and abundance of the different agents of woodland change, it has not been possible to apply the multiple regression techniques of Norton-Griffiths (1979) to investigate the response of woodlands to Maasai pastoral activities. Only three years of cattle, smallstock and wildebeest distribution data, and one year of elephant and giraffe data are available to correlate against information on woodland changes covering the 33 years of the aerial photography. The use of this KREMU systematic reconnaissance flight data of 1979-1982 has therefore demanded great caution.

There are also difficulties in the estimation of grass biomass and cover from the LANDSAT data of 1975, a year in which there is no ground data whatsoever on the absolute values of these parameters.

The limitations of the various analysis techniques are discussed in the context of their applications.

1:6 Testing the Hypotheses

Using the data described above, combined with a programme of ground sampling, the two hypotheses presented in section 1:1 were tested using the following procedure:

1. The distribution of Maasai settlements was determined for each set of aerial photography. The 1983 vertical aerial photography systematically covered only 15% of the study area, and the distribution of settlements for this year was therefore recorded on the ground and from the air in the reconnaissance survey of June 1982 and the oblique airphoto survey of October 1983 (Chapter 4).

2. Mathematical models were derived to obtain estimates of livestock stocking densities from the settlement distribution maps. These estimates were then tested against those obtained from KREMU SRFs (Chapter 5).

3. Dot-grid analysis of each set of aerial photography was conducted to assess woodland change along the gradient of grazing intensity (Chapters 6 and 7).

4. The tree-age distribution structure was determined along the gradient of grazing intensity by ground sampling methods to

examine the relationship between tree survival and grazing pressure (Chapter 8).

5. LANDSAT imagery digital processing techniques were used to examine the relationship between stocking density and relative estimates of green biomass and cover (Chapter 9).

In this study data have been gathered on a 5 km and 10 km UTM grid base so that data from all sources are spatially compatible (Western 1979). Statistical conventions that have been used in the text are explained in Appendix A. This appendix should be consulted before proceeding further with this thesis. To maintain the continuity of the text, all figures, plates and tables (except Table 6:1) have been placed (in that order) at the end of each chapter.

Fig. 1:1. The Serengeti-Mara ecosystem and the position of the study area. The dashed line represents the limits of the movements of the Serengeti and Loita wildebeest populations. The stipled areas are high ground. Adapted from Sinclair (1979a).

SNP = Serengeti National Park
MMNR = Maasai Mara National Reserve.

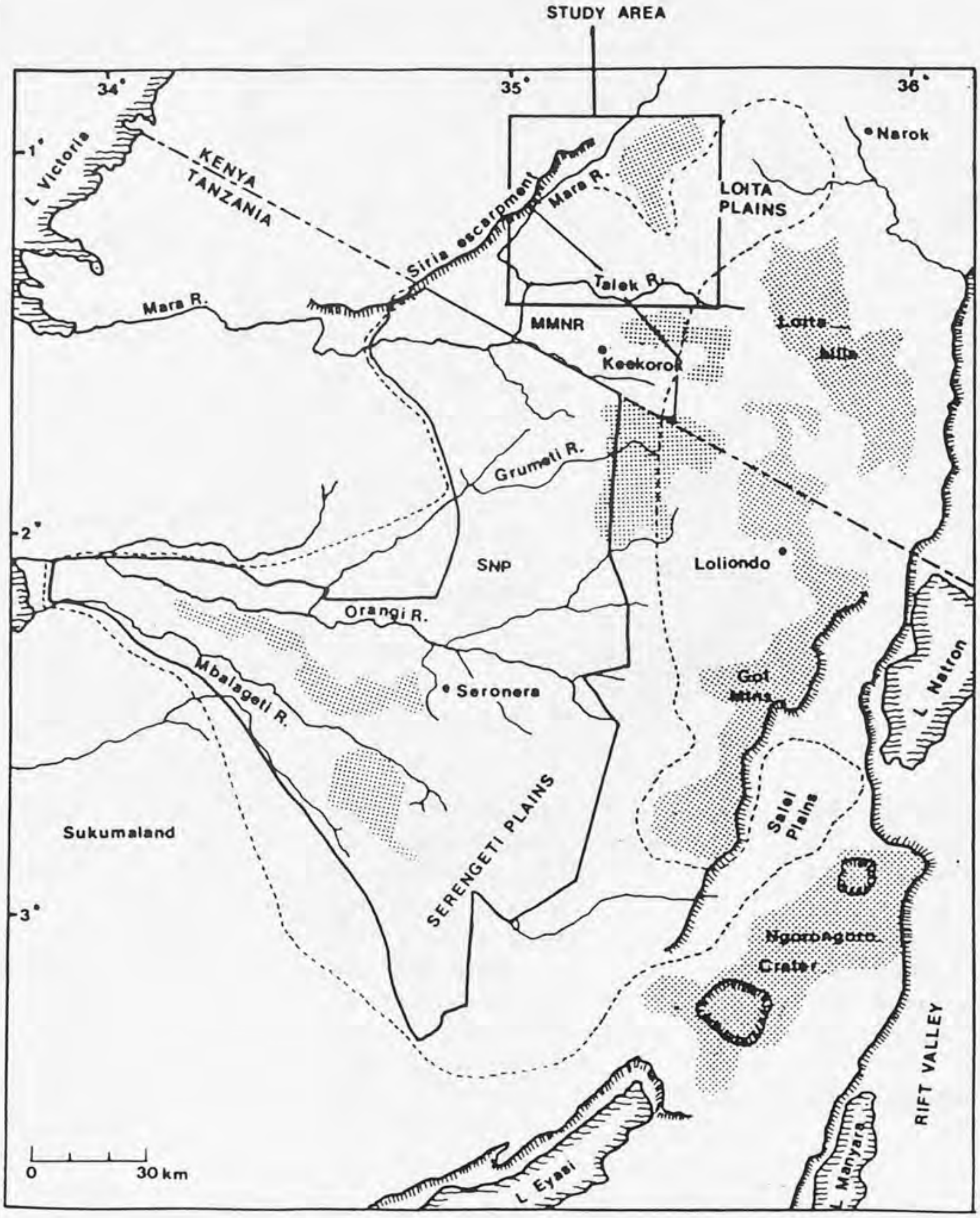
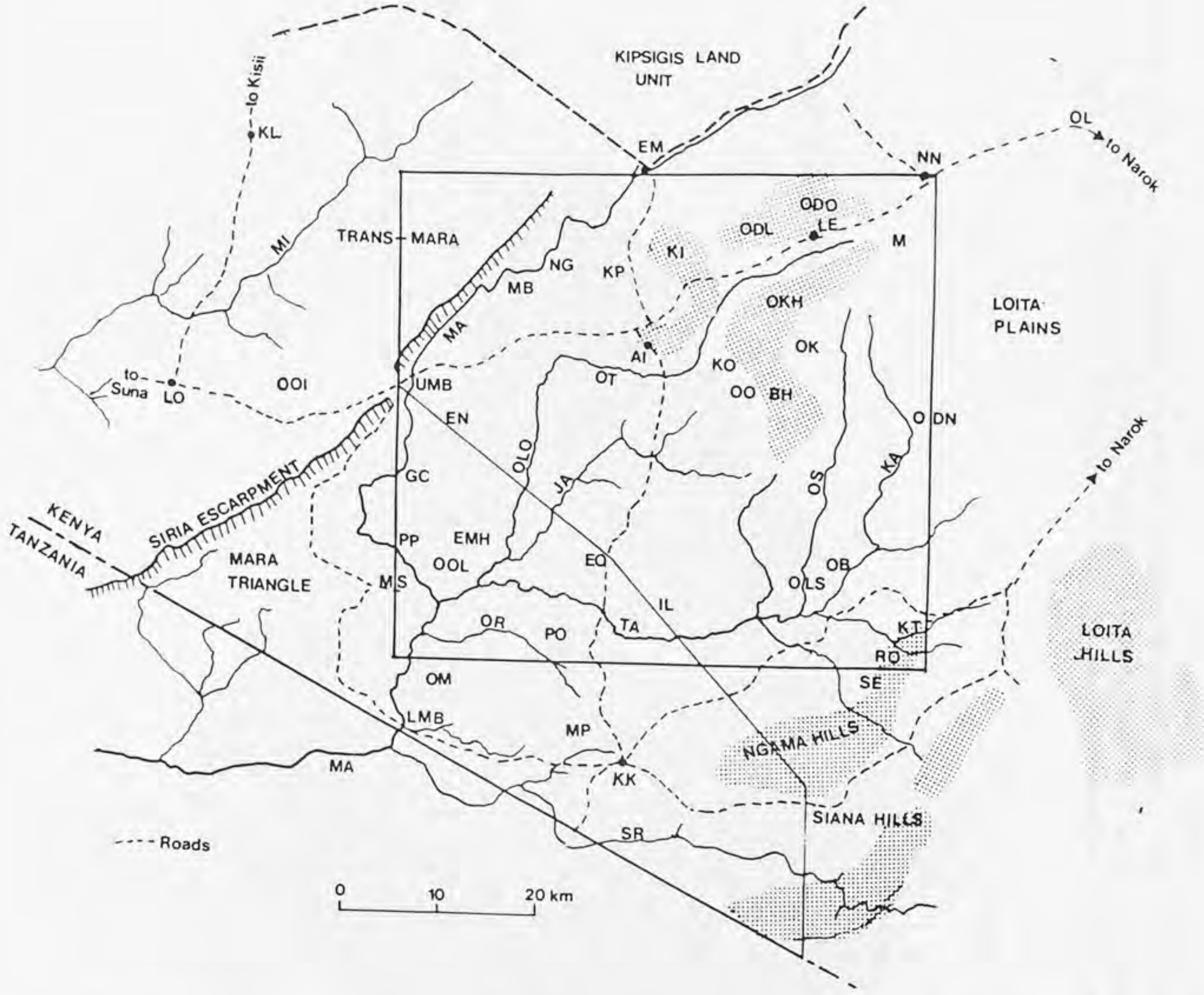


Fig. 1:2. The study area in the context of the Mara region. Place names have been coded for the identification of areas and features described in the text.



AI	Aitong
BH	Bardamat
EM	Emarti
EMH	Emarti hill
EO	En Doinyo Oloip
EN	Enkikwe
GC	Governor's Camp
IL	Ilbaan
JA	Jagartiek
KA	Kaimurunya
KT	Kaitapini
KK	Keekorok
KL	Kilgoris
KP	Kiloriti plain
KI	Kipleleo hill
KO	Koyage
LE	Lemek
LO	Lolgorien
LMB	Lower Mara bridge
MB	Mara Buffalo
MA	Mara river
MS	Mara Serena Lodge
M	Medekata hill
MP	Meta plains
MI	Migori river
NG	Ngirende
NN	Ngorengore
OLO	Olare Orok river
OLS	Olare Sambu
ODL	Ol Doinyo Lalagalesho
ODO	Ol Doinyo Olenabala
OO	Ol Doinyo Orinka
OR	Ol Keju Ronkai river
OK	Ol Kinyie
OKH	Ol Kinyie hill
OM	Ol Misingiyoi
OOI	Oloirien
OB	Oloiburmurt hill
OL	Ololunga
OOL	Ongata Olduroroi
OS	Ol Sabukiai river
OT	Oltorotua river
PP	"Paradise plain"
PO	Posee plain
RO	Ropile hill
SR	Sand river
SE	Segenani hill
TA	Talek river & Talek
UMB	Upper Mara bridg

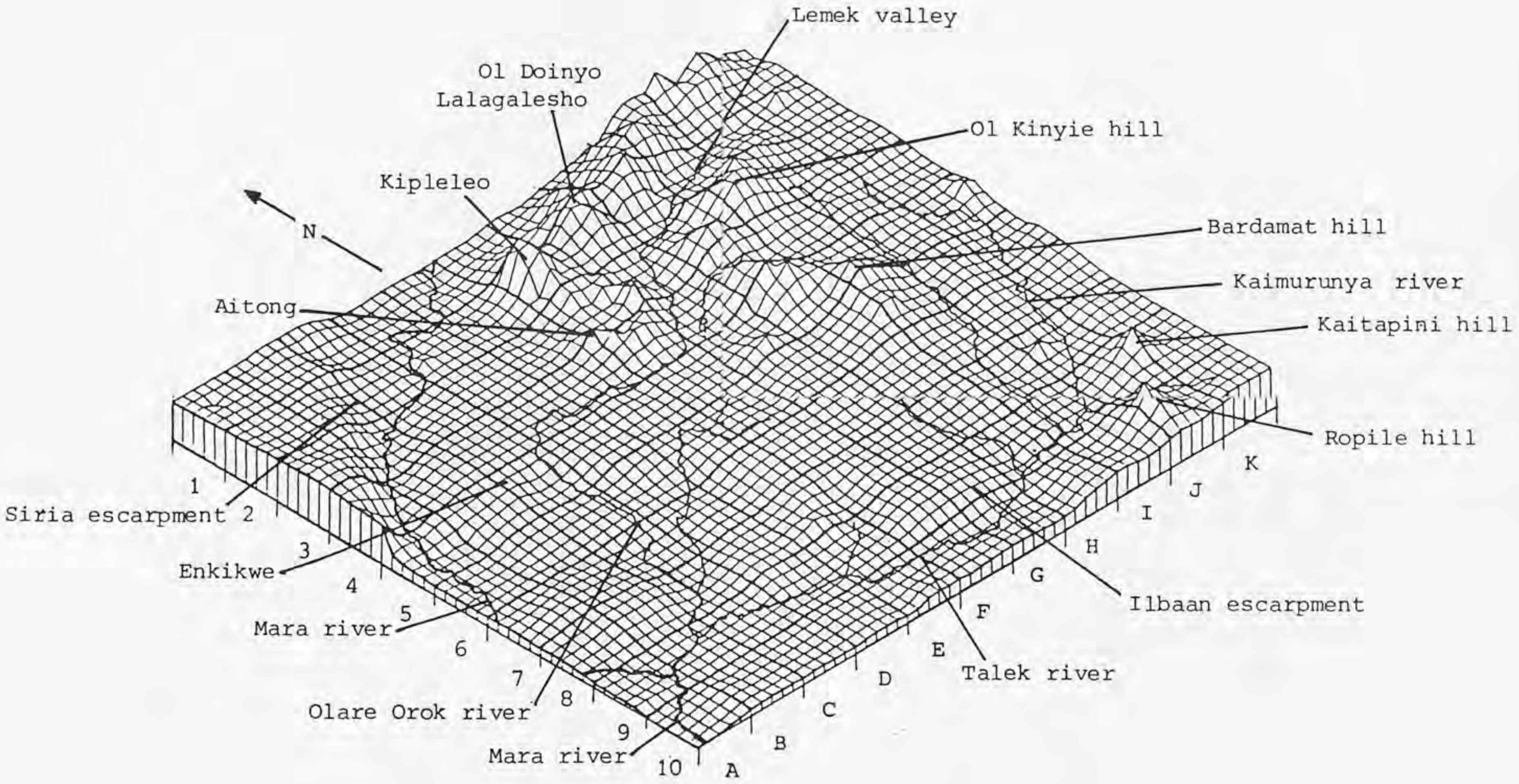
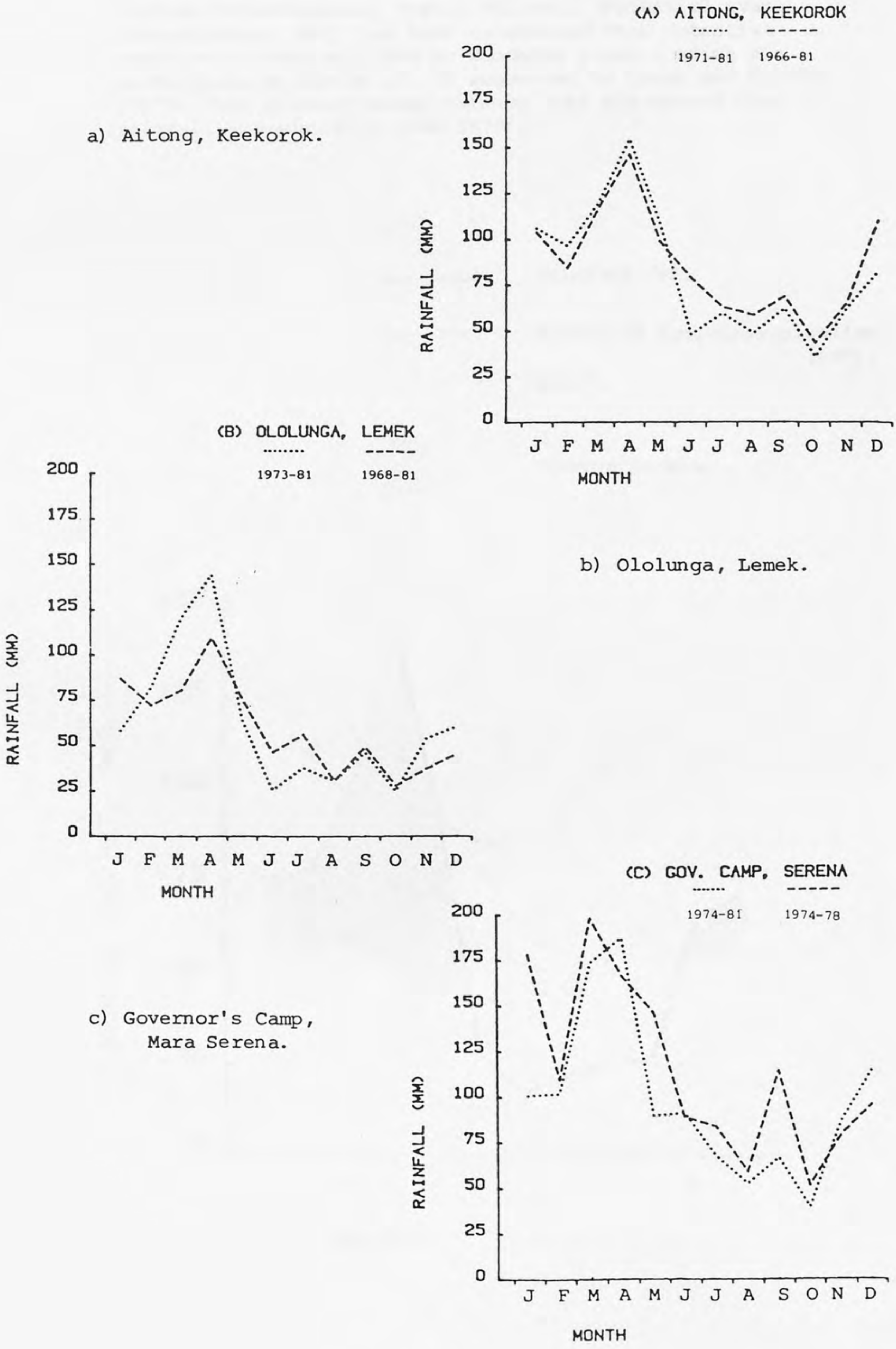


Fig. 1:3. A 3-dimensional topographic representation of the study area prepared using GINOSURF graphics. The study area is 'viewed' from the south-west corner. The smallest grid units are 1 km^2. The vertical scale ('altitude') has been greatly exaggerated to emphasize the relief (horizontal scale = 1:500,000: vertical scale = 1:100,000).

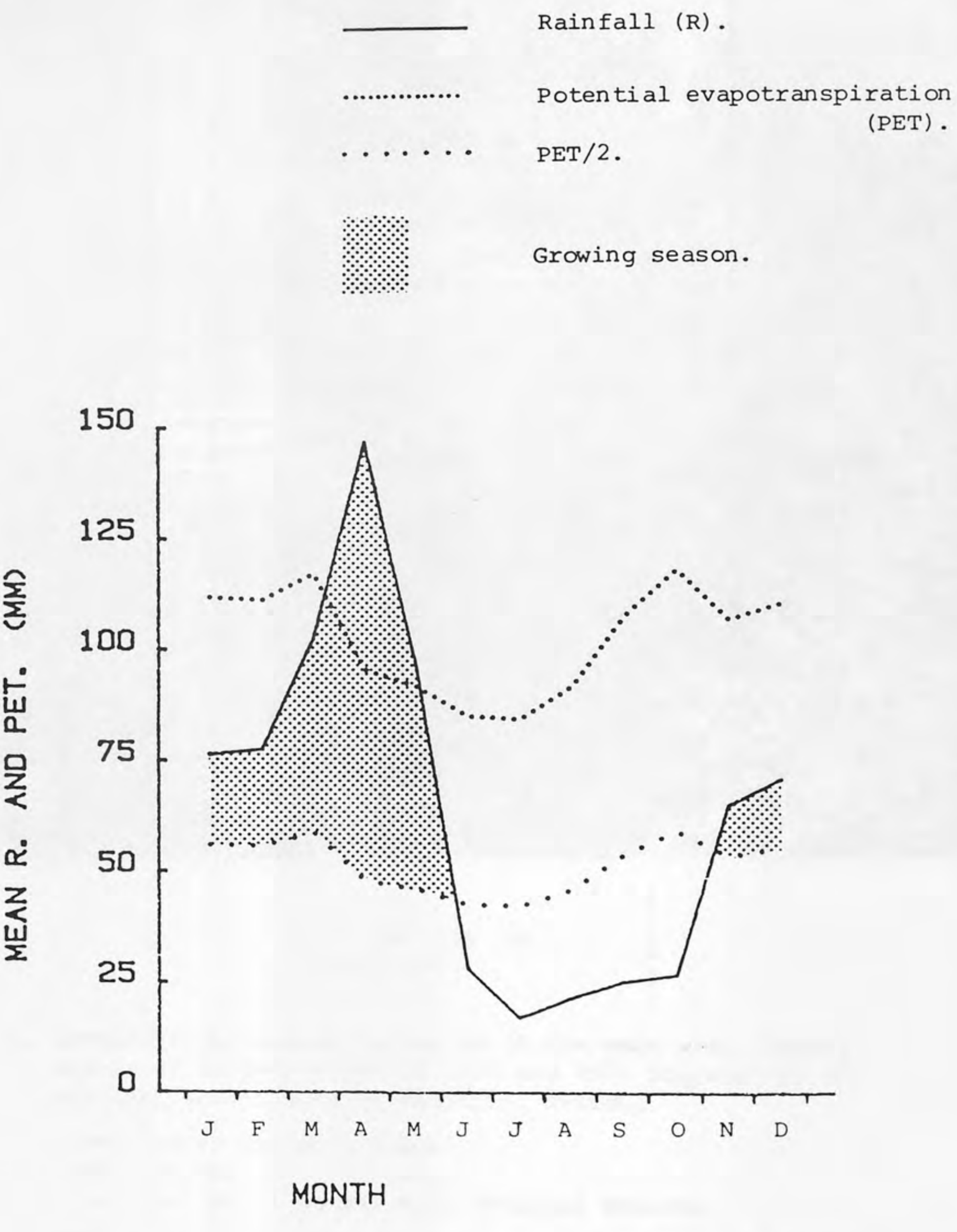
Figs. 1:4 a)-c): Mean monthly rainfall for six rainguage stations in the Mara area.


a) Aitong, Keekorok.

b) Ololunga, Lemek.

c) Governor's Camp, Mara Serena.

Fig. 1:5. Climatogram for Narok. The mean monthly rainfall data are from records of 1914-32 and 1938-82 (courtesy of the East African Meteorological Dept., Nairobi). Potential evapotranspiration (PET) has been calculated from potential evaporation data supplied by Woodhead (1968), using the multiplication factor of .75 suggested by Brown and Cocheme (1973). The growing season extends over the period when rainfall exceeds PET/2 (FAO 1978).



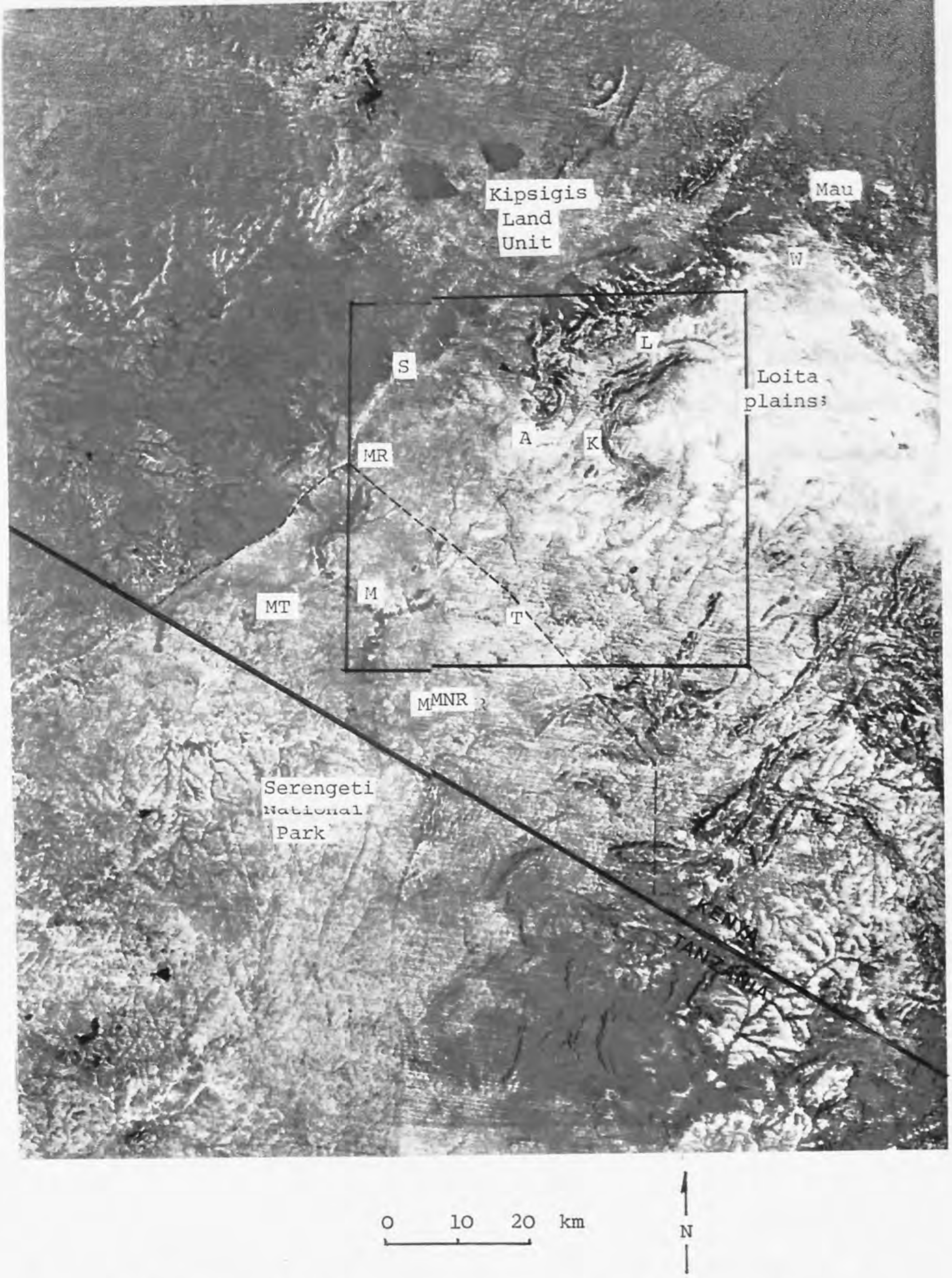


Plate 1:1. LANDSAT false colour composite of the Mara area, from a poster of merged images of 1975 and 1976 prepared by the Regional Remote Sensing Facility, Nairobi.

━ : Kenya-Tanzania border.
— : border of study area.
--- : border of Maasai Mara National Reserve.

MMNR = Maasai Mara National Reserve: A = Aitong: K = Koyage: MR = Mara Rienda: MT = Mara Triangle: M = Mara river: S = Siria escarpment: T = Talek river and area: L = Lemek valley: W = wheat schemes.

Table 1:1. Details of the aerial photography acquired for this study.

Year of photography	Camera format	Coverage	Approximate image scale	Film
- 1950[a]	152 mm (9")	Total	1:30,000	panchromatic
Jan. 1961[a]	152 mm	Total	1:50,000	panchromatic
Feb. 1967[a]	152 mm	Total	1:57,000	panchromatic
Jan. 1974[b]	152 mm	Total	1:68,000	panchromatic
Aug. 1983[c]	152 mm	@ 6%	1:6000	panchromatic
	70 mm	@ 15%	1:15,000[d]	panchromatic
	70 mm	@ 15%	1:23,000	colour infrared
	35 mm	@ 2%	1:9000	panchromatic

[a]: photography obtained by Royal Air Force

[b]: photography obtained by Meridian Airsurveys Ltd.

[c]: photography obtained by Kenya Rangeland Ecological Monitoring Unit.

[d]: these photographs were enlarged to a scale of approximately 1:5000 for woodland cover analysis.

Table 1:2. The temporal spread of aerial photography, systematic reconnaissance flights (SRF's) and LANDSAT false colour composites (FCC's) and computer-compatible tapes (CCT's) of the study area that were available for use in this study.

Years of photography	Years of SRF's (No. of SRF's)	LANDSAT FCC's.	LANDSAT CCT's.[a]
1950			
1961			
1967			
			09/10/72
		01/02/73	
		31/07/73	
1974			24/06/75
		22/09/75	17/08/75
			21/12/75
	1979 (11)		05/03/79
	1980 (2)	10/10/80	17/08/80
	1981 (4)		
	1982 (3)		
1983			

[a]: all LANDSAT CCT images were also available as FCC's.

CHAPTER 2: THE PASTORAL MAASAI OF THE MARA - AN INTRODUCTION

2:1 Pastoralism Defined

Pastoralism can be defined as the subsistence, either from necessity or choice, of people on the products of their stock: milk, meat, blood and hides (Brown 1971). In the tropics pastoralism is usually practised in areas with insufficient rainfall for cultivation (less than about 600 mm), but in some cases, as in the Mara area, the early allocation of the country to pastoralists as Tribal Trust Land has precluded agriculture. In Baxter's (1975) scale of pastoralism the Maasai fall within the first category, the 'pure pastoralists' who depend almost entirely on their livestock for food. The limitations of this dependence were well illustrated by the devastating effect of rinderpest on the Maasai during the 1890s (Ford 1971). However, vegetable products, especially maize meal ('unga'), are now being bought in larger quantities from local markets (Nestel 1984) and there has been a gradual shift away from a pure milk-and-meat diet. In the Mara the consumption of 'unga' has become a virtual necessity during the dry season, when the arrival of the Serengeti wildebeest migration forces the Maasai to remove over 30% of their cattle from the area (see Chapter 10).

2:2 Maasai Political and Social Structure

The following account draws on the works of Hollis (1905), Sandford (1919), Fosbrooke (1948) and Jacobs (1965).

In East Africa the 'maa' language and its derivations unite a large number of tribal groups, with differing degrees of relatedness. At the first division these groups are separated into the **il-Maasai** and the **il-oikop**, the former the true Maasai, the latter the more agricultural maa-speakers. The Arusha, Njemps and Baraguyu are all examples of **il-oikop** tribes, and although the Samburu are virtually pure pastoralists, the Maasai also place them within the **il-oikop**. The Maasai themselves can be considered as a 'federation' of about 11 subtribes often referred to as 'sections' (**ol-osho**, pl. **il-oshon**). These sections are of greatly varying populations, each with its own territory and each characterized by its own variations of ceremonial procedure, dress and dialect. The different **il-oshon** are independently governed by their own elders. Before the current disintegration of their social system, the decisions of the elders was backed by the force of their own warriors (pl. **il-murrani**). Relations between neighbouring sections may be hostile, especially over grazing rights and there are often disagreements over sectional boundaries and cattle thefts.

The Mara study area falls within the sectional territory of the most numerically powerful group of Kenya Maasai, the **il-Purko** (population approx. 60,000), who occupy the region to the east of the Mara river. The 8% of the study area to the west of the Mara river is occupied by the **Siria** section (population 8000) and the **il-Uasin Gishu** section (population 4000).

The role of a male Maasai in his society is governed by a complex system of 'age-sets' and reference should be made to Fosbrooke (1948) for a detailed explanation. Following his circumcision a young man becomes a warrior for about 18 years, entering either the 'right hand' or the 'left hand' of a generation or age-set, depending on the timing of the circumcision ceremony. At the 'milk drinking' (**eunoto**) ceremony he graduates to the status of junior elder at the age of about 30 and is entitled to marry and own cows. Each age-set has a name and a 14-20 year span in which the members were at the warrior stage. Events in history are recorded according to the age set in which they fall. For example, the Maasai of the Mara often referred to a very extensive fire that ocurred in the overlap period between the **Territo** (1926-1948) and **Nyankusi** (1942-1959) age sets. Reference to this fire was found in the Archives District Officer Report for 1946.

Recently it has become more difficult for the Maasai to justify the continued existence of the warrior class. Cattle stealing by the **il-murrani**, previously treated as 'youthful exuberance' on the part of the warriors has been condemned not only by the Kenya Government but the Maasai elders themselves. As early as the 1940s the elders were pressing for the abolition of the warrior class (Archives 1942) and, although the circumcision ceremonies still remain mandatory, the **il-murrani** today are hurried through to the milk-drinking ceremony as soon as possible. However, the authority of the elders is slowing becoming eroded because young Maasai elders in their early twenties are demanding a greater voice in the running of their society.

The traditional Maasai settlement or **en-kang** (pl. **in-kangiti**), referred to by Jacobs as a 'kraal camp' but usually termed a 'manyatta' consists of a ring of mud and dung huts (pl. **in-kajijik**) enclosed by a thorn fence (**e-sita**). Manyattas are very flexible in their social structure. According to Jacobs (1965): "there is no persistent kinship structure nor formal political element to characterize kraal camp organization .... kraal camps consist of an informal loosely organized association of independent families who, although they may have joined together as a residential association for a variety of individual reasons, share a common interest .... in the economic exploitation of their immediate vicinity."

Each house within the settlement is constructed and owned by a married Maasai woman. Each gate in the perimeter fence is the 'property' of a married man. The Maasai are polygynous and thus the number of gates in the thorn fence loosely defines the number of families living there. The man's first wife builds her hut to the right of the gate (as one enters), the second to the left, the third to the right and so on.

Cattle, sheep and goats are brought into the settlement at night and the gates are sealed to prevent their escape and the entry of predators. In the Mara area sheep and goats (hereafter referred to as smallstock) are herded into separate pens, inside of and adjacent to the family gate. Changes in the grazing strategies of cattle and smallstock have been an important feature of the Mara ecosystem and will be discussed in Chapter 4.

Manyattas are frequently clustered in favoured 'localities' (pl. **in-kutot**), usually with a permanent water supply. As the Maasai become increasingly sedentary dispensaries, cattle dips and (sometimes) schools are built in these localities. In the Mara seven such localities can be identified (see Fig. 1:2); Lemek, Aitong, Koyage, Ol Kinyie, Talek, Mara Rienda and Ol Doinyo Narasha. Reference will be made to these localities throughout this thesis.

2:3 Recent History of Pastoral Use of the Mara

Archaeological excavations in the Lemek valley reveal that pastoralists were inhabiting the Mara 2000-3000 years ago (Marshall and Robertshaw 1982). Although little can be inferred about their society, it is clear that they were using settlement sites favoured today by the Maasai. An example is the well drained strip of land along the Oltorotua (Olare Orok) river just to the south of Aitong (Robertshaw pers. comm.).

The Maasai and **il-oikop** tribes are classified as nilo-hamites, being linguistically related to the nilotic Toposa and Lotuko of the Sudan but having many features in common with the hamitic groups, such as male and female circumcision.

Huntingford (1953) suggests that the plain between Lake Turkana and the Dodos-Karamajong escarpment in north-western Kenya was the area from which most of the pastoral nilo-hamites originally dispersed. Of these groups the Maasai moved south and east, ascending the Kerio Valley on the way. During this expansion, which occurred "several hundred years before 1750" (Jacobs 1965) the **il-oikop** and the **il-Maasai** separated, the former going well to the east and west of the Rift Valley, the Maasai continuing southwards until they were stopped by the Wagogo and Wahehe of Tanzania (Sir Charles Elliot in Sandford 1919).

In the 19th century East Africa Maasailand (with the **il-oikop** land) covered 200,000 km^2 of territory, extending from Mount

Elgon, Lake Baringo and the Ndoto mountains in the north, southwards to Lake Eyasi and the 'Maasai-Steppe' of northern Tanzania. Evidence from local traditions suggests that a maa-speaking group arrived in the Mara around 1750 (Mol 1980) and Wakefield (1870) indicates that the area corresponding to the Mara was inhabited by a 'wakwavi' (**il-oikop**) group, probably the **Siria** section. The **Siria** were later raised in status to Maasai (by the Maasai), as a reward for the assistance they gave to the **Loita** section during the rinderpest epidemic (Jacobs 1965).

The arrival of rinderpest signalled the downfall of the Maasai at the end of the 19th century. The disease was introduced into Africa by european interventions in the mid 1890s. It swept through East Africa in 1889-90 destroying virtually the entire cattle population of the Maasai, and the wild ruminants of the savannas. It was followed by smallpox and the Maasai of the Mara were decimated (Sandford 1919), the remnants of the **Siria** fleeing westwards towards Lake Victoria. In the last decade of the 19th century the Mara became almost empty of human habitation.

Disease was succeeded shortly by civil war, exacerbated by starvation and stock thefts. Mbatian, the great ritual export (**laibon**) of the Maasai died, and the rivalry between his two sons Lenana and Sendeu for the succession drew in various **il-oshon** on one side or the other. The wars continued intermittently until the arrival of the white settlers.

In Kenyan history the period 1900-1910 is associated with rapid colonization by europeans. Grazing applications by settlers in the Rift Valley were favoured, and, in what became known as the '1904 Agreement', the Maasai were moved into two reserves. The northern reserve was situated in the Laikipia area, north and east of the Aberdare range of mountains. The southern reserve extended from the Uaso Ngyiro river (just to the west of Narok), eastwards across the floor of the Rift Valley to Ol Doinyo Orok (Namanga Hill) close to Kilimanjaro. After several years however, the victor of the Maasai wars, Lenana, residing in the southern reserve, felt that he was losing his influence over the Maasai in the north. Since settlers were also applying for farming rights in the Laikipia, it was decided to move the northern Maasai into an extension of the southern reserve. This extension comprised the Mara area, from the Uaso Ngyiro to the Mara river. This area became known as 'cis-Mara' and was described by Sandford (1919) as "some of the best stock country in British East Africa". Shortly afterwards this extension was enlarged further to include 'trans-Mara' to the west of the Mara river. The southward move of the Maasai, most of whom were **il-Purko** was completed in 1913 and the forerunners immediately occupied the Lemek valley with its freshwater springs, and spread along the eastern bank of the Mara river (Humphrey 1947). The **Siria** section, who since the rinderpest epidemic had not been confined to any reservation, returned from the Lake Victoria area and re-established themselves in trans-Mara.

Once the Maasai had arrived in the Mara, the colonial administration embarked upon an ambitious plan for pastoral development. Six large dams were constructed in the Mara; three at Lemek, two at Ngorengore and one on the west side of Bardamat hill and "10,000 cattle watered [at these dams] daily" (Sandford 1919). Trading centres were also proposed for Bardamat, the old Mara bridge at Ngirende and Angata Posee (the Posee plains) in what is now the Maasai Mara National Reserve. An enterprising settler, Mr Judd, constructed a store very close to the junction of the Mara and the Talek rivers to trade livestock with the Maasai. The implications of the distribution of these trading posts is discussed in the next chapter.

Over the following 25 years other Maasai sections were settled in Narok District. In an effort to formally demarcate tribal and sectional boundaries, the Carter Land Commission (Archives 1934) allocated certain portions of trans-Mara to the remnants of the **il-Uasin Gishu** section, a formerly powerful group who until 1930 had been living in their own small reserve centred on the Laikipia village of Eldama Ravine. One large portion of trans-Mara that was allocated to them, the upper Migori river area, consisted of the heavily wooded and bushed land up against the border with the agricultural Kipsigis. Border skirmishes between the **il-Uasin Gishu** and the Kipsigis were common and continued through the 1940s and 1950s. Following Kenya's independence in 1962 there was a rapid expansion of the Kipsigis across the border into the 200 km^2 of this part of **il-Uasin Gishu** territory. Although it was true that the Maasai had allowed a number of Kipsigis and Kikuyus to settle in Maasailand as 'acceptees', observing certain rules, complaints were lodged by the **il-Uasin Gishu** at a large meeting in 1966 that acceptees had invited numerous friends and relatives to join them in Maasailand. Lewis R.W. (1965) estimated that 60% of the population of trans-Mara consisted of acceptees. By 1974, of the original 200 km^2 of forest area of the upper Migori **il-Uasin Gishu** territory, only 55 km^2 remained free of cultivation. It is clear that a small proportion of the 'slash-and-burn' cultivation of the forest areas was due to the activities of agricultural **il-Uasin Gishu**

Maasai. However, most of the 1500 Maasai left this area between 1961 and 1974, settling in **il-Moitanik** and **Siria** territory and in the second half of **il-Uasin Gishu** land south-west of the town of Kilgoris. Many more have established themselves in the far north of the study area at the small town of Emarti on the Mara river, and distinctive **il-Uasin Gishu** settlements appear in the Lemek valley and Aitong areas on the 1967 and 1974 aerial photography, contributing to the rapid population increase within the cis-Mara portion of the Serengeti-Mara ecosystem (see Chapter 4).

The foregoing summaries of Maasai political and social structure, history and occupance of the Mara form an essential prerequisite to the understanding of environmental change in this area over the past century. Vegetation changes, tsetse-fly invasions and the movements and distributions of the Maasai have been closely linked, and by examining past events it has been possible, with the interpretation of the aerial photography, to make a few tentative predictions concerning future changes in the Mara.

2:4 Maasai Group Ranches in the Mara Area

In the mid-1960s the Kenya Government embarked on a program of land adjudication in Maasailand (Lewis R.W. 1965; Lawrence Report 1966). In the adjudication process Maasai were given title deeds to tracts of rangelands to which, through their long-term use of the area involved, they believed they had rights. In a few cases land has been allocated to individual Maasai, but usually title deeds were given to groups of Maasai acting as a corporate body. In the 'group ranch' system the land is owned by the group but the individual pastoralists still retain ownership of their livestock herds. Group ranch boundaries are rarely fenced but are marked by hills, rivers, roads and other terrain features.

There were two closely linked objectives to this program of group ranch development (Lewis R.W. 1965; Davis R.K. 1970; Hedland 1971; Oxby 1982). Firstly it was hoped that livestock production in rangeland areas would be increased in line with national development efforts. Secondly, it was felt that if the Maasai were given their own land they would manage it in an ecologically sound way by designing their own grazing management schemes and selling their surplus stock. If the Maasai were not prepared to sell cattle it was thought that stock quotas could be imposed upon them.

By organising themselves into groups, adopting constitutions, electing group committees and behaving as 'corporations', the Maasai became eligible to acquire loans for the development of their land. These loans, granted by the Agricultural Finance Corporation of Kenya, would go towards the construction of dips, dispensaries and schools for the ranch.

In Narok District there are three other ways in which money can be brought into the group ranch (Doherty 1979):

1) Group ranch land can be leased to wheat or barley growers.
2) Rent can be received from tented tourist camps.
3) Money can be reinvested from cattle sales, which is after all one of the main objectives of the ranch system.

The 1960s was a time of rapid agricultural encroachment onto Maasailand by tribes such as the Kamba, Kikuyu and Kipsigis. The introduction of an official system of land tenure was therefore initially welcomed by the Maasai. However, in commercial terms group ranches have been a complete failure for the following reasons (Oxby 1982):

a) Most group ranches can only be considered as viable ecological units in years of good rainfall. In poor years, instead of selling stock, the Maasai usually move their cattle into neighboring group ranches under reciprocal agreements (Halderman 1972).

b) Stock quotas are unenforcible. There are great difficulties in accurately counting livestock in group ranch areas (see Chapter 5) and even if stock controls were enforced, the Maasai would simply remove their surplus stock from the ranch to graze in other areas. Furthermore, the Maasai of the Mara are very reluctant to sell stock, for reasons explained in Chapter 10.

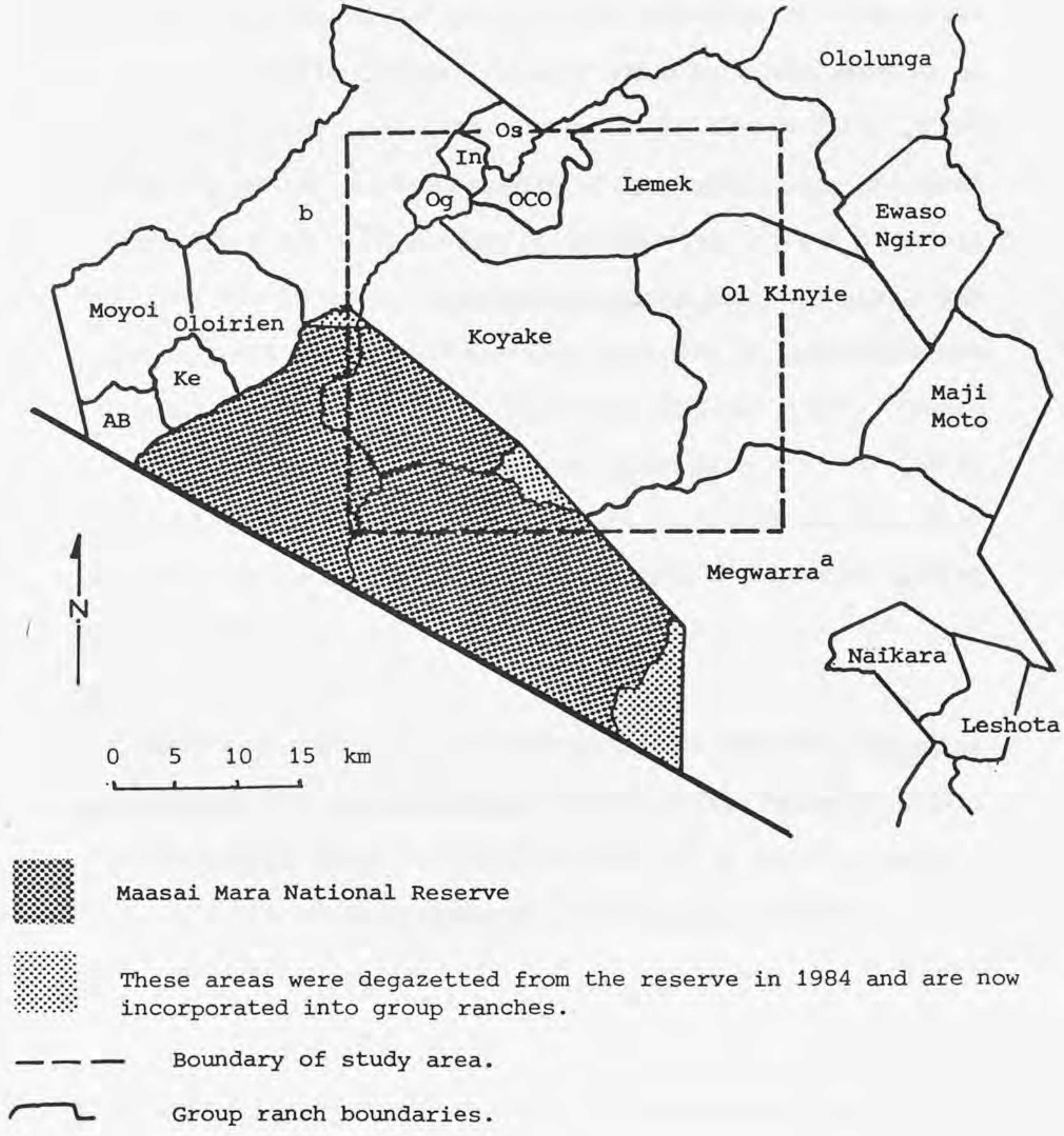
c) In the group ranch system it is of great importance for ranch members to coordinate grazing strategies so that they can make the best use of available resources. However, it is difficult, if not impossible, to achieve this coordination if ranch members live many kilometres apart.

The similar 'ranching associations' of Tanzania have been even less successful than the Kenya group ranches, but for many of the same reasons (Jacobs 1980).

The group ranches of the Mara area are shown in Fig. 2:1. The **il-Purko** group ranch of Koyake is completely contained within the study area and has been chosen as a 'sub-study-area' for much of the cattle distribution, tree recruitment and satellite image analyses (Chapters 5, 8 and 9 respectively). In addition to the problems described above the group ranches of the study area and Loita plains now face a set of unique difficulties resulting from agricultural expansion, rapid Maasai immigration and increased competition for grazing resources from wild herbivores. These problems are exacerbated by the unwillingness of the Maasai to sell their stock. Koyake, Lemek, Oloirien and Megwarra group ranches all receive rent from tented tourist lodges located on group ranch land. In the case of Lemek and Koyake this may be as much as Kshs.150,000 (£7,500) per annum. According to Doherty (1979): "Because of such a lucrative source of funds these ranches [Lemek and Koyake] have not yet had to apply for a development loan. This worries the Ranch Planning Office in the District because officers feel that, without a loan to repay, there will no be significant offtake of cattle, but rather, ranch finances will be used to purchase more cattle thereby leading to a chronic overstocking problem".

The difficulties faced by group ranches in the area are discussed in greater detail in Chapter 10.

Fig. 2:1. The group ranches of the Mara area. (from an unpublished land adjudication map at the Survey of Kenya, Nairobi). Most of the group ranches were adjudicated over the period 1970-1977.



^{a}: Boundaries unknown.

b: This area now incorporated into Oloirien and Olongoilin Group Ranches.

AB: Angata Barigoi Group Ranch.
Ke: Kerinkani Group Ranch.
Og: Olongoilin Group Ranch.
In: Intulele Group Ranch.
Os: Olosakwana Group Ranch.
OCO: Ol Choro Oroiwa private ranches.

CHAPTER 3: TSETSE-FLIES AND HUMAN DISTRIBUTION IN THE MARA, 1900-1960

3:1 Introduction

Through their exclusion of livestock, tsetse-flies (Glossina spp) have been responsible for the continued existence of large areas of pristine wildlife habitat, many of which have been gazetted as conservation areas (Ford 1971; Simon 1963). Tsetse flies ('fly') act as vectors for the transmission of Trypanosoma spp, protozoan endoparasites which, depending on the species, infect livestock with trypanosomiasis (Trypanosoma congolense, T. vivax and T. brucei) and humans with sleeping sickness (T. gambiense and T. rhodesiense) (Buxton 1955; Ford 1971; Challier 1982). Cattle are highly susceptible and cannot be taken into areas of tsetse infestation, whilst sheep and goats are more tolerant (Whitelaw 1983) and only become infected in areas with a high 'fly' density (Glover 1967).

Two species of tsetse have been recorded for the Mara, Glossina swynnertoni and G. pallidipes (Lewis 1935; Beaumont 1945; Langridge et al 1970). At Talek in 1960, 4% of the flies caught were carriers of T. congolense and T. vivax (Whiteside and Langridge 1960).

Wild animals rarely succumb to trypanosomiasis but act as reservoirs for Trypanosoma spp. Between 5% and 50% of the different wild herbivores tested by Baker and Sachs (in Glover 1967) in the north western Serengeti were infected, although the flies themselves tend to confine their feeding to warthogs, buffalo and giraffe (Langridge 1960).

Tsetse-flies inhabit forest and bush country, requiring shade and resting below leaves and branches. The habitat of both G. swynnertoni and G. pallidipes is defined as savanna thicket and bush (Glover 1967), although G. swynnertoni is considered to prefer drier areas.

3:2 Tsetse and Maasai Interactions in the Mara

At the time of the extension of the southern reserve in 1913, the Mara was almost completely free of fly (Sandford 1919). A small band of fly-infested bush existed at the junction of the Mara and Talek rivers (MacLure in Lewis 1935) but densities were low and did not prevent the Maasai from settling in the Mara triangle (Woosnam 1914) and along the Talek. Sandford (1919) describes a German military raid on two Maasai settlements "near Ol Keju Talek" in 1915 in which 200 cattle and 6000 sheep were taken. It is also likely that there were settlements along the northern limit of the Posee plains, inside the present Maasai Mara National Reserve, for it was in this area that a trading post was proposed (Sandford 1919).

Over the period 1915-1920 a sudden fly invasion occurred in the Mara, simultaneous with another taking place in the Sukumaland of Tanzania (Swynnerton in Ford 1971). Ford proposes that following the almost complete eradication of ruminant herbivores (and browsers in particular) and the retreat of pastoralists during the rinderpest epidemic, woodland regeneration was taking place in many areas, bringing with it an increase in the tsetse population. Their food source was also recovering rapidly at this time.

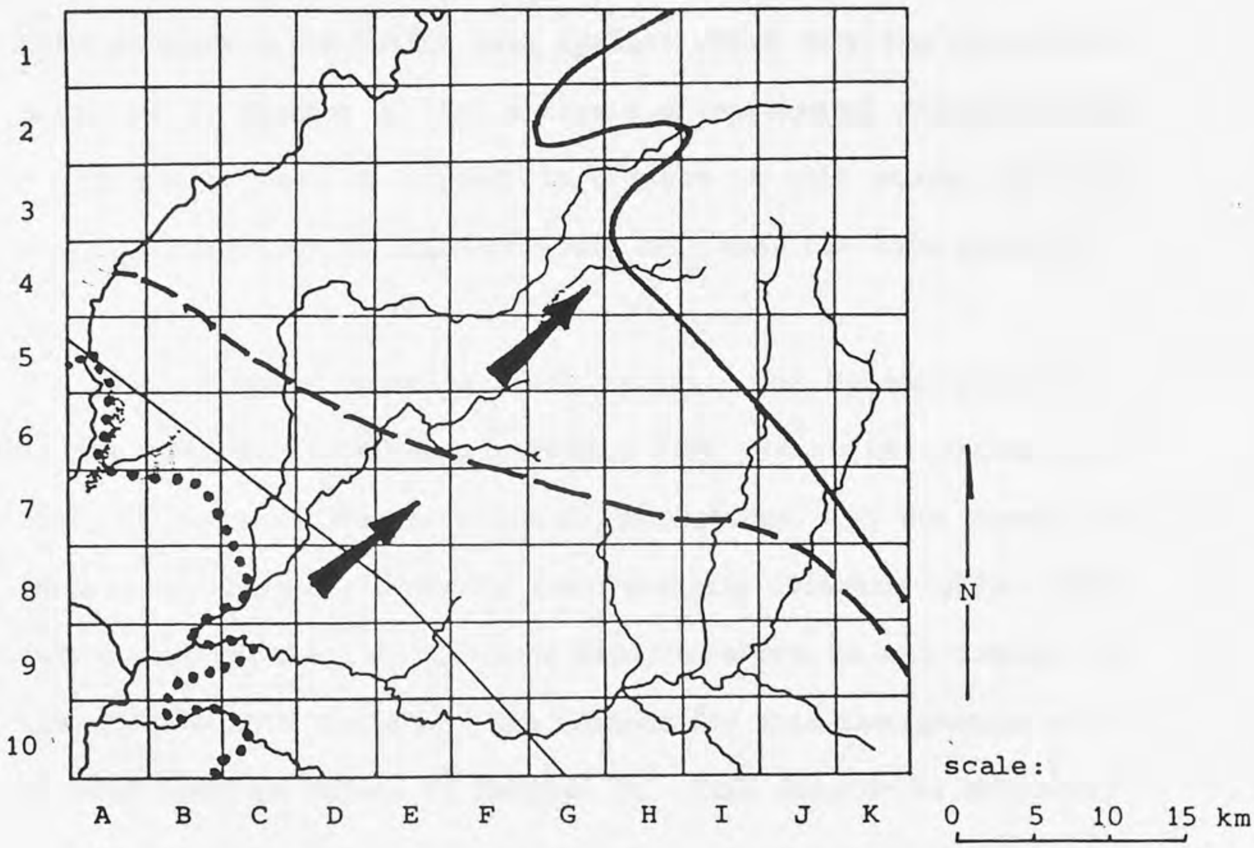
The first sign of this northward spread of tsetse into the Mara was in 1911 when Mr Judd, the livestock trader who lived in the area now known as 'Paradise Plain', began to lose stock from trypanosomiasis and moved his store to the site of the upper Mara bridge to the north (Woosnam 1914).

Lewis E.A. (1935) reported that, by 1932, the fly had advanced to "a line drawn from the Mara river, across the Ol Arorok [Olare Orok] to about six miles south of the Bardamat" and concluded that "the two species [of tsetse] have spread to a large extent since the arrival of the Maasai in the extended southern reserve. The traces and remains of Maasai bomas [settlements] point to occupation of areas now inhabited, and the progressive evacuation of villages with the advance of the tsetse and animal trypanosomiasis". Lewis also describes the complete evacuation of the Mara triangle, the **il-Purko** Maasai moving to the top of the Siria escarpment. The northward advance of tsetse is shown in Fig. 3:1.

By 1945 the 'front line' of tsetse had reached Aitong and Bardamat (Beaumont 1945). The 1950 aerial photography reveals that Maasai settlements were confined to the Lemek valley and eastern side of Bardamat hill (Ol Kinyie) only, both covered with <u>Tarchonanthus camphoratus</u> bush **(ol-leleshwa)** (see Chapter 6), a habitat which does not appear to favour tsetse. After 1945 there was no further spread of fly, the northern limit remaining the same until about 1960 (Darling 1960). Tsetse disappeared from the Mara almost completely over the next six years.

This disappearance is closely linked with the destruction of bush in the Mara area (Chapter 7).

Fig. 3:1. The northern limits of tsetse flies in the Mara in 1908 (●●●●●●), 1934 (— — —) and 1950 (———), from an unpublished tsetse distribution map (by Lewis E.A. @ 1955) at the Kenya Veterinary Laboratories, Kabete, Nairobi. The 1908 limit is confirmed by Woosnam (1914), the 1934 limit by Lewis E.A. (1935) and the 1950 limit by Beaumont (1945) and Darling (1960).



CHAPTER 4: SETTLEMENT DISTRIBUTION AND SIZE, 1950-1983

4:1 Introduction

In the absence of long-term livestock distribution data for the study area, the determination of grazing gradients has had to depend largely upon mathematical models that relate the grazing intensity at a certain point to the distance and distribution of Maasai settlements from that point. These models and the SRF livestock distribution data against which they are tested are described in Chapter 5. The analysis of settlement distributions has therefore been of primary importance in this study, and the aerial photography of 1950-1974 has been used for this purpose.

The results reveal some alarming trends. The Maasai population of the area is increasing at about 7.5% per annum or doubling every 11 years. However, pastoral populations, and the Maasai in particular, have a relatively low fertility (Blacker 1972). This very rapid population increase can therefore be attributed to immigration into the area. The reasons for this immigration will be considered in detail in Chapter 10. This chapter is primarily concerned with the description of settlement distribution, settlement size and other relevant demographic parameters to provide the necessary background from which to investigate changes in grazing intensity and explore the concept of 'carrying capacity' for this area. To this end the following factors are examined:

a) Settlement distribution through time.

b) The number of huts/settlement.

c) The number of individuals/hut.

d) The number of individuals/family.

e) Overall population trends for the Mara area.

4:2 Methods

The aerial photographs of 1950, 1961, 1967 and 1974 were carefully and systematically scanned for settlements, initially using a Perry binocular microscope with a x 7 and x 14 power magnification; at the beginning of this study, only 'monocoverage' (every second photograph in each flight line) could be afforded. At later stages the 'gap' photographs were purchased and the 1961 and 1974 photographs were reinterpreted stereoscopically using a Wild ST 4 stereoscope with a x 3 and x 8 magnification. The 1950 photographs were examined monoscopically and stereoscopically at the Survey of Kenya in Nairobi; these photographs were not purchased for this study, because of the large number of photographs involved.

The position of each settlement encountered was recorded on the 1:50,000 topographic maps and on small scale 'data store' maps, where each settlement was assigned to a 1 km^2 grid cell. If the contrast and resolution of the photograph were sufficient, the huts within that settlement were counted; where there was some doubt the hut-count was rejected. To increase the hut-count sample size several settlements located just outside the study area were included in this exercise.

From the airphoto-interpretation, settlements can be divided into two types; settlements with huts and settlements without.

a) Settlements with houses: these are the **in-kangiti** or 'kraal camps' referred to by Jacobs (1965). The most common name for this settlement type is 'manyatta', which will be used throughout this thesis although, technically speaking, manyattas are the traditional villages of the warriors or **il-murrani.** In the Mara manyattas are generally found within 5 km of a permanent water source. This water source may consist of a spring, a river or a small water course that dries to a series of stagnant pools in the dry season. Over the year of the fieldwork studies (1983) all major tributaries of the Talek - the Kaimurunya, Ol Sabukiai, Olare Orok and Jagartiek - held water throughout the year although in the dry season this water was confined to pools. However, it was not possible to locate all of these pools because of the large size of the study area, and an analysis of the manyatta distance to water was not attempted.

In contrast to the manyattas of the **il-Kisongo** Maasai of the Amboseli area, which are inhabited on a seasonal basis (Western 1973; Western and Dunne 1979), the manyattas of the **il-Purko** are occupied throughout the year. The life-span of the manyatta, however, is about the same, approximately 4 years. At the end of this period the build up of livestock parasites and the accumulation of dung that becomes waterlogged in the wet season renders the manyatta unsuitable for further habitation, and a new manyatta is constructed, often within 200 metres of the old. The manyatta may also be deserted if an adult occupant dies. The abandoned manyatta is left to dry for 3 months or longer and is then burnt.

From the total coverage aerial photography of the range of scales available (1:30,000-1:68,000) it has not been possible to ascertain whether a manyatta is inhabited or has been abandoned prior to burning. It should therefore be recognized that the manyatta counts should be reduced by about 7% to give a better estimate of human population numbers. Only one manyatta remains in the same position between two consecutive years of the whole range of photography - between 1961 and 1967. This would represent the extreme 'tail end' of the longevity distribution. Manyatta burn scars are identifiable on the aerial photography but there has been some difficulty in their recognition and they have not been mapped.

b) Settlements without houses: these consist only of a circular thorn fence, although very small shelters may be constructed which can barely be detected on the aerial photography. These settlements can best be described as 'temporary livestock camps' (Maasai pl. **im-booitie**) and in this thesis they will be referred to by the abreviation TLC. Until the late 1960s TLCs were used for the dry season dispersion of sheep and goats, apparently (as was indicated by the Maasai) to remove these smallstock from the northern areas where they were liable to be stolen by the Kipsigis. More recently their function has changed somewhat and they now generally serve as staging posts for the movement of cattle into less heavily utilized parts of the area. Temporary livestock camps are usually abandoned after one year's use and are never burned. The thorn enclosure is slowly eaten away by termites and, from field observations, it is unlikely that a TLC would be visible on a 1:50,000 scale aerial photograph if it is more than 2 years old. TLCs cannot be aged from the aerial photography. All TLCs have therefore been plotted to give a cumulative distribution over the 2 years or so before the photography was taken.

The 1983 aerial photographic coverage represented a 15% sample. The total manyatta count for this year had to be conducted on the ground with further checks during the aerial surveys. Manyatta distributions were mapped from hilltop vantage points using binoculars, a compass and the 1:50,000 topographic maps. The 1974 aerial photographs were used for orientation and the recognition of terrain features. The entire north eastern quarter was scanned from peaks in the Lemek hills, whilst manyattas to the southwest were mapped from Segenani hill in the Ngama chain and Ilbaan escarpment to the north of the Talek river. The distribution of all manyattas in the western half of the study area was determined by systematically searching the area by motorcycle. This was made easier by the profusion of tourist vehicle tracks in this part of the study area. As the manyatta search progressed the characteristics of a good manyatta site - good drainage, accessibility to water and suitable building materials and the absence of tsetse-flies - became evident and increased the search efficiency. The process of Maasai population expansion in the Mara has followed a pattern of steady saturation of suitable sites with sudden jumps to new areas. Most of the high population density localities - the Lemek valley, Aitong, Koyage, Ol Kinyie and Talek - were therefore known in advance from the airphoto interpretation and the appropriate time could be allocated to searching them.

Any manyattas missed by the ground counts were detected from the air in both the vertical and oblique aerial photography flights and it is considered that no more than 2 or 3 are missing from the total count of 204.

The major proportion of manyattas were detected and mapped from some distance, and it was again difficult to determine whether they were occupied or not. Therefore, as in the photographic counts, approximately 7% will have been abandoned before being burnt.

The hut count for 1983 was made from the 29 manyattas photographed in the 1983 15% sample vertical photography. These 29 manyattas represent a 14.2% sample.

Temporary livestock camps were not mapped in 1983 because they are usually small and, unless viewed vertically, blend very well into their surroundings. Nevertheless, it has been possible to describe their distribution qualitatively for they were much more numerous and were encountered more often in some areas than others.

In order to determine the number of people/hut, 8 manyattas in the Talek and Koyage areas were selected for the counts. The co-operation of two influential Maasai, Karani and Ole Gereto, was much appreciated in this rather delicate exercise. For each hut within each settlement a count was made of the number of adults and the number of children below the age of 16.

Maasai 'families' can be defined as the total number of wives and children of one married man. Each gate in a settlement is the 'property' of a married man (see Section 2:2). A count was made of the hut/gate ratio for 15 settlements photographed in stereo in the 1983 aerial photography to determine the approximate number of individuals in a Maasai family. A Zeiss

Interpretoscope was used for the stereo interpretation. This method was used because this aspect of Maasai population structure was unfortunately not included in the ground counting procedure.

4:3 Results: Settlement Distribution

The distributions of manyattas and temporary livestock camps for the years 1950-1983 are shown in Figs. 4:1 to 4:5.

In 1950 almost all manyattas are restricted to the Lemek hills (Fig. 4:1a)) for this was the only area that was free of tsetse fly (see Section 3.2). One 'pioneer' manyatta, however, has been estabilished in the south east corner of the study area to the east of Ropile hill and inside the fly belt. It is not clear why Maasai should have settled here. The TLCs are more widely distributed, forming an arc to the south and west of the Lemek hills. The Mara Buffalo area and the upper reaches of the Ol Sabukiai and Kaimurunya tributaries were particularly favoured areas, but in 1950 temporary livestock camps did not penetrate as far south as the Maasai Mara National Reserve, the present boundaries of which were gazetted in 1961.

By 1961 there were 65 manyattas in the study area, the number having doubled since 1950, but again these settlements are confined to the Lemek hills, with some expansion southwards towards Ol Doinyo Narasha and the southern end of Bardamat hill. Manyattas have also become established at Aitong and along the Oltorotua (the extension of the Olare Orok river) to the west of the Lemek hills. The arc of TLCs, however, has been extended southwards well into the Maasai Mara National Reserve, the Talek area having particularly high densities. The Maasai, therefore, were bringing their smallstock further south each year, but, as they indicated, smallstock were never taken south of Keekorok to maintain a 'buffer zone' between themselves and the hostile Watende tribe of the north-western Serengeti area.

As noted in Section 3:1 sheep and goats are more resistant to trypanosomiasis than are cattle. The re-utilization of the tsetse area corresponding to the present Maasai Mara National Reserve was therefore spearheaded by the wider dispersion of smallstock, in herds of up to 2000 animals (Talbot et al 1961). The Maasai confirmed that TLCs were used only during the dry season when tsetse densities were lower (Langridge et al 1970) and when malaria is less prevalent. Several **il-murrani** from the families of each manyatta would be detailed to look after the smallstock and were usually aided by small boys who were given the responsibility of looking after small flocks. The Maasai considered that the areas of open plains in the south of the study area would afford greater visibility and protection for the smallstock flocks and their child herders. They also believed that the cattle herds in the Lemek hills, closer to the Kipsigis border, could be more effectively guarded by the **il-murrani** against Kipsigis raids. They therefore regarded the dry season separation of smallstock from cattle as a more efficient division of labour since cattle were required to remain in the manyatta areas to provide milk throughout the year. Apparently, a rotational smallstock grazing system was used, whereby a particular area was favoured for TLCs in one year, with a switch to a new area in the following year. However, because TLCs cannot be accurately aged on the photography, this system cannot be clarified by airphoto interpretation.

The Maasai also described the controlled burning which they conducted before returning with their smallstock to the manyattas in the north at the beginning of the wet season in November. Using natural firebreaks such as watercourses and rocky escarpments, they would systematically set fire to the grasslands, leaving areas of unburnt forage for their smallstock which they would burn just before their departure.

The strategy for Maasai expansion in the 1950s and 1960s can be described as one of 'burn and advance', involving the clearing of bush and the eradication of tsetse. Grimwood (1960) noted that "the Mara National Reserve [as it was then called] .... has not been used much by the Maasai since most of it is to some degree under the influence of tsetse fly. In recent years, however, goats and sheep have been grazed further and further into the fly zone, and grass burning, which has been carried out to improve grazing for them, has progressively destroyed the bush, pushing back the tsetse fly and allowing cattle to follow on the heels of the smaller stock". Langridge _et al_ (1970) and Darling (1960) also describe the process and Talbot _et al_ (1961) made some valuable observations in the late 1950s and early 1960s when they recorded that:

a) The 'Egolok' plains - now referred to as the Meta plains between Keekorok and Talek - had not been grazed by cattle "for at least 50 years" but that sheep and goats had moved in recently.

b) Talek had been subjected to heavy smallstock grazing although cattle had moved in for the first time in 1961.

c) The Bardamat plains just to the west of Bardamat hill had been grazed heavily by all livestock "for about 5 years".

d) The Aitong region has been grazed by cattle for 6 years only, which suggests that manyattas first became established in the Aitong area around 1955.

These observations fit well with the movement patterns determined from airphoto interpretation. Both Grimwood (1960) and Talbot _et al_ (1961) indicate that there was a larger scale movement of cattle than the author's Maasai informants have described. These herds were probably 'fora' or unproductive herds, dispersed further to avoid competition for forage with the productive cattle centred on the manyattas in the northern areas.

By 1967 the Maasai advance had progressed to the point where manyattas could be established at Talek and in the Olare Sambu area, to the west of Kaitapini and Ropile hills (Fig 4:3a)). Temporary livestock camps are distributed in a similar pattern to the 1961 distribution (Fig. 4:3b)).

The first manyatta at Talek, which appears on the 1967 photography, was situated within the northern border of the Maasai Mara National Reserve. These Maasai were not evicted by the reserve management, and the subsequent colonization of the Talek area was very rapid. By 1974 (Fig. 4:4a)) there were 10 manyattas within the game reserve. In this year, however, the TLCs are much more confined to the Olare Sambu area, in the south eastern quarter of the study area (Fig. 4:4b)). There are two reasons for this distribution:

a) In the western half of the study area, which includes a portion of the game reserve, bushland had become so depleted by fire that little suitable material remained with which to build TLCs. The Olare Sambu area also lost much of its bushland in the 1960s (see Chapter 7), but has still retained a significant bushland cover of 10-20% and there is an ample supply of <u>Acacia</u> and <u>Commiphora</u> trees for thorn fence construction.

b) The Serengeti wildebeest migration, which has occupied the Mara every dry season since 1969 (Pennycuick 1975) favours the western more open half of the study area (see Chapter 10) (Stelfox <u>et</u> <u>al</u> 1980). By 1974 the function of TLCs had begun to change and they were more often used for cattle. The Maasai try to herd their cattle away from areas of high wildebeest concentrations because the wildebeest pass on diseases to cattle, the most notable being parasitism by the larvae of Oestrid nasal bot flies (Talbot and Talbot 1963; Sachs and Debbie 1969). Aspects of the interaction of wildlife and livestock will be discussed in further detail in Chapter 10.

In 1983 the number of manyattas within the study area had increased to 204, with 18 inside the reserve at Talek. Occupation had also begun of the Mara Rienda area, adjacent to the upper Mara bridge, where there were 12 manyattas many of which have been constructed since 1980. The Lemek valley, Aitong, Ol Kinyie and Koyage areas are now completely saturated with manyattas and at Lemek the pastoralists cannot subsist by their livestock alone but are attempting small-holding agriculture (Chapter 10). Three manyattas were also located in another new area, Enkikwe, to the north and west of Governer's Camp and adjacent to the game reserve. Both this and the Mara

Rienda areas are likely to be heavily settled in the future by immigrating Maasai.

Whilst many TLCs in 1983 were encountered in the Olare Sambu area, most were found in Enkikwe, an area which in 1974 had no bushland for TLC construction. The re-utilization of this area has occurred for two reasons:

a) The Maasai of Koyake Group Ranch (Chapter 2), which encompasses the central plains part of the study area, now remove over 30% of their cattle from the study area when the wildebeest migration arrives and take them to the top of the Siria escarpment. They cross the Mara river at the upper Mara bridge and Enkikwe is used as the staging and holding area for this movement of some 15,000 cattle. Herds arrive at Enkikwe as early as December and January and remain in what can now can be considered as the wet season grazing area until June and July, before crossing the bridge.

b) Enkikwe is the area where much of the 'bush encroachment' is taking place; Acacia gerrardii has been regenerating very rapidly over the late 1970s (see Chapter 7) and is an ideal species with which to build TLCs.

This section has been concerned with the movement patterns of the Maasai in the study area over the past 30 years. The sequence of events which has resulted in the increased human population pressure on the Maasai Mara National Reserve is briefly described. The assumption that manyatta increases can be equated with human population increases is tested in the next section.

4:4 Results: Huts/Manyatta

The results of the hut count exercise, summarized in Table 4:1 and represented graphically in Fig. 4:6, indicate that the increase in the number of manyattas in the study area is due to a population increase and not simply to a fragmentation of settlements into smaller units. Using a one-way analysis of variance (ANOVA) there is no significant difference in the number of huts/manyatta between the years (d.f. = 4,346: F = 0.85 : N.S.): manyattas have an average of 11.0 ± .65 huts (95% c.l.).

4:5 Results: People/Hut

These results are shown in Table 4:2 and are presented in two ways: the mean number of people per hut and the mean number of adult equivalents per hut. In the latter, children under the age of 16 are counted as 0.5 persons. There is no significant difference between manyattas for either the number of individuals per hut (4.66 ± .322: 95% c.l) or the adult equivalents per hut (3.30 ± .209: 95% c.l). The former figure corresponds well with those obtained for the **il-Kisongo** Maasai (Western pers. comm.) and the Rendille pastoralists of northern Kenya (Lamprey pers. comm.).

Children under the age of 16 comprised 56.0% ± 6.65% (95% c.l.: statistics follow arcsine transformation) of the population, similar to the figure of 50.9% obtained for this area by the 1969 Kenya population census.

4:6 Results: Individuals/Family

These results are presented in Table 4:3. Using the hut/gate ratios shown in the table and the figure of 4.66 individuals per hut, the mean number of individuals per family is 8.51 ± .888 (95% c.l.) or about 6.0 adult equivalents. Brown (1971) suggests figures of 8 individuals or 6.5 adult equivalents for a 'Maasai-type' family, whilst Dahl and Hjort (1976) consider a generalized pastoral family to consist of 6 individuals or 4.9 adult equivalents. Spencer (in Dahl and Hjort 1976) indicates a value of 6.75 persons for an average Samburu family.

There is no significant difference between the number of huts/manyatta for the very high Maasai density area of the Lemek valley (approximately 29 individuals.km^{-2}) and the lower density Talek area (approximately 14 individuals.km^{-2}). However, a significant difference does exist between the number of individuals/family for these two areas: 7.69 ± .853 (95% c.l) for Lemek and 10.52 ± .973 (95% c.l) for Talek ($t = 5.88$: d.f. = 13: $p < 0.001$). A possible reason for this difference stems from the fact that the 'carrying capacity' of the Lemek valley has been greatly exceeded (see Chapter 10). When this happens through a rapid human population increase the number of livestock per person decreases since the given area cannot support any more stock. Families become smaller, not only because they do not have as many cows to supply their needs, but also because a man cannot afford as many wives (who are 'paid for' in cows) as a man from a lower density area. This latter suggestion is tentative and could only be supported by an assessment of the number of individuals/hut for the Lemek area, which was not undertaken (although Koyage can be considered a 'high density' area).

However, if true, a direct link between Maasai family structure and environmental condition would be indicated.

4:7 Population Changes in the Mara Study Area

Changes in the Maasai population over the years of photography are shown in Table 4:4 where the number of huts/manyatta for that year has been used in the calculation (see Table 4:1). The density data in Table 4:4, based on an area of 2025 km^2 which excludes the trans-Mara and Maasai Mara National Reserve portions of the study area, are presented in Fig. 4:7. The densities relating to the Kenya National Census figures of 1962 (Morgan 1966), 1969 and 1979 (Central Bureau of Statistics, Nairobi) for this region are also shown in Fig. 4:7. However, census location boundaries changed between the 3 census years and do not correspond with the boundaries of the study area. The census density figures therefore refer to an area which also includes the Maasai Mara National Reserve, the Loita plains and the Ololunga 'sub location' along the southern limit of the Mau. Ololunga has a very high density of Maasai and Kipsigis (12 individuals.km^{-2} according to the 1979 census figures) which would account for the higher density for the region than is indicated by my results. However, the sub-location of Lemek corresponds well with the study area and a density estimate is available for 1979 of 6 individuals.km^{-2}, significantly higher than the 4.7.km^{-2} indicated by the settlement counts. This suggests that quite a high proportion of the Maasai in this study area are itinerant, moving from manyatta to manyatta. These individuals, mostly young unmarried men, would probably be counted in the census but not in a ground count of individuals/hut. It should, on the other hand, be noted that African population censuses are notoriously unreliable (Blacker 1972) and that these figures should be treated with caution.

4:8 Conclusions

In this chapter the expansion of the Maasai into the Maasai Mara National Reserve and the environmental changes which have allowed this expansion to take place are briefly described. Over the 1960s the destruction of woodland through the action of fire and elephants, and the subsequent elimination of tsetse flies, enabled the Maasai to migrate southwards and westwards from the Lemek hills and occupy formerly uninhabitable areas. The analysis of woodland change from the airphotos, described in Chapter 7, and the examination of information from other sources provide further evidence for this sequence of events. However, in order to clarify the relationship between pastoral activities and environmental changes in the Mara, each facet of this relationship - woodland changes, Maasai movements and grass biomass changes - will be examined separately in this thesis: the chronological order of these changes should be noted.

Fig. 4.1: Settlement distributions and densities, 1950.
a) Manyattas.
b) Temporary livestock camps.

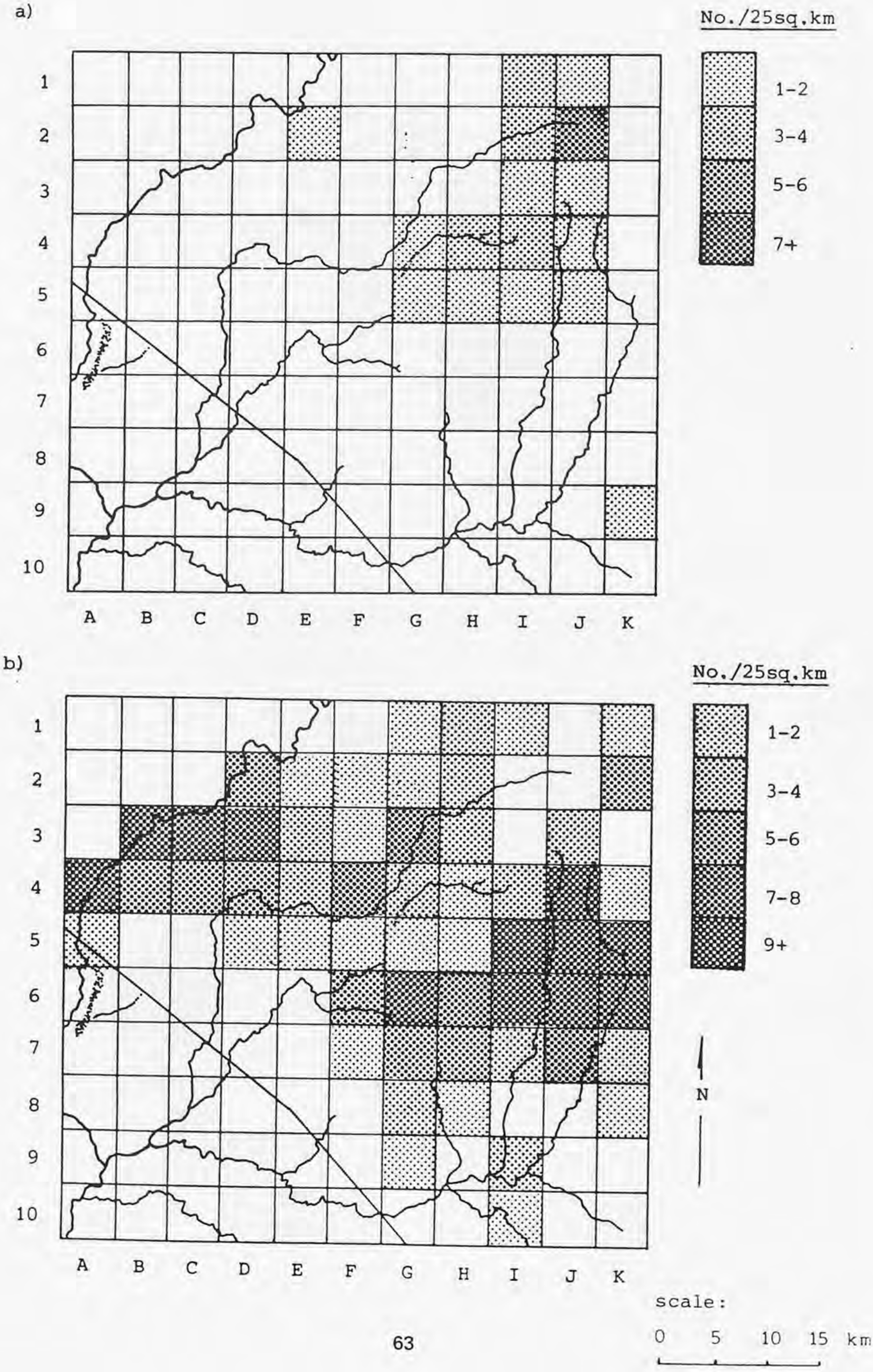


Fig. 4.2: Settlement distributions and densities, 1961.
a) Manyattas.
b) Temporary livestock camps.

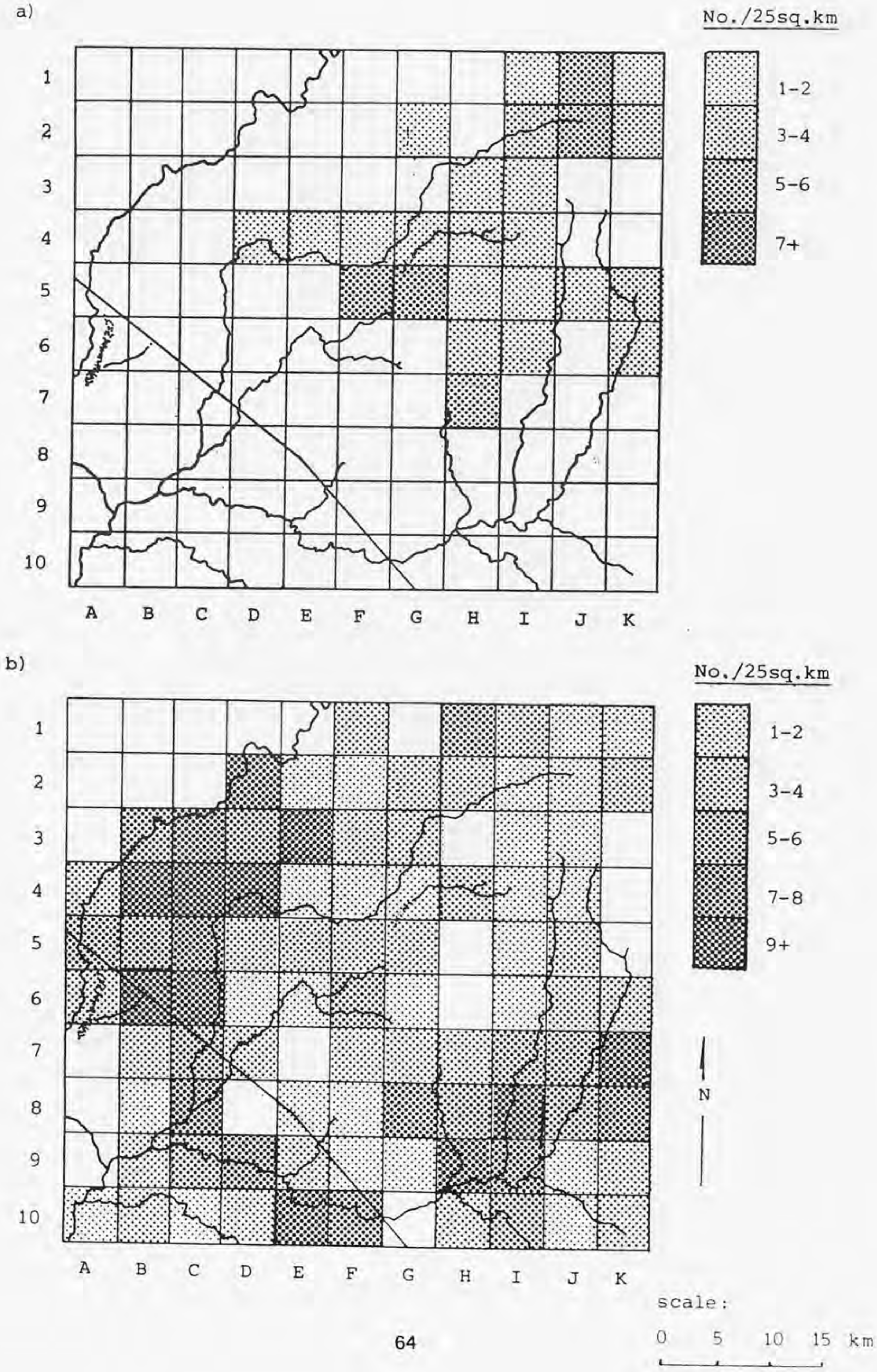


Fig. 4.3: Settlement distributions and densities, 1967.
a) Manyattas.
b) Temporary livestock camps.

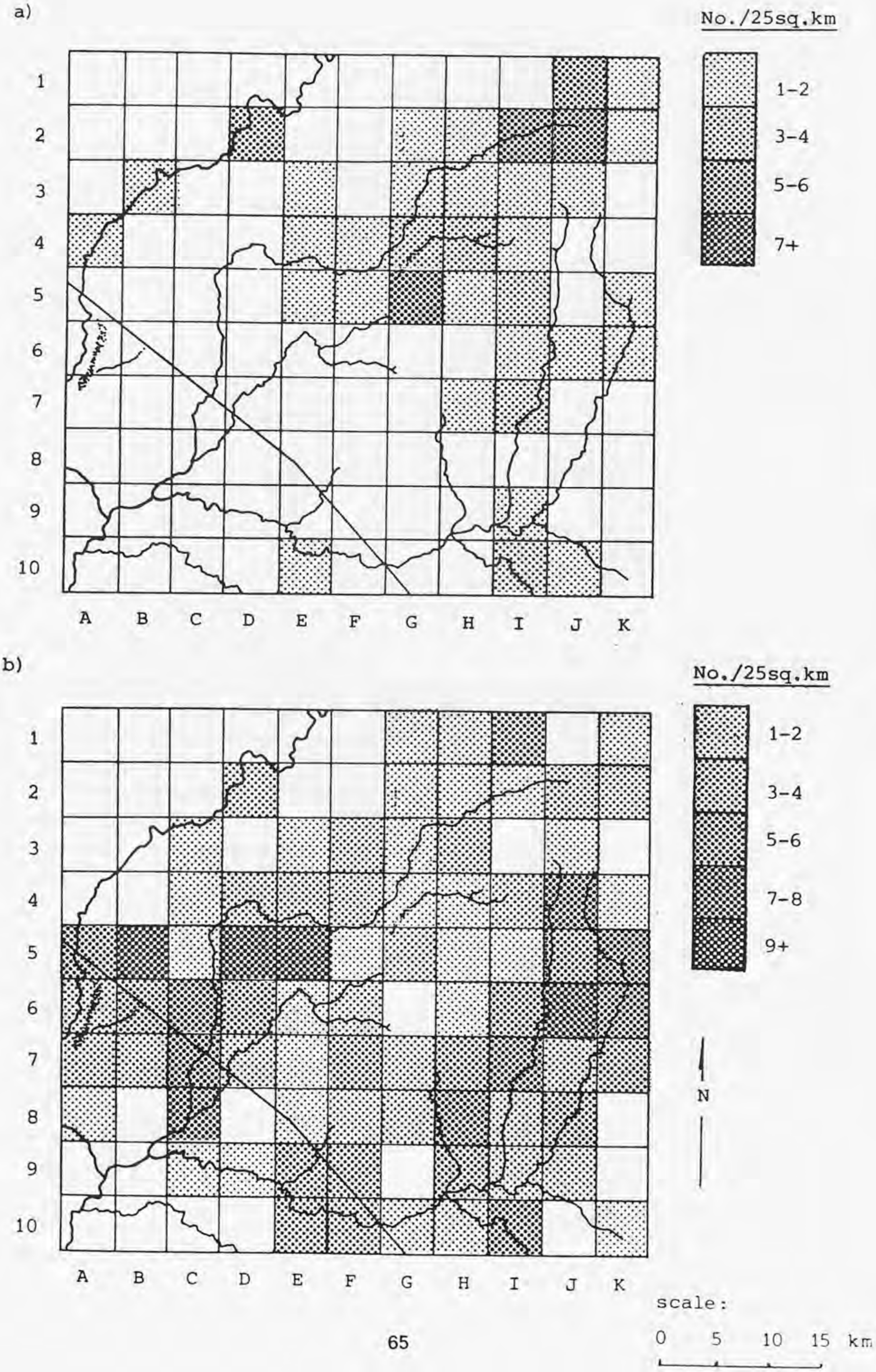


Fig. 4.4: Settlement distributions and densities, 1974.
a) Manyattas.
b) Temporary livestock camps.

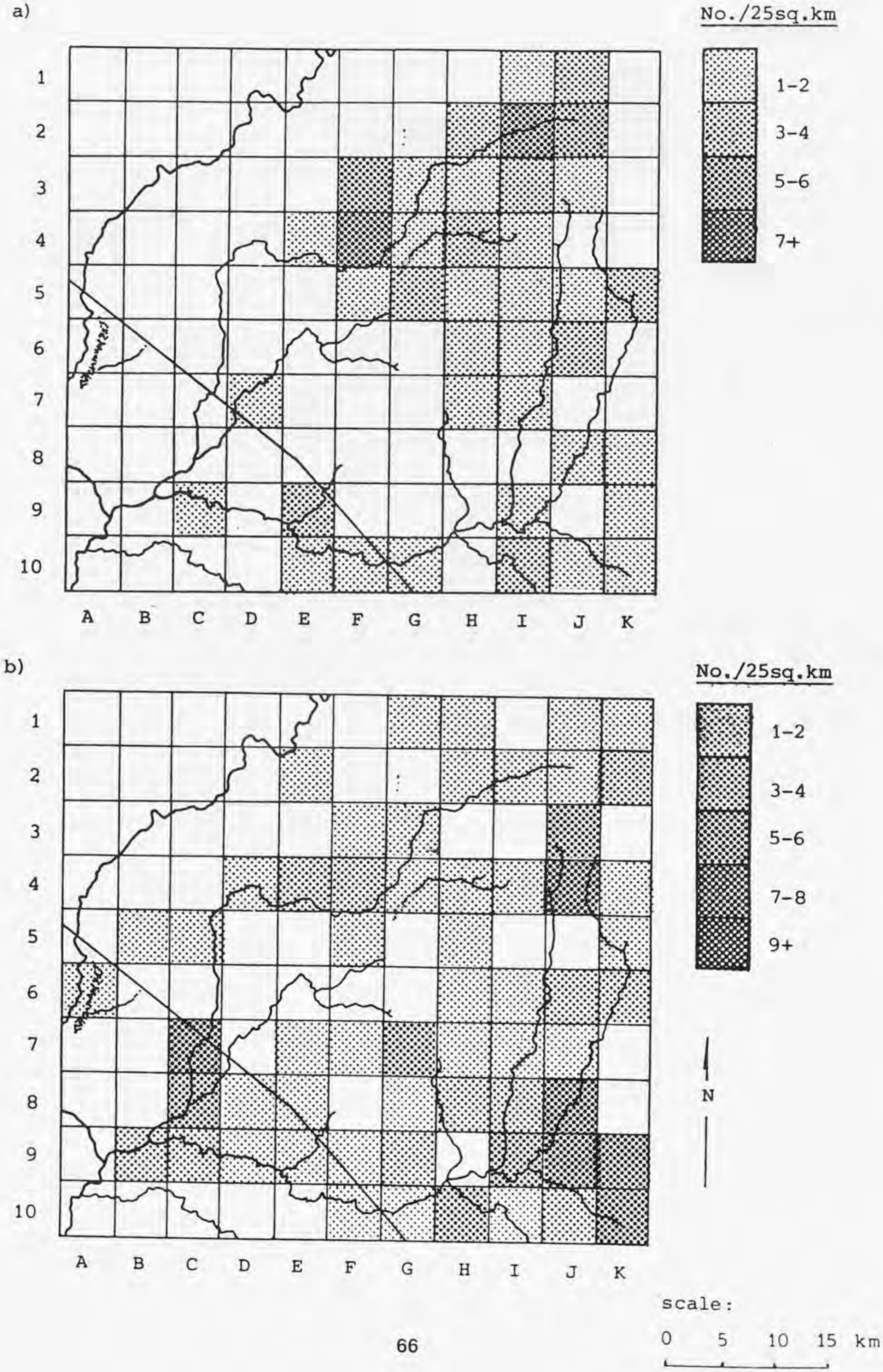
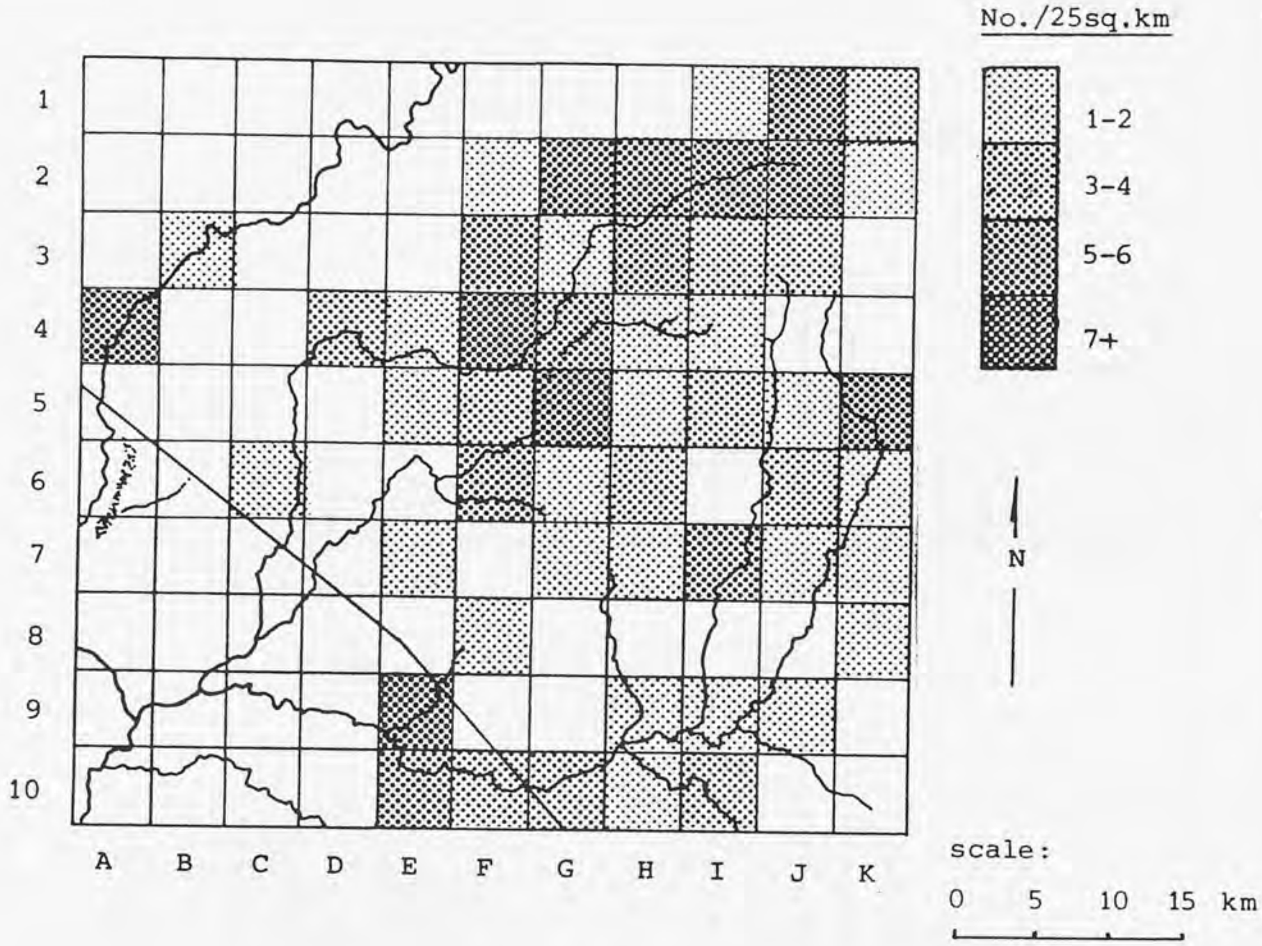


Fig. 4.5: Manyatta distribution and density, 1983.



Figs.4:6a)-e). The number of huts per manyatta for a) 1950, b) 1961, c) 1967, d) 1974 and e) all data combined (which includes data from 29 settlements in 1983): in e) the frequencies are expressed as % frequencies.

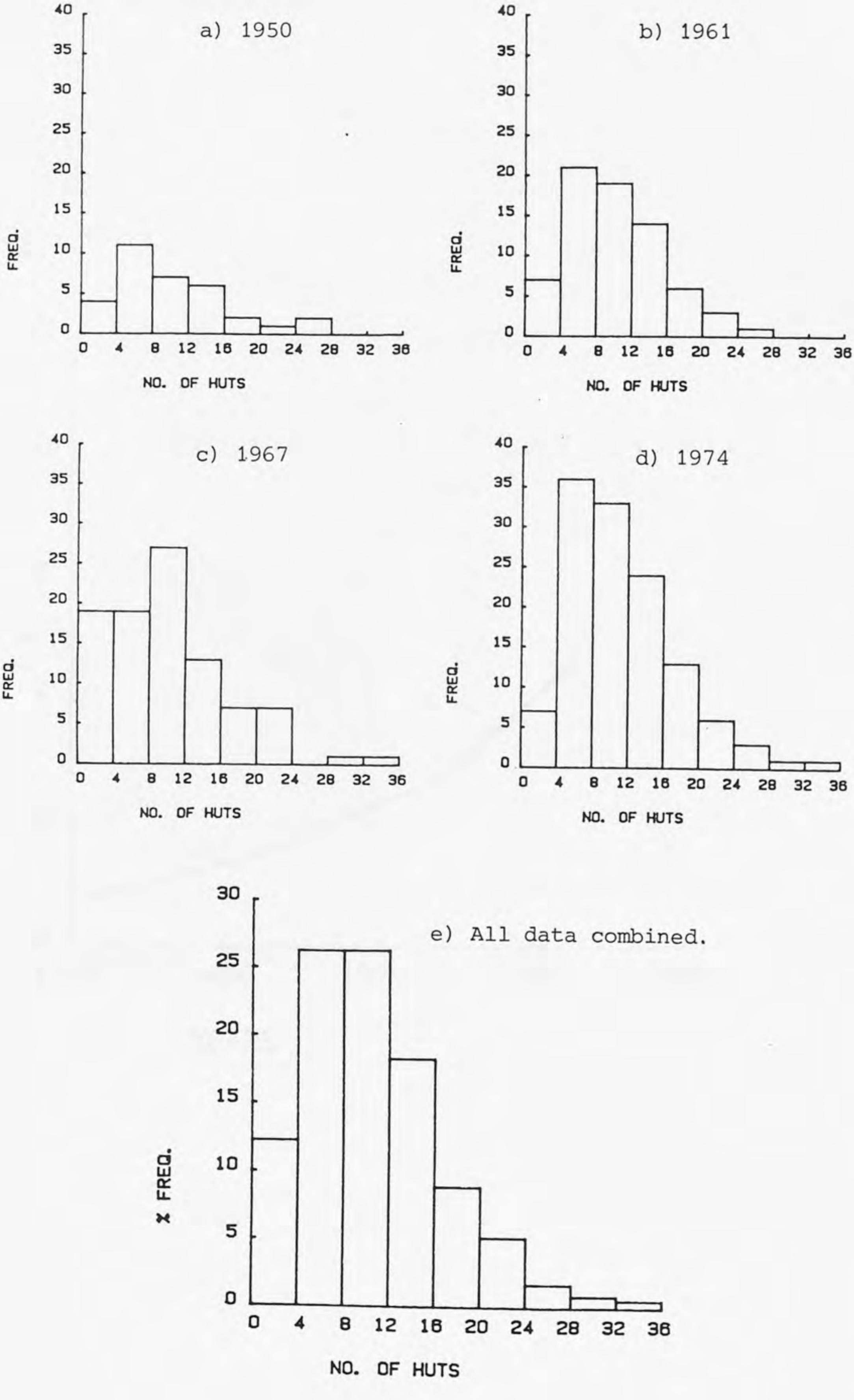


Fig. 4:7. Population density changes in the study area. The unbroken line represents the trend calculated from settlement numbers (using a mean of 51 people.manyatta^{-1}); the dotted line shows the trend calculated from national census data which also includes the densely populated Ololunga area. The differences in the trends may also result from the exclusion of itinerant Maasai from the 1983 estimate of the mean number of people per hut (see text).

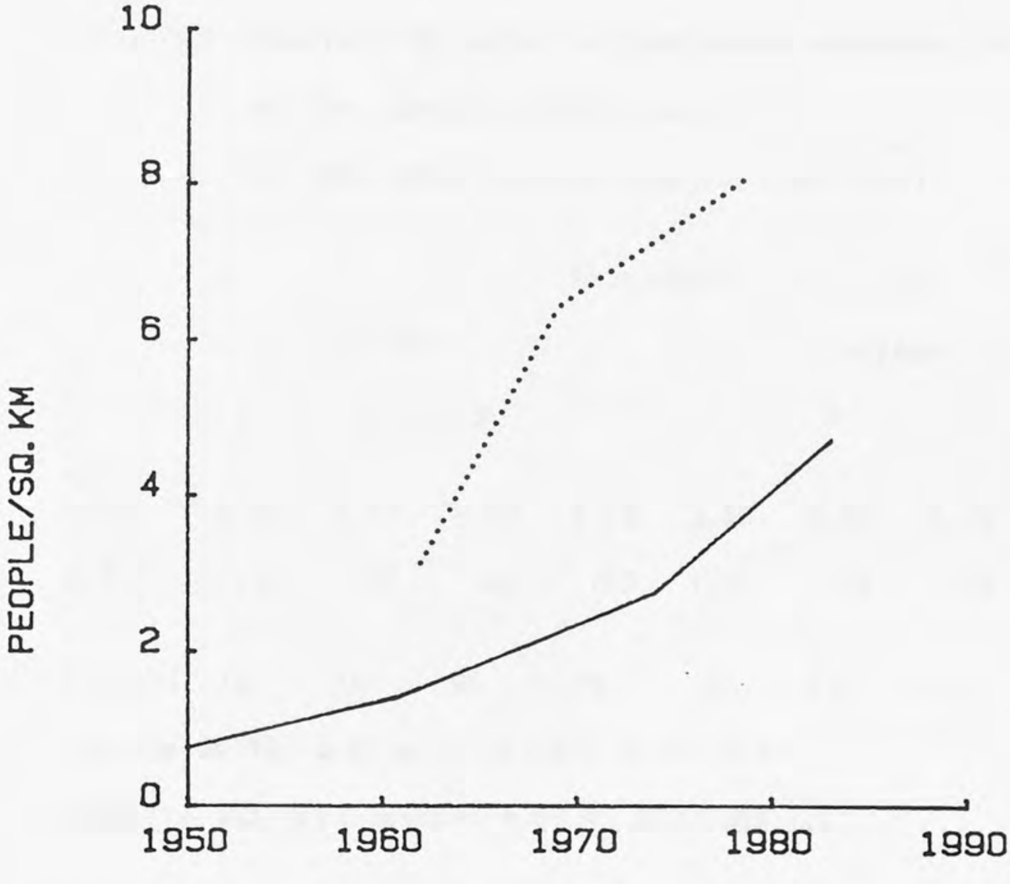


Table 4:1 Analysis of the number of huts/manyatta for the 5 years of aerial photography

	1950	1961	1967	1974	1983
Mean	10.97	10.66	10.31	11.78	10.72
S.E.	1.06	.63	.69	.55	1.29
n (manyattas)	33	71	94	124	29

One-way ANOVA: d.f. = 4, 346: F = 0.85: N.S.

Mean for all years: 11.00 ± .649 (95% c.l)

Table 4:2 Analysis of number of people/hut according to

a) No. individuals/hut and

b) No. adult equivalents/hut (see text)

	Manyattas							
	Talek				Koyage			
	1	2	3	4	5	6	7	8
a) Mean	4.30	4.64	4.62	4.79	3.80	5.00	5.15	4.22
S.E.	.40	.67	.25	.60	1.07	.39	.39	.49
N(huts)	10	14	26	14	5	14	13	9

One-way ANOVA: d.f. = 7, 97: F = 0.59: N.S.

Mean for all settlements: 4.66 ± .322 (95% c.l)

	1	2	3	4	5	6	7	8
b) Mean	3.65	3.25	3.23	3.36	2.80	3.29	3.50	3.11
S.E.	.30	.46	.18	.36	.66	.20	.23	.26

N(huts) as for a)

One-way ANOVA: d.f. = 7, 97: F = 0.41: N.S.

Mean for all settlements: 3.30 ± .209 (95% c.l)

Table 4:3 Individuals/family for 15 manyattas, based on 4.66 individuals/hut (see Table 4:2)

Location	Manyatta	huts/gate	individuals/family
	1	1.44	6.71
	2	1.50	6.99
	3	1.71	7.98
	4	1.67	7.78
Lemek valley	5	1.20	5.59
	6	2.00	9.31
	7	1.80	8.38
	8	1.83	8.52
	9	1.71	7.98
	10	2.44	11.36
	11	2.13	9.90
Talek	12	2.22	10.34
	13	2.25	10.48
	14	2.00	9.31
Others	15	1.50	6.99

Mean individuals/family		
	Lemek valley:	7.69 ± .853 (95% c.l)
	Talek:	10.52 ± .973 (95% c.l)
	All manyattas:	8.51 ± .888 (95% c.l)

Table 4:4 Changes in the human population of the study area (cis-Mara portion only) from 1950 to 1983, based on the number of huts/manyatta for that year and 4.66 individuals/hut (see Table 4:2)

	1950	1961	1967	1974	1983
Total No. manyattas	32	62	91	109	204
7% correction (see text)	30	58	85	101	190
Population	1533	2881	4084	5544	9491
Population density (per sq. km)	.75	1.42	2.02	2.74	4.69

CHAPTER 5: QUANTIFYING THE GRAZING GRADIENT

5:1 Introduction

The analysis of livestock numbers and distribution is central to studies in the conservation and management of grazing resources, whether for commercial ranching schemes, or for pastoral development projects. The ability to predict ecological responses to varying grazing intensities hinges on the accurate monitoring of forage availability and forage use. If in Third World countries the political will exists to bring about changes in grazing resource utilization by pastoralists, these predictions can form the basis for new management plans.

In this study the impact of Maasai livestock on the vegetation of the Mara is assessed by examining and quantifying woodland and grassland changes along a gradient of grazing intensity. Having established the direction and magnitude of this gradient, hypotheses 1 and 2 in Section 1:1 can be tested.

In the absence, however, of long-term livestock monitoring data of the Mara, the formulation of grazing simulation models has been necessary. These models are designed to enable the investigator to relate the grazing intensity in, for example, a grid cell, to the distribution and distance of settlements from that grid cell.

The time sequence of remote sensing and SRF data with which to determine livestock distributions and numbers, woodland changes, settlement distributions and grassland standing crop biomass and cover has been shown in Table 1:2.

With reference to this sequence, the models can be derived and tested according to the following rationale.

The simulation models are based on the 1974 and 1983 settlement distributions. If the cattle distributions determined from the 1979-1982 KREMU systematic reconnaissance flights (SRFs) correlate well with the data from the simulation models for both 1974 and 1983, there is a strong possibility that the models are valid. The models can then be used to a) study grassland biomass and cover responses from the 1975 satellite imagery (manyatta distributions are available for 1974), and b) investigate tree size-class recruitment under varying grazing intensities to determine whether bush encroachment has taken place or is imminent.

Little work has been previously undertaken concerning the mathematical analysis of pastoral grazing strategies. However, insofar as the models relate livestock to settlements a number of studies have revealed the strong and obvious association between the two (Cobb 1976; Spencer 1973). Ruthenberg (1976) and Groeneveld (1968) go further to qualitively describe zones of weaker grazing intensity away from settlements and note that zone 'distortion' occurs if the watering point is some distance from the settlement. In the Mara, however, this potentially complicating factor is virtually removed by the fact that settlements are usually located very close to water. The zonation pattern will not be affected if cattle are watered every day or every other day (the latter was generally the case).

This chapter is concerned primarily with the derivation of models which describe the grazing of cattle, the largest livestock biomass component (Stelfox et al 1980). The additional impact of smallstock will be discussed in Section 5:6.

There is a well-known stigma attached to asking pastoralists questions about, and counting, their livestock (Dahl and Hjort 1976) and this is particularly true of the **il-Purko** Maasai. Some of the discussion below therefore relies on qualitative observations that can be supported by other lines of evidence.

5:2 The Simulation Models

In order to determine grazing intensities from settlement distributions, it is necessary to examine the strategies by which an average pastoralist grazes his cattle.

This pastoralist and his family have a certain number of cattle to support them. Using the criteria of Brown (1971) and Pratt and Gwynne (1977) for Ecozone IV in which the study area lies, the family of 8.5 individuals or 6.0 adult equivalents will require a minimum of about 60 animals to provide their needs (Section 5:5 and Chapter 10).

The division of herds into productive and unproductive or 'fora' animals is not common in the Mara. For the purposes of the models, therefore, both productive and unproductive stock are assumed to be herded together. However, a small area around each manyatta is set aside for calves and smallstock. This corresponds to the **olopololi** of the **il-Kisongo** Maasai (Western 1973). An **il-Purko olopololi** generally comprises that area within the 500 m radius of the manyatta, although this area is commonly offset to an area adjacent to the manyatta with well defined boundaries such as watercourses or roads.

According to the Maasai that were interviewed, the approximate maximum distance they are prepared to take their cattle away from a manyatta is 10 km. Terrain features were pointed out to indicate this distance, which is the same as that suggested for the **il-Kisongo** Maasai by Western (1973).

The pastoralist (or his son) therefore leaves the manyatta with his cattle in the early morning, grazes them to a maximum distance of about 10 km, and then brings them back to the manyatta in the evening at around 7.00 p.m.

Two models are described, and for reasons that will be discussed, both are tested using KREMU SRF data for the area corresponding to Koyake Group Ranch only. Both models make the following assumptions:

a) That topography does not influence grazing intensity. With the exception of the west face of Kipleleo hill, no hills inside the study area were found to be too steep for cattle, and the topography of Koyake Group Ranch itself is remarkably uniform.

b) That group ranch boundaries are ignored. In the field there was irrefutable evidence that this was so. Many rutted cattle tracks link Koyake Group Ranch with both Lemek and Ol Kinyie Group Ranches. This continued movement of stock across group ranch boundaries, documented for both Narok District group ranches (Doherty 1979) and Kaputei group ranches (Halderman 1972) is considered to be one of the main failings of the group ranch system (see Section 2:4).

c) That settlements are located close to water.

To derive the models, the grazing pressure away from a manyatta can be examined with reference to a series of concentric circles of increasing diameter surrounding the settlement (Fig. 5:1).

Model 1 This model assumes that all forage within 10 km radius of the settlement is utilized equally and that grazing intensity does not become greater closer to the manyatta. Thus, in Fig. 5:1, the density of cows is the same for ring 5 as it is for ring 1. Throughout the day cattle herds belonging to the pastoralists are evenly distributed throughout the 10 km radius 'circle of influence' of the settlement.

In this model the livestock density (D) (animals.km^{-2}) at the centre-point of a given grid cell follows the equation:

$$D = k_1 . N_r$$

where N_r is the number of settlements within 10 km of that point and k_1 is a constant.

Model 2 If the average Maasai pastoralist leaves the settlement with his cattle at 7.00 a.m. and slowly grazes them away from the manyatta at about 2 km.hr^{-1} to the maximum distance of 10 km, before bringing them back to the settlement at the same rate in the afternoon, he will remain in each ring in Fig. 5:1 for approximately the same length of time. In Fig. 5:2 it can be determined that ring B, with mean radius 10 km, has 10 times the area of ring A, with mean radius 1 km. Grazing intensity is proportional to the reciprocal of the distance to the settlement and therefore increases towards the settlement. At a grid centre-point the livestock density (D) becomes:

$$D = k_2 (\Sigma (1/d_r))$$

where d_r is the distance in km of each settlement within 10 km.

Both models provide, through an exclusion of the k_1 and k_2 terms, indices of grazing intensity. These indices can be simply converted, by the inclusion of the constants k_1 and k_2, to livestock density once the mean number of cattle/manyatta is known.

The KREMU SRFs were based on a 5 km UTM grid sampling system. The models were designed to determine the grazing intensity at the centre of each 5 km grid cell of the study area.

An Apple II microcomputer was used for the calculations. The southwestern corner of the study area bcame the 0,0 origin of a cartesian plot and the 1 km grid co-ordinates of each settlement for the years 1950-1983 were entered as a 'data sequence'. The distance of the 5 km cell centre-point to each settlement was measured by Pythagoras' theorem, and the 'maximum livestock range', beyond which settlements did not contribute to the Model 1 or Model 2 data value for the 5 km cell, could be varied. Two maximum livestock distances were used in the calculations, 10 km and 15 km.

The Models 1 and 2 10 km and 15 km index values for each 5 km grid cell, for 1974 and 1983, are shown in Appendix D.

5:3 Validation of the Models

The simulation results were tested against the KREMU SRF data for the 13 surveys of 1979 and 1980, and the 7 surveys of 1980-82.

KREMU systematic reconnaisance flights follow the methods laid down by Jolly (1969) and described by Norton-Griffiths (1978) and Stelfox and Peden (1981). The aircraft is accurately flown, at an altitude of 100 m a.g.1. measured by a radar altimeter, along the centre of a series of 5 km grid cells. The pilot of the aircraft calls the code number of the 5 km grid cell as the aircraft enters it. A front seat observer records environmental variables such as presence of water bodies, grass greenness and vegetation type, whilst observers in the rear seats count all animals that pass between markers on the wing struts, or the windows, of the aircraft. In KREMU SRFs these markers are aligned to delimit a ground strip width of 125 m on each side of the aircraft, giving a combined width of 250 m and a 5% sample size. In the Mara surveys 12 species of herbivore are counted (Stelfox <u>et al</u> 1980), including cattle and smallstock. Sheep and goats cannot be distinguished from the air and are referred to as 'shoats'.

Animal census data collected by this method are subjected to the statistical analysis formulated by Jolly (1969). This procedure will be followed in Section 5:5 to determine the number and standard errors for the livestock population of the study area, and thereby obtain approximate values for k_1 and k_2 in the models. The testing of the model data in this section relies on the use of the unprocessed SRF livestock distribution data and of the index values of the simulation models.

Only systematic reconnaissance flight data relating to Koyake Group Ranch were used to examine the validity of the models for the following reasons:

a) According to the SRF data maps retrieved from the KREMU computer storage system, 9 of the total of 11 1979 aerial surveys did not extend further north than the northern border of Koyake Group Ranch.

b) The boundaries of Koyake Group Ranch correspond well with the boundaries of a regular array of 5 km UTM grid cells. This array can be easily converted, by the averaging of four adjacent 5 km cells, to an array of ten 10 km cells: the latter are coded I-X (Fig. 5:3).

c) Koyake Group Ranch is entirely contained within the study area. The model data values will not be much affected by the presence of settlements, lying outside the study area, that were not recorded in the settlement counts.

d) The valuable assistance of key members of this group ranch provided supporting information with which to critically examine model and SRF data.

e) Koyake Group Ranch lies adjacent to the Maasai Mara National Reserve. The greatest human and livestock population pressure on the reserve originates from this group ranch.

Simulation model and SRF data, gathered on the 5 km grid basis are averaged into the ten 10 km grid blocks in Fig. 5:3 to reduce sampling variability and exert a 'smoothing' effect on the data. For each 10 km block in Fig. 5:3 the following simulation data have been calculated:

a) Models 1 and 2 10 km and 15 km index data for 1974

b) Models 1 and 2 10 km and 15 km index data for 1983

c) Models 1 and 2 10 km and 15 km index data for 1979, taken as the mean, or 'half-way point' between 1974 and 1983; this assumes a linear increase in grazing intensity in each block between the two years.

Similarly, for each 10 km block, the following adaptations have been made to the KREMU SRF data:

a) The number of cattle counted in all the surveys for each 5 km sampling unit were totalled on the yearly basis and the seasonal basis. For example, in block III, for the 13 1979-80 surveys, a total of 5514 cows were counted, representing the sum of all cattle counted within the four 5 km subunits; 3532 of these cattle were counted in the surveys of November-June (the wet season) and 1982 were counted from July-October (the dry season). All cattle number data were then converted to mean cattle densities for the subsequent model validation analysis. For the purpose of this analysis the survey of 5th June 1979 is considered a wet season survey.

b) The 'occupance' of each block by cattle has been determined, adapted from the method of Pennycuick (1975). Occupance is calculated on a presence/absence basis and represents the percentage of the total number of surveys in which cattle were counted in the 5 km subunits of the 10 km block. Thus, with the 13 1979-80 surveys and 4 sampling units in each 10 km block, the 52 potential 'sightings' of cattle in a 10 km block are equivalent to an occupance of 100%.

Occupance may be a more accurate indicator of grazing intensity than the SRF cattle density estimates. Systematic reconnaissance flights give the best results, with the lowest standard errors attached to their population estimates, when the individuals of the species to be counted are distributed randomly over the area (Norton-Griffiths 1978). Very significant errors arise, with an increase in the standard error/mean ratio, when animals such as cattle or smallstock occur in herds (Pennycuick and Western 1972; Caughley 1974; Pennycuick et al 1977; Norton-Griffiths 1978). The estimates of cattle numbers for Koyake Group Ranch, calculated according to Jolly's 'Method 1' (Jolly 1969) and presented in Table 5:6 reveal this variability. A presence/absence occupance analysis, therefore, would tend to compensate for the counting difficulties experienced by KREMU aerial survey observers with regard to these clumped distributions.

KREMU systematic reconnaissance flights are undertaken in the mornings between 8.30 a.m. and 11.00 a.m. (Stepanowich pers. comm.). By 11.00 a.m. most of the cattle herds will be well on their way to their grazing destinations and it is unlikely that SRF timing will adversely affect any conclusions drawn concerning livestock distributions.

Finally, in order to reduce the chance that correlations between simulation model and SRF data might simply be the result of environmental conditions pertaining to the years 1979 and 1980 (for which count data have been obtained for 11 and 2 surveys respectively) the testing procedure has been extended to cover the years 1981 (4 surveys) and 1982 (3 surveys). To increase 'occupance' and 'cattle density' sample sizes, 1979 and 1980 data have been combined, as have 1981 and 1982 data.

Model 1 and Model 2 data for the 10 km and 15 km maximum livestock ranges for blocks I-X of Koyake Group Ranch, are presented in Table 5:1. Seasonal cattle density and occupance data are shown in Table 5:2.

All model and SRF data were tested against each other using the (product-moment) correlation coefficient option available with the MINITAB statistical package (Ryan _et al_ 1981). The correlation coefficients (r) for the 10 km models are shown in Table 5:3 and for the 15 km models in Table 5:4.

The regression equations for some of the more important relationships in Tables 5:3 and 5:4 are presented in Appendix E.

With the exception of the 1981-82 wet season data, all occupance data are significantly correlated with 10 km and 15 km model data. In simple terms, the probability of counting a cow or cows in a block is directly proportional to the number of settlements within 10 km or 15 km of the block (Model 1). The probability is also proportional to the sum of the inverses of the settlement distances (Model 2). Density data are also correlated with the models for all SRF data sets except the 1981-82 wet season and 1981-82 yearly means. It is surprising that cattle occupance for the 1981-82 yearly means correlates well with the models, whilst cattle density does not. There are three possible reasons for this observation:

a) In Chapter 10 the concept is explored that the total number of cattle counted/number of cattle sitings gives an estimate of mean herd size. It is possible that the discrepancies between cattle occupance and cattle density in 1981-82 reflect a greater variability in herd size in these years. This herd size variability may result in a more even cattle density over the group ranch, such that the density vs model relationship disappears, at least over the wet season. This suggestion is consistent with the Maasai assertion that, during recent wet seasons, they have been dispersing their cows into TLCs (such as those at Enkikwe) more than they used to in the 1970s.

b) Significant correlations between density data and model data may not emerge over 7 aerial surveys in 1981-82, compared with 13 surveys in 1979-80.

c) Difficulties with observer reliability and motivation over 1981-82 may have led to erroneous counting. However, this is more likely to have affected estimates for livestock numbers than livestock distributions (Peden pers. comm.), and the models are sensitive to the latter.

This analysis suggests that both simulation models are valid for both 10 km and 15 km ranges. Both Models 1 and 2 are, in fact, highly correlated with one another (for the 1974 10 km Model 1 and 2 data r = .946: for 1983 data r = .941) and the reason for this can be deduced from an examination of Fig. 5:2. If settlements are scattered relatively evenly within specific areas, there are likely to be ten times as many settlements in ring B as in ring A (with 1/10th the area).

Occupance is significantly related to cattle density for both 1979-80 and 1981-82, and, with the exception of the wet season of 1981-82, for the wet and dry seasons of these periods.

The use of the Enkikwe area (blocks I and IV) as a wet season grazing area (see Section 4:3) is not readily apparent from the SRF data, although Table 5:2 indicates that the 1981-82 occupance of this area was marginally higher in the wet season than it was for the dry. This is the case for all blocks, however, since by 1981-82 the Maasai were moving a large proportion of their cattle out of the study area for the duration of the dry season (see Section 10:3:ii). The rainfall over the 1979-82 period was reasonably typical, although the 1982 'dry season' total was greatly increased by exceptionally heavy rain in November of that year. There is therefore no reason to suspect that the agreement between the models and the SRF data is linked to any unusual rainfall patterns. The rainfall for 1979, in which 11 of the 20 SRFs were flown, is shown in Fig. 5:4a)-c) for Aitong, Keekorok and Ololunga.

5:4 A Further Statistical Analysis of Livestock Distribution

To reexamine the relationship between cattle and settlement distributions, X^2 (chi-squared) tests were performed to test the null hypothesis that there is no association between the two. Again using SRF cattle distribution data of Koyake Group Ranch, 2 x 2 contingency tables were prepared, with the sub-cells indicating:

a) the number of 5 km grid cells in which cattle and manyattas occurred together

b) the number of 5 km grid cells with cattle only

c) the number of 5 km grid cells with manyattas only

d) the number of 5 km grid cells with neither manyattas or cattle.

The procedure was applied to the wet and dry season SRF data of the 1979-80 period and the 1981-82 period. The 1979-80 SRF data were tested against both the 1974 and the 1983 settlement data, whilst the 1981-82 SRF data were tested against the 1983 settlement data only. All X^2 tests were significant ($p < 0.01$) and the strengths of the associations were tested using Cole's Coefficient of Association (Cole 1949), a test used to examine the relationship between animal distributions and other environmental factors (Field and Laws 1970; Sinclair 1974; Western 1979): a value of +1 indicates complete association, -1 complete avoidance and 0 random association. The results are shown in Table 5:5.

All of the Cole's tests of association reveal a consistent positive association of cattle with settlements. This association varies from .30 - .38 for the 1974 settlement distribution and .39 - .46 for the 1983 distribution. According to this presence/absence analysis, the strengths of the associations do not differ significantly (statistically) from season to season, although the lower association in the 1981-82 wet seasons may suggest a greater dispersion of cattle. This suggestion is supported by the presence/absence 'occupance' analysis of the previous section. However, the model analysis, and the statistical procedures described in this section indicate that, over the whole year, cattle densities are closely linked to settlement distributions.

These tests rely of the selection of an appropriate sampling unit (Western 1979). It is likely that, in this analysis, more accurate results could be obtained if livestock were monitored accordingly to a 2 km rather than a 5 km, grid base. However, this would be prohibitively expensive.

5:5 The Analysis of Cattle Numbers

In order to calculate the constants K_1 and K_2 in Models 1 and 2 respectively, and obtain empirical estimates of cattle densities, it has been necessary to determine cattle numbers for Koyake Group Ranch and for individual manyattas. This has not been easy, for reasons mentioned at the start of this chapter; the Maasai have been very reluctant to give me these figures directly. In the Amboseli area, Western (1973) determined the number of cattle/manyatta by photographing herds from the air in the early mornings before they had left the manyattas. It was not possible, however, to implement this method in the Mara because an aircraft was never available at this time. The analysis was therefore undertaken in the following ways:

a) KREMU SRF data of Koyake Group Ranchwere analysed using Jolly's (1969) 'Method 1' statistical procedure.

b) Cattle dipping records for the 4 cattle dips of Koyake Group Ranch were consulted to calculate mean herd sizes.

c) Information from other sources has been collected.

a) Analysis of SRF Data

With a total strip width of 250 m and a 5 km grid base, each KREMU SRF represents a 5% sample. Jolly's Method 1 has been employed to give the mean and standard errors for the cattle population for the 11 1979 SRFs which covered the 40 5 km blocks of Koyake Group Ranch. The calculation is conducted as follows (from Norton-Griffiths 1978):

N = the total number of units in the population, in this case $(5000/250) \times 40 = 800$

n = the number of sample units in the sample: 40 units

y = the number of animals counted in a unit, obtained from the KREMU computer printouts

$\bar{y}$ = the sample mean = $\Sigma y/40$

S_y2 = the sample variance

$$= \frac{1}{n-1} . \{ \Sigma y^2 - \frac{(\Sigma y)^2}{n} \}$$

Population total $\hat{Y} = N.\bar{y}$

Population variance $\text{Var.}(Y) = \frac{N(N-n)}{n} . S_y2$

Population standard error $\text{S.E.}\ (\hat{Y}) = \sqrt{\text{Var.}(Y)}$

95% c.l. of $\hat{Y} = t.\text{SE}\ (\hat{Y})$

where t is for n - 1 degrees of freedom: 39 d.f.

The results of this analysis are shown in Table 5:6 in which the estimates from all 20 SRFs are presented with their standard errors. The estimates are very variable and their standard errors very high, probably as a result of the 'clumping' of the cattle into herds (see previous section). However, these estimates from 1979-80 are not significantly different from one another (F ratio: mean of variances/variance of estimates = 1.535: NS) (Norton-Grifiths 1978) and they can be combined to give a total cattle population estimate for 1979-80 of 33,551. This estimate is then increased by a factor of 1.18, according to the recommendations of Stelfox et al (1980) to obtain a cattle population estimate, for Koyake Group Ranch, of 39,590.

Assuming a linear increase in the number of manyattas in Koyake Group Ranch between 1974 and 1983, the mean number of cattle/manyatta is 566. Calves can probably be excluded from this figure. They generally spend most of the day lying down in the **olopololi** and would almost certainly be confused with smallstock in the SRFs.

b) Analysis of Dipping Records

There are 4 cattle dips in Koyake Group Ranch: at Aitong, Koyage, Talek and Mara Rienda. The Maasai herd owners of a locality, usually married men, bring their herds to be dipped as often as they can afford. Their names are entered in a register and the number of cows and the number of calves is recorded. The definition of a 'calf' is somewhat subjective but it usually refers to an animal less than a year old that is still kept on the **olopololi** or calf grazing area. It was hoped that the records would give an accurate indication of cattle numbers in the vicinity of the dip but complications arose when it was found that:

a) A man may bring a relative's cattle to be dipped at the same time as his own.

b) Some people may dip their cattle much more often than others and extreme caution was needed to avoid 'double-counting'.

c) With the exception of Koyage dip there was no dipping order by manyatta. At Koyage a systematic procedure was adopted whereby all cattle from manyatta A would be dipped, then cattle from manyatta B and so on.

Despite these difficulties it was felt that the examination of dip records would provide reasonably accurate information on herd sizes. On the basis that there are 6.0 families/manyatta (calculated from Section 4:3), or, in other words, 6 married men, cattle numbers per manyatta can be determined (mean herd size x 6.0).

Cattle data from three dips, Koyage, Aitong and Mara Rienda were combined to calculate the mean number of cattle per married man. The frequency histograms of adult cattle herds and cattle-with-calves together are shown in Figs. 5:5a) and b). The histograms are skewed towards large cattle herds owned by the wealthier Maasai, a 'lognormal' distribution that also has been observed in the Kaputei group ranches (Bekure 1984). The mean adult cattle group size is 104.8 ± 8.2 (± S.E: n = 144) and the mean cattle-with-calf group size is 129.9 ± 9.8 (±S.E: n = 144). This gives an estimate of 629 adult cattle, or 779 adult cattle-with-calves for each manyatta.

However, because the group size distributions are skewed, the mode categories of the distributions will be more descriptive of group sizes than the means. The modes of the distributions in Figs. 5:5a) and b) lie in the 50-100 cattle categories, which approximates to the estimated minimum of 60 cattle required to support a family of 8.5 individuals or 6.0 adult equivalents (Brown 1971; Pratt and Gwynne 1977). The majority of Maasai in the Mara are therefore living close to the minimum pastoral subsistence level, although herd size means are increased by the presence of a few, very large, individually owned herds of 400-600 cattle.

At Koyage in June 1983 seven manyattas had dipped their total of 5289 adult cattle and 1136 calves. This suggests that there are approximately 760 adult cattle, or 918 cattle-with-calves for the average manyatta.

By treating each cattle dip as a single sample, calves made up 18.4% ± 2.16% (±S.E: n = 3) of the total cattle population. This estimate compares well with other estimates obtained for Maasai and Samburu herds (Jahnke et al 1974; Lewis J.G. 1980; Jacobs 1965; Dyson-Hudson 1980) and for models of 'generalized pastoralist herds' (Dahl and Hjort 1976). The first reasonably thorough cattle census for Narok District in 1939 gives an **il-Purko** cattle herd structure of 20.6% calves, 67.1% cows, 9.3% steers and 3.0% bulls (Archives 1939). Comparisons between different studies, however, are subject to differences in the choice of cattle categories and should be treated with caution.

c) Cattle Data from Other Sources

The group ranches of Maasailand are each year required to send estimates of their human and livestock populations to the Central Bureau of Statistics in Nairobi, to provide a record of their development and progress. Only Lemek Group Ranch has done so and for 1979 only, when there were 2553 people (the equivalent of 50 manyattas) and 21,381 cattle; a figure of 342 adult cattle/manyatta is indicated. In Section 4:6 it was postulated that smaller Maasai families might be the result of a lower livestock number/manyatta as the 'carrying capacity' is greatly exceeded. The data above would tend to support this supposition.

Using the data obtained from the 3 methods outlined above, a 'conservative estimate' of 600 adult cows/manyatta was decided upon, or 750 cows and calves. The model constants K_1 and K_2 could then be calculated by simple trigonometry such that;

K_1 for the 10 km Model 1 = 1.9

K_2 for the 10 km Model 2 = 9.5

K_1 for the 15 km Model 1 = 0.8

K_2 for the 15 km Model 2 = 6.4

These constants have been calculated according to a cattle density estimate of 600 cattle/manyatta, because, as I have already suggested, calves cannot be accurately counted in the SRFs, nor do they contribute significantly to the overall grazing pressure. The constants have been inserted into their respective models to test the predictive accuracy of the models against SRF data. In Figs. 5:6a)-d) the 1983 10 km and 15 km model cattle density estimates (for each 10 km block in Koyake Group Ranch) have been plotted against the cattle density estimates calculated from the total of 20 1979-82 KREMU SRFs (see Table 5:2). In only one case, the 15 km Model 1, does the slope diverge significantly ($p < 0.05$) from unity. It would therefore appear that the models, especially those that assume a 10 km maximum livestock range, provide a reasonably accurate estimation of cattle density with respect to settlement distribution.

5:6 The Distribution of Sheep and Goats with Respect to Settlements

According to Stelfox et al (1980), smallstock contribute 1.3% to the total grazing herbivore biomass of the Mara area (see Table 10:1). As I shall show in Chapter 10, smallstock counts per manyatta indicate that for Koyake Group Ranch, sheep and goats may contribute 5-6% of the total herbivore biomass. However, this is low in comparison to the 60-70% contributed by cattle (Table 10:1). Grazing and browsing by sheep and goats was therefore considered to have a relatively low impact on the vegetation, except in the immediate vicinity of manyattas. However, X^2 and Cole's Coefficient of Assocation (C.c.i.a.) tests were performed on 1979 KREMU SRF data to investigate the relationship between smallstock and settlement distribution, and to test the null hypothesis that there is random association between the two. Sheep and goats were significantly associated with the 1983 settlement distribution for the wet season (X^2 = 7.02: d.f. = 1: $p < 0.01$: C.c.i.a. = .34 ± .089: ± S.E.) but not for the dry season (X^2 = 1.98: NS). The Maasai of the Mara have traditionally dispersed their smallstock in the dry season (see Chapter 4), and this is supported by the tests of association described above. However, the Maasai emphasized that TLCs are now more often used for cattle than smallstock (see Chapters 4 and 10) and this was evident from field observations in 1983. Nevertheless, sheep and goat herds were occasionally encountered far from settlements in the dry season.

5:7 Conclusions

The results of this investigation indicate that cattle grazing in the Mara study area follows a distinct pattern that stands up well to simple mathematical analysis. It has been shown that the cattle density of an area is directly proportional to the number of settlements within 10 km range. This has several advantages for this study. For example, changes in grazing intensity through time can be determined for the years in which settlement distributions are available. It may then be possible to predict when the 'carrying capacity' of an area is exceeded and changes in land management are needed. This concept is discussed in more detail in Chapter 10.

Further use has been made of the simulation models in the spatial analysis of green herbaceous biomass and cover using the 1975 LANDSAT satellite imagery (Chapter 9). This has been necessary because no SRF data is available from this time.

The Maasai of the Mara have become relatively sedentary. Areas such as the Lemek valley and Koyage have always been favoured for settlements and these, and other more recent sites such as Talek, tend to 'fill' with settlements before immigration begins into a new area. Manyattas are also located close to water and are occupied on a year-round basis. The simulation models lend themselves particularly well to this type of pastoralism. A number of modifications would be needed before the models could be successfully applied to more 'trans-humant' pastoralists such as the **il-Kisongo** Maasai of Amboseli (Western 1973) or the Rendille and Samburu of northern Kenya (Lusigi 1981).

Fig. 5:1. Zones of grazing intensity around a manyatta (M). This figure is required for the explanation in the text.

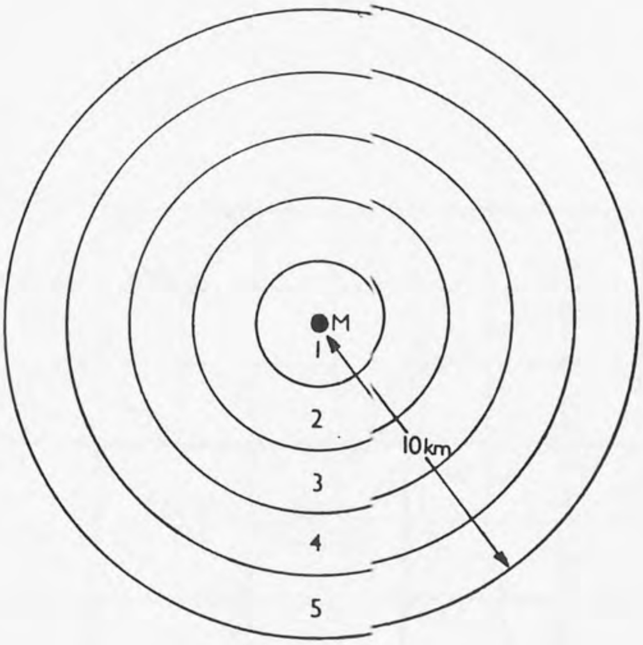


Fig. 5:2. Zones of influence around a manyatta required for the description of the derivation of Models 2.

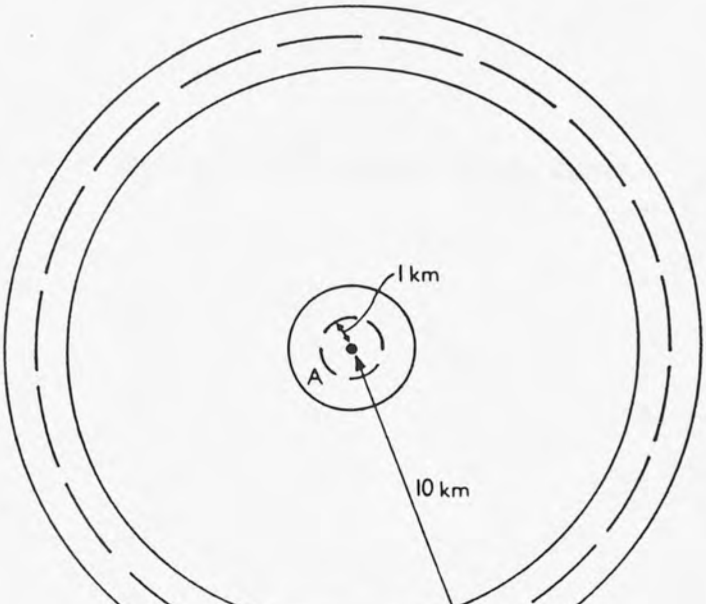
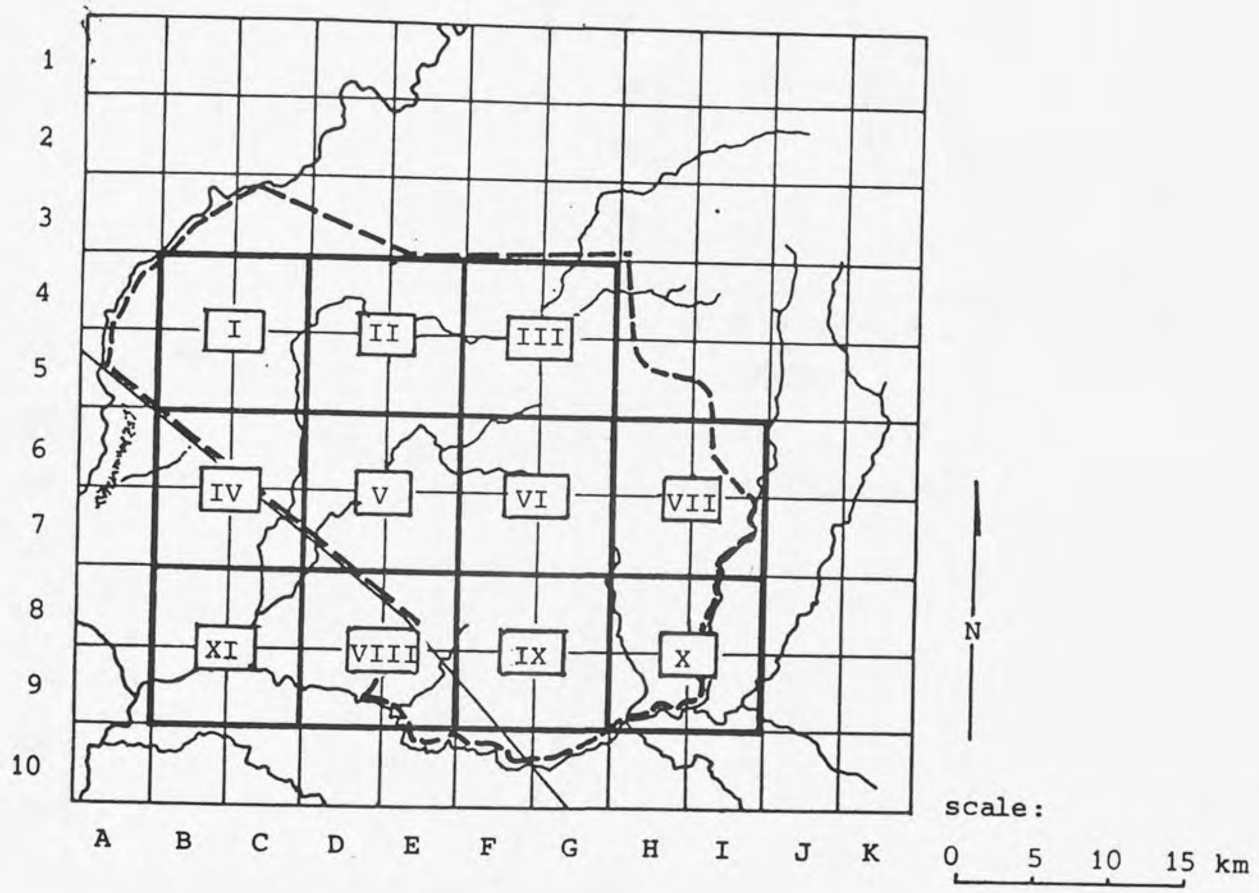
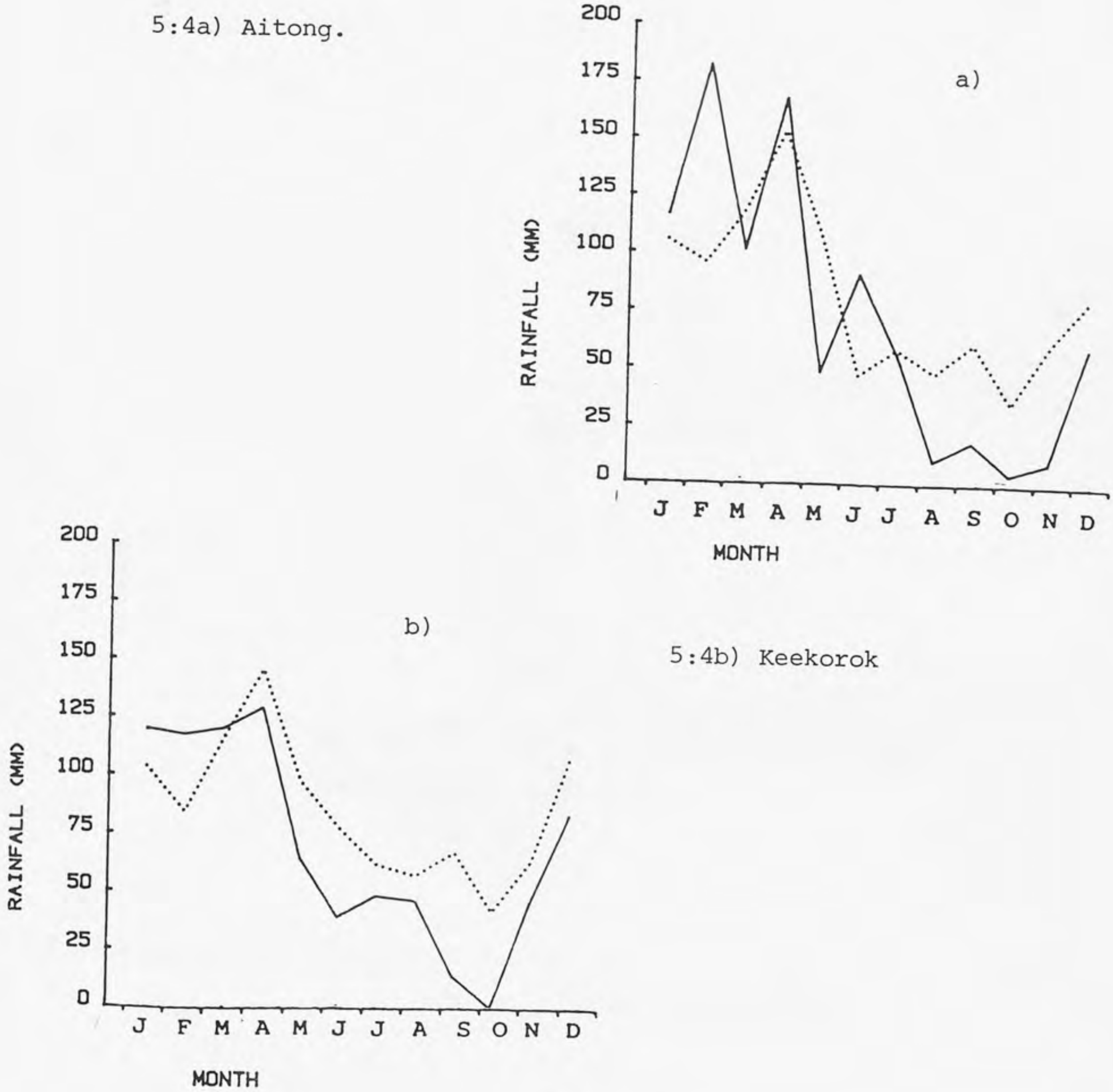


Fig. 5:3. The coding (I-X) of the ten 10 km blocks in Koyake Group Ranch. An additional block, block XI lying within the reserve, is also shown. Reflectance data from this block are used in the LANDSAT reflectance analysis (Chapter 9).



— — — — Boundary to Koyake Group Ranch.

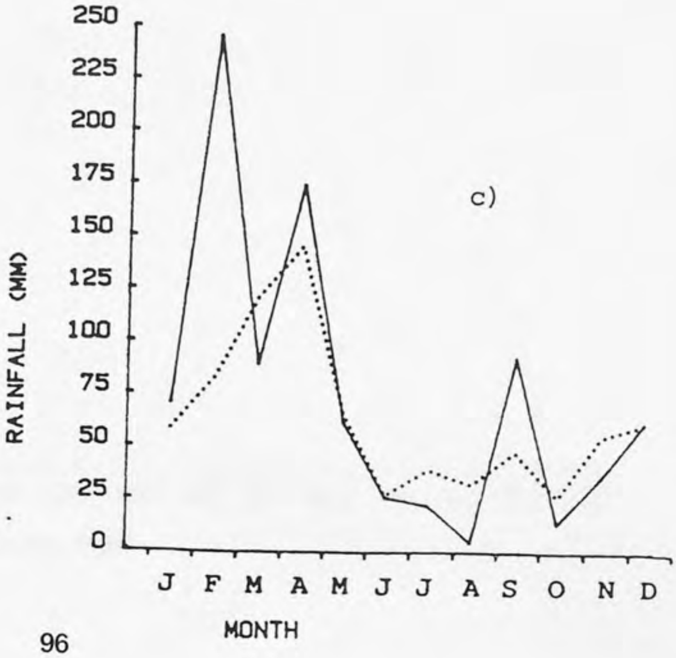
Figs. 5:4a)-c). The 1979 monthly rainfall for three rainguage stations in the Mara area, a) Aitong, b) Keekorok and c) Ololunga. The dotted lines show the mean rainfall for each month for the station.



5:4a) Aitong.

5:4b) Keekorok

5:4c) Ololunga.



Figs. 5:5a) and b). Frequency histograms of a) adult cattle group size and b) cattle-with-calf group size, calculated from cattle dip records from Koyage, Aitong and Mara Rienda.

Fig. 5:5a)

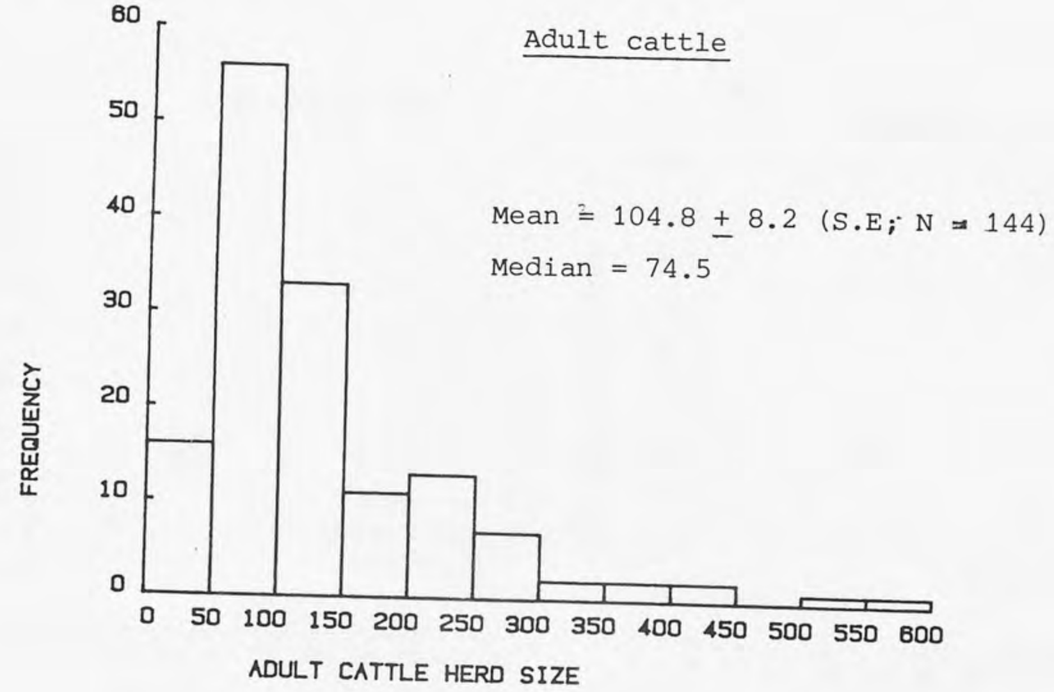
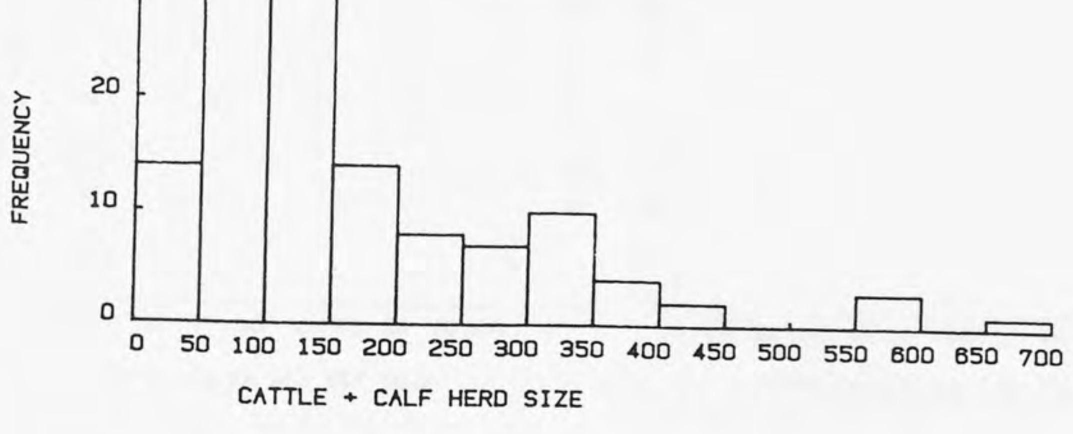


Fig. 5:5b)



Figs. 5:6a)-d). The relationship between cattle densities as predicted by 1983 Models 1 and 2 for a 10 km and 15 km livestock range, and mean cattle densities as calculated from all 20 SRFs.

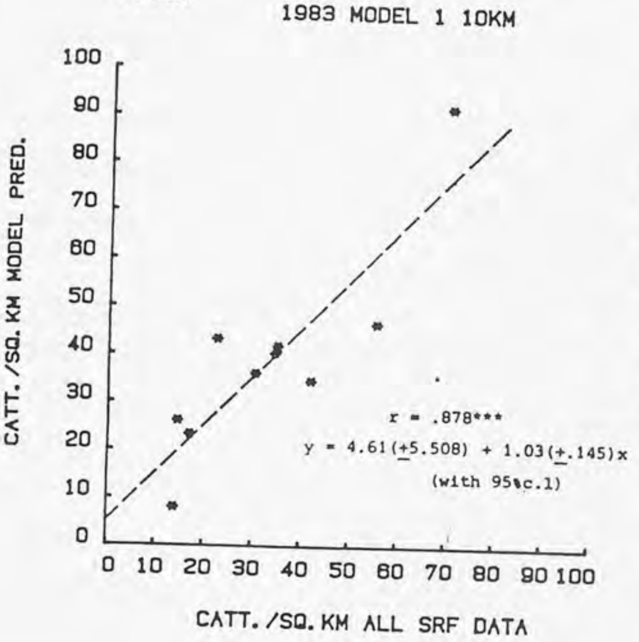
Fig. 5:6a). The 1983 10 km Model 1 against all SRF data.

Fig. 5:6b). The 1983 10 km Model 2 against all SRF data.

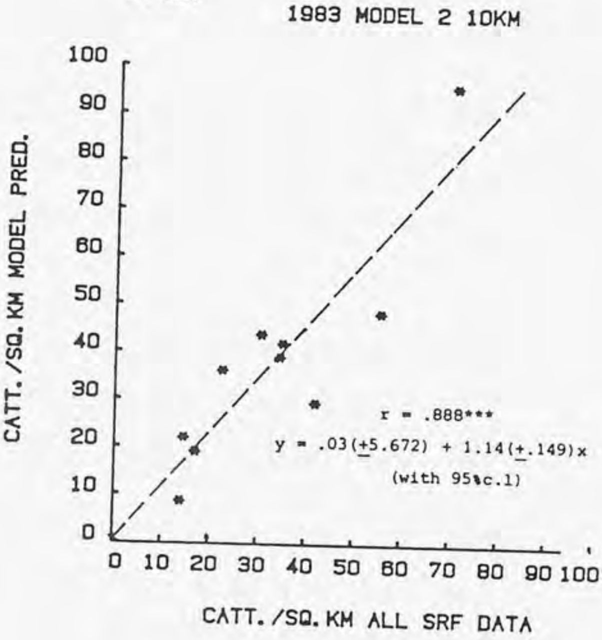
Fig. 5:6c). The 1983 15 km Model 1 against all SRF data.

Fig. 5:6d). The 1983 15 km Model 2 against all SRF data.

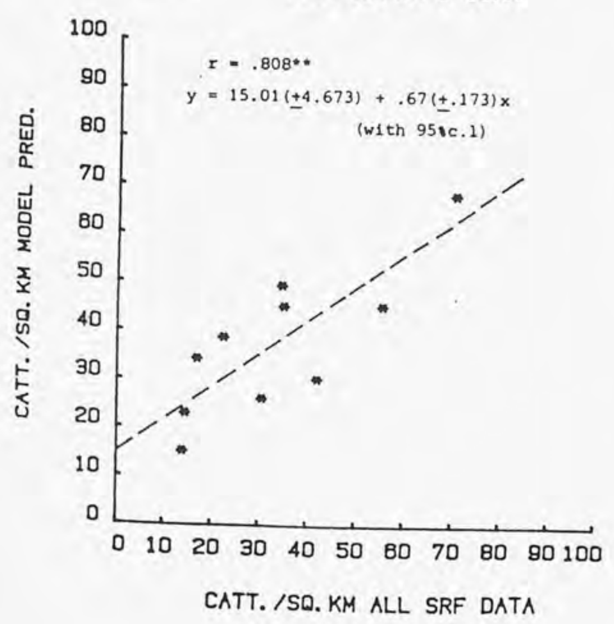
5:6a)



5:6b)



5:6c)



5:6d)

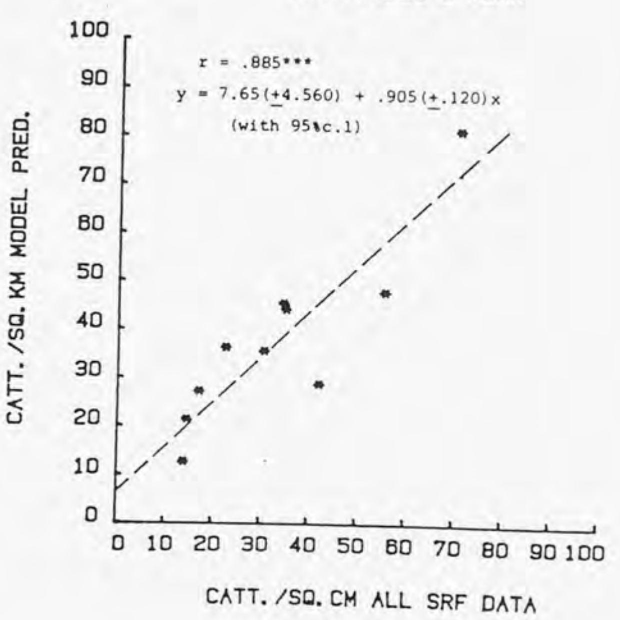


Table 5:1. Models 1 and 2 index data for 1974 and 1983, for a 10km and a 15km maximum livestock range. MV's are the series of 1974-83 model mid-values (see text for explanation). All data presented according to the ten 10km sampling blocks of Koyake Group Ranch (see Fig. 5:3).

	10km Blocks									
	I	II	III	IV	V	VI	VII	VIII	IX	X
10km max. range										
1974 Model 1	0.2	17.0	37.0	1.2	2.0	10.2	17.7	6.5	7.7	10.0
1983 Model 1	13.7	24.5	48.2	4.2	12.2	21.2	22.0	19.0	22.7	18.2
MV Model 1	7.0	20.7	42.6	2.7	7.1	15.7	19.9	12.7	15.2	14.1
1974 Model 2	0	2.8	8.2	0.2	0.4	1.5	3.8	1.5	1.1	1.5
1983 Model 2	2.3	5.1	10.1	0.9	2.0	4.1	4.4	4.6	3.8	3.1
MV Model 2	1.2	4.0	9.2	0.6	1.2	2.8	4.1	3.1	2.6	2.3
15km max. range										
1974 Model 1	7.3	32.0	56.3	2.8	17.5	37.5	32.8	10.5	18.5	23.5
1983 Model 1	27.0	53.3	80.3	17.8	40.2	58.0	53.0	30.8	45.5	35.5
MV Model 1	17.1	42.6	68.3	10.3	28.9	47.8	42.9	20.6	32.0	29.5
1974 Model 2	0.5	4.1	9.8	0.3	1.6	3.7	5.0	1.8	2.0	2.5
1983 Model 2	3.3	7.5	12.7	2.0	4.2	7.1	6.9	5.6	5.7	4.5
MV Model 2	1.9	5.8	11.3	1.1	2.9	5.4	5.9	3.7	3.8	3.5

Table 5:2. Yearly, wet season and dry season cattle densities (animals.km^{-2}) and occupance (%) for 1979-80, 1981-82 and all SRF data combined (averaged according to seasonal means to avoid bias towards the 11 SRF's in 1979). All data presented according to the ten 10km sampling blocks in Koyake Group Ranch.

	10km Blocks									
	I	II	III	IV	V	VI	VII	VIII	IX	X
<u>1979-80 SRF data</u>										
<u>Yearly mean</u>										
density	4	35	100	7	14	44	47	26	36	64
occupance	8	27	63	11	11	36	36	21	21	35
<u>Wet season</u>										
density	1	31	119	4	17	57	52	28	41	88
occupance	7	25	57	7	14	39	32	21	25	32
<u>Dry season</u>										
density	7	40	78	11	11	28	42	23	29	35
occupance	8	29	71	17	8	33	42	21	17	37
<u>1981-82 SRF data</u>										
<u>Yearly mean</u>										
density	25	76	41	21	20	25	23	35	9	20
occupance	14	39	50	14	21	21	46	29	18	25
<u>Wet season</u>										
density	37	112	47	37	32	2	19	44	8	27
occupance	19	44	56	25	25	6	50	25	19	31
<u>Dry season</u>										
density	8	27	32	0	4	56	29	22	9	12
occupance	8	33	42	0	17	42	42	33	17	17
<u>All SRF data</u>										
<u>Yearly mean</u>										
density	15	56	71	14	17	35	35	31	23	42
occupance	11	33	57	13	16	29	41	25	20	30
<u>Wet season</u>										
density	19	72	83	21	25	30	36	36	25	58
occupance	13	35	57	16	20	23	41	23	22	32
<u>Dry season</u>										
density	8	34	55	6	8	42	36	23	19	24
occupance	8	31	57	9	13	38	42	27	17	27

Table 5:3. Product-moment correlation coefficients (r) between Models 1 and 2 and "occupance" (%) and cattle density (cattle.km^{-2}). Models 1 and 2 assume a 10km maximum livestock range. MV is the series of 1974-83 mid-values (see text for explanation)

	1974 Model 1	1983 Model 1	Model 1 MV	1974 Model 2	1983 Model 2	Model 2 MV
1979-80 SRF data Yearly mean						
Cattle density	.903***	.879***	.904***	.872***	.849***	.873***
Cattle occupance	.938***	.890***	.927***	.913***	.881***	.910***
wet season						
Cattle density	.833**	.819**	.838**	.800**	.778**	.800**
Cattle occupance	.895***	.893***	.907***	.858***	.870***	.877***
dry season						
Cattle density	.988***	.938***	.977***	.966***	.933***	.963***
Cattle occupance	.948***	.852***	.913***	.937***	.860***	.911***
1981-82 SRF data Yearly mean						
Cattle density	.442	.372	.412	.391	.450	.427
Cattle occupance	.891***	.775**	.845**	.894***	.816**	.867***
wet season						
Cattle density	.246	.165	.208	.215	.237	.229
Cattle occupance	.773**	.606*	.698*	.796**	.636*	.725*
dry season						
Cattle density	.535	.536	.543	.477	.562	.528
Cattle occupance	.722*	.711*	.727*	.694*	.747*	.731*
All SRF data Yearly mean						
Cattle density	.926***	.872***	.912***	.877***	.888***	.895***
Cattle occupance	.971***	.888***	.942***	.957***	.902***	.942***
wet season						
Cattle density	.849***	.783**	.828**	.802**	.799**	.812**
Cattle occupance	.972***	.872***	.935***	.964***	.877***	.933***
dry season						
Cattle density	.903***	.871***	.900***	.859***	.881***	.883***
Cattle occupance	.921***	.858***	.902***	.901***	.880***	.903***

*: $p < .05$
**: $p < .01$
***: $p < .001$

Table 5:4. Product-moment correlation coefficients (r) between Models 1 and 2 and "occupance" (%) and cattle density (cattle.km^{-2}). Models 1 and 2 assume a 15 km maximum livestock range. MV is the series of 1974-83 mid-values (see text for explanation)

	1974 Model 1	1983 Model 1	Model 1 MV	1974 Model 2	1983 Model 2	Model 2 MV
1979-80 SRF data						
Yearly mean						
Cattle density	.877***	.813**	.849***	.895***	.851***	.880***
Cattle occupance	.928***	.864***	.900***	.944***	.900***	.929***
wet season						
Cattle density	.836**	.759**	.801**	.834**	.783**	.814**
Cattle occupance	.942***	.902***	.927***	.917***	.909***	.921***
dry season						
Cattle density	.900***	.869***	.889***	.962***	.932***	.955***
Cattle occupance	.882***	.802**	.845**	.939***	.863***	.907***
1981-82 SRF data						
Yearly mean						
Cattle density	.367	.346	.358	.383	.441	.416
Cattle occupance	.781**	.754**	.772**	.873***	.826**	.856***
wet season						
Cattle density	.089	.076	.083	.157	.190	.176
Cattle occupance	.555	.515	.537	.716*	.606*	.665*
dry season						
Cattle density	.724*	.695*	.713*	.597*	.656*	.632*
Cattle occupance	.810**	.810**	.815**	.767**	.816**	.799**
All SRF data						
Yearly mean						
Cattle density	.868***	.808**	.842**	.890***	.885***	.895***
Cattle occupance	.913***	.863***	.892***	.965***	.918***	.949***
wet season						
Cattle density	.747**	.675*	.713*	.791**	.771**	.787**
Cattle occupance	.870***	.824***	.851***	.951***	.882***	.923***
dry season						
Cattle density	.944***	.909***	.931***	.918***	.929***	.931***
Cattle occupance	.924***	.876***	.904***	.838**	.915***	.934***

*: $p < .05$
**: $p < .01$
***: $p < .001$

Table 5:5. The association of cattle with 1974 and 1983 settlement distributions using X^2 and Cole's Coefficient of Association (C.c.i.a.) (see text for explanation). 1981-82 SRF data are tested against the 1983 settlement distribution only.

	Settlements 1974	Settlements 1983
1979-80 SRF data yearly mean		
X^2	43.93***	30.09***
C.c.i.a.	.34 ± .051	.45 ± .082
wet season		
X^2	16.60***	14.84***
C.c.i.a.	.30 ± .073	.45 ± .116
dry season		
X^2	28.14***	15.34***
C.c.i.a.	.38 ± .072	.46 ± .116
1981-82 SRF data yearly mean		
X^2		16.14***
C.c.i.a.		.41 ± .101
wet season		
X^2		9.24**
C.c.i.a.		.39 ± .127
dry season		
X^2		6.96**
C.c.i.a.		.44 ± .166

All Cole's coefficients ± S.E.

* : $p < .05$
** : $p < .01$
*** : $p < .001$

d.f. = 1

Table 5:6. Estimates of the total cattle population of Koyake Group Ranch, calculated from the 20 KREMU SRFs of 1979-82 using Jolly's Method 1 (Jolly 1969). Biomass density has also been calculated using a mean Maasai cow weight of 180 kg (Watson 1972); these data are required in Chapter 10. All data corrected upwards by a factor of 1.18 according to the recommendations of Stelfox _et al_ (1980).

Date of survey	Population estimate ± S.E. (n = 40)	Biomass density $kg.km^{-2}$ ± S.E.
1979		
23/01	38161 ± 16705	6869 ± 3007
26/02	71579 ± 18236	12884 ± 3282
28/03	52911 ± 21839	9524 ± 3931
26/04	30727 ± 102304	5531 ± 1837
05/06	33512 ± 14540	6032 ± 2617
02/07	25630 ± 9694	4613 ± 1745
30/07	55106 ± 21304	9919 ± 3835
26/08	29925 ± 11086	5387 ± 1996
05/10	21924 ± 8423	3946 ± 1516
30/10	26479 ± 8028	4766 ± 1445
19/11	49536 ± 18725	8917 ± 3371
1980		
23/06	35896 ± 10596	6461 ± 1907
01/07	23624 ± 11760	4252 ± 2117
1981		
15/01	37359 ± 16303	6725 ± 2935
09/03	14160 ± 7245	2549 ± 1304
27/08	24591 ± 8903	4426 ± 1603
27/10	13310 ± 7748	2396 ± 1395
1982		
22/05	32403 ± 9621	5833 ± 1732
30/08	21830 ± 6015	3929 ± 1083
06/12	68511 ± 21862	12332 ± 3955

CHAPTER 6: THE VEGETATION COMMUNITIES OF THE STUDY AREA

6:1 Introduction

Woodland changes in the Mara over the past 30 years have not been consistent from one vegetation community to the next. There have been marked variations in the ways the different communities have responded to the actions of fire and elephants. Therefore, before woodland changes can be meaningfully investigated by airphoto interpretation, it has been necessary to define and describe the vegetation types of the study area and discuss their origins.

The term 'community' is a very broad one and is open to different interpretations (Greig-Smith 1964). According to Daubenmire (1968b), a community is a "group of species showing coordinate patterns of relative abundance over the landscape", a definition which is adequate for this investigation. In ecological studies ordination techniques, such as the use of similarity matrices and principal components analysis, are being used progressively more to define and make fine distinctions between communities. Examples from East Africa are given by Welch (1960), Barkham and Rainy (1976) and Herlocker (1976).

In this study, however, the use of small scale panchromatic aerial photography precludes a detailed analysis of community composition and changes in composition. Trees appear as very small black dots, and unless the community is characterized by a distinct pattern, and has a very even structure, woodland changes can only be described in terms of 'cover' or 'area'. Ordination techniques, giving a 'one-off' description of the composition of vegetation types that may be changing very rapidly in time, as are those of the Mara, were felt to be too elaborate for a study of this kind. However, a simpler quantitative approach has been adopted, in which the cover of the species making up the community has been recorded using the variable-plot method of Cooper (1957). This method has been used successfully in a number of studies in East Africa (Agnew 1968; Western and Dunne 1979).

The main aim of this chapter is to provide brief descriptions of the vegetation types of the study area, using a classification compatible with the limits set by the airphoto interpretation (Blair Rains 1973), with the rangeland classification of Pratt et al (1966) and with the various vegetation studies that have been conducted in the Serengeti-Mara ecosystem.

The distribution of the communities is also presented in this chapter in the form of maps prepared from interpretations of the vertical aerial photography of 1974 and the oblique photography of 1983.

6:2 The Vegetation Communities

Edwards and Bogdan (1951), in one of the earliest classifications of East African vegetation, placed the Mara area in the 'scattered tree grassland (Acacia-Themeda) zone' whilst Heady (1960) chose a Themeda-Hyparrhenia classification. Talbot (1970), referring to his Mara studies of the early 1960s, divided the vegetation into a number of distinct categories: tall grass and short grass plains, woodland bushland, thicket and riverine forest. Darling (1960) in his ecological reconnaissance of the area also recognized a number of communities, although these are not readily compatible with more recent classifications.

In 1966 Pratt, Greenway and Gwynne provided a new framework for rangeland classification (Pratt _et al_ 1966). The Mara could then be defined as lying within Ecozone IV, the sub-humid zone, and subsequent vegetation classifications of the Serengeti and Mara began to fall into a readily interpretable pattern based on physiognomic and floral characteristics. Trapnell _et al_ (1969) used this classification to prepare 1:250,000 vegetation maps of south-western Kenya for the Directorate of Overseas Surveys Land Resources Division Ecological Survey. However, their vegetation map did not extend further south than latitude 1° 15' south and it therefore covers the northern half of the study area only. 50 vegetation types in Narok District were recognized. In a southward continuation of their map, Trump (1972), working with the 1967 aerial photography, reduced this to 18 types, 8 of which lie within the Mara study area.

Further vegetation studies have been conducted by Taiti (1973) and Epp and Agatsiva (1980). The former is not based on the classification of Pratt _et al_ (1966) but provides useful information on soil types and the vegetation in the early 1970s. The study of Epp and Agatsiva relies on the KREMU modification of the Pratt _et al_ classification with a 1:250,000 map prepared by interpretation of the 1961 aerial photography and the manual interpretation of 1975 LANDSAT imagery.

In a detailed study of the vegetation of the Serengeti, Herlocker (1976) presents useful categories into which a number of Mara vegetation types can be placed.

The study of the vegetation of Narok District by Trump (1972) is unique in that the author has based his classification not only on the vegetation as it appeared at the time of study, but on what it was derived from. His classification therefore implies change, and the classification presented in this chapter relies to a certain extent on Trump's interpretations.

Pratt and Gwynne (1977) note that, for Ecozone IV, there is a "strong successional force towards woody vegetation". 'Bush encroachment' should therefore be considered as a seral stage in the successional process. It is with reference to human and naturally induced changes in savanna ecosystems that Glover (1968) has suggested that "the savanna regions of Africa are made up of communities of plants and animals which have been 'deflected' from their normal course of ecological succession by the influence of cultivation, fire, grazing and browsing". In the case of the Mara, vegetation changes have been so rapid (see Chapter 7) that maps based on the interpretation of early sets of aerial photography have become outdated. It is for this reason that the 1983 vegetation map has been prepared for this study.

Rough estimates of the species composition by cover of the different woody vegetation communities were obtained by the following method. Representative areas of each community were preselected from the aerial photography after the mapping exercise (Section 6:3). Cover was measured using the variable-plot method at 20 m intervals along transects of 2-6 km running through the community. This procedure was applied to the Tarchonanthus and Balanites - Acacia seyal communities (see next section). The composition of the Acacia-Commiphora community is described in Chapter 8 (see Figs. 8:3a) and b).

The primary physiognomic vegetation categories of Pratt et al (1966), with references to the vegetation types defined in this Mara classification, are shown in Table 6:1.

Table 6:1 Specifications of the primary physiognomic vegetation categories of Pratt, Greenway and Gwynne (1966), with references to the secondary physiognomic and floral classification of the text.

Primary Physiognomic Categories	Specifications	Text Classification
Forest	Tree cover with closed canopy of one of more strata > 7.5 m tall	Types 1(a) 1(b)
Bushland	Upper stratum of woody plants of low stature and shrubby habit. Minimum canopy cover 21%	Types 2(a) 2(b) 2(c)
Bushed and wooded grassland	Trees and shrubs conspicuous but scattered. Canopy cover 2-20%	Types 3(a) 3(b) 3(c) 3(d) 3(e)
Grassland	Vegetation dominated by grasses. Canopy cover < 2%	Types 4(a) 4(b)

1. Forest: Evergreen Forest

Type 1(a): Euclea-Diospyros Forest (Plate 6:1)

This very diverse community occurs as a wide ribbon along the Mara river between Governor's Camp and the Mara bridge. The upper canopy at 10-20 m is rapidly being opened up by elephants (see Chapter 7). The dominant upper storey trees are *Euclea divinorum* and *Diospyros abyssinica*, but other very common species include *Warburgia ugandensis*, *Cassine buchananii*, *Cussonia holstii*, *Olea africana*, *Garcinia huillensis*, *Pappea capensis*, *Ekebergia rueppeliana* and *Celtis africana*. Along the river banks, figs (*Ficus spp*) and the 'Phoenix palm' (*Phoenix reclinata*) are abundant.

The shrub understorey is composed chiefly of *Teclea trichocarpa*, *T. nobilis*, *Croton dichogamus*, *Grewia trichocarpa*, *Scutia myrtina*, *Zizyphus mucronata*, *Carissa edulis*, *Phyllanthus sepialis* and *Chaetacme aristata*.

Common herbs are *Hibiscus spp*, *Abutilon spp*, *Withania somnifera*, *Allophyllus spp*, *Achyranthes aspera* and *Commelina spp*, whilst abundant grass genera are *Panicum spp*, *Sporobolus spp*, *Brachiaria spp*, *Digitaria spp*, and *Setaria spp*.

This evergreen forest type is also present as a wide band between Ol Doinyo Lalagalesho and the Mara (Amala) river in the north-east of the study area, where a canopy height of 20 m is attained. Relic patches also remain in the Mara Buffalo area. The presence of lone *Cassine buchananii* trees - a forest species (Brenan and Greenway 1949) - in the now open plains of the Mara Buffalo area indicates that the forest Type 1(a) must have been very extensive in this area through the early part of this century. Its destruction through the 1950s and 1960s is described in Chapter 7. The forest in the trans-Mara portion of the study area is also of this type, but in places it has been broken down into a fire-induced thicket clump community where the small forest patches are centred on termite mounds. The foraging activities of the termites (Macrotermes bellicosus), result in local soil nutrient depletion; grass productivity in the areas immediately surrounding the clump is lowered and the clump is protected from fire. (Glover and Trump 1970; Gillet pers. comm.).

Type 1(b): Teclea-Croton Forest (Plate 6:2)

This distinct community is essentially a derivative of forest Type 1(a) where the destruction of most of the upper storey is complete, leaving a tall understorey of Teclea trichocarpa, T. nobilis, Croton dichogamus, Strychnos henningsii and Grewia trichocarpa. However, a few emergents, such as Euclea divinorum, Diospyros abyssinica and Olea africana still survive. This forest type occurs at the junctions of the Jagartiek and Talek, and Talek and Mara rivers. From the latter it extends south along the Mara river to the Tanzania border. In some areas the mean canopy height falls below the 7.5 m criterion for forest (Pratt et al 1966), but, for the continuity of the classification system, it is still placed in the forest category. Trump (1972) describes this type as 'evergreen thicket'.

The soils under these forest types are described as slightly basic at the surface (pH 7.6), with increasing acidity with depth (pH 5.3 at 50 cm) (Taiti 1973). With the exception of phosphorus, all nutrient levels are high, suggesting that nutrient turnover rates are relatively rapid for a tropical forest community. This may be the result of accelerated tree destruction by elephants.

2. Bushland: 'Evergreen and Semi-Deciduous Bushland' (Trump 1972) Type 2(a): Croton Thicket Community

Stands of relatively pure Croton dichogamus are common in the Maasai Mara National Reserve, often on the tops of shallow hills. These thickets are also present in the Maasai areas outside the reserve, especially in the south-east of the study area between Ilbaan escarpment and Segenani hill. Further large patches are located along the western sides of the Ngama hills and Bardamat hill in what would appear to be fire-protected positions (the prevailing winds are easterly). The small hill of Ol Doinyo Orinka in the heavily settled Koyage area is capped exclusively by this vegetation type.

In the Maasai areas the wickedly armed Acacia brevispica is associated with these thickets, which are almost completely impenetrable as a result. Other species found in small numbers in this type are Teclea trichocarpa, T. simplicifolia, Grewia similis, G. tembensis, Tarrena graveolens, Rhus natalensis and Cordia ovalis.. Occasional emergents are Olea africana, Strychnos henningsii, Lannea stuhlmannii, Boscia angustifolia and Euclea divinorum. Isolated Gardenia jovis-tonantis trees can be found at the thicket edges.

Common climbers are Thylachium africanum, Rhoicissus revoilii, Asparagus africanus and Capparis spp.. The herb layer is sparse.

This woody vegetation type can be distinguished from Type 1(b) by its low stature (4-6 m) and almost pure composition of Croton dichogamus. It is one of the most important types in the Maasai Mara National Reserve, providing food for browsing animals and cover for predators. Darling (1960) refers to it as the "lion bush community", and expressed concern over its disappearance from the Mara through burning and elephant damage. Kuchar (1981) considers Croton dichogamus to be relatively unpalatable to stock and wild herbivores. However, it is an important food source for the black rhinoceros, Diceros bicornis, (Muckinya 1973) and as current research indicates, for elephants (Loxodonta africana) (Dublin pers. comm.). Croton bushland is much favoured by the tsetse fly Glossina swynnertoni.

Trump (1972) believes that this vegetation type is derived from evergreen forest, the few emergents remaining as relics. As suggested by its common hillside and hilltop location, the Croton thicket community occurs on well drained, rather sandy and gravelly soils (Taiti 1973; Trump 1972), which are slightly acid (pH 6.0-7.0) and have a chemical composition similar to that of the evergreen forest (Trump 1972). In geological terms its distribution appears to coincide well with areas where the basement system is exposed (Williams 1964), chiefly along the eastern stretches of the Talek river before it branches into the Ol Sabukiai and Kaimurunya tributaries.

Type 2(b): Tarchonanthus ('leleshwa') Community (Plate 6:3)

Tarchonanthus camphoratus (Maasai: **ol-leleshwa**) bushland covers some 7000 km^2 of Kenya's rangelands (Pratt and Knight 1971), where it is considered a 'weed' species and a major constituent of bush encroachment (Ivens 1967, Pratt and Gywnne 1977). Tarchonanthus is a silvery-leaved aromatic bush, notoriously difficult to eradicate due to its habit of coppicing from cut or burnt stumps. In this study its density has been difficult to determine because there have been problems in defining 'a leleshwa bush' - coppicing frequently occurs from underground root stock.

This vegetation type covers 15% of the study area and notably the heavily grazed Lemek hills, from where, with a gap at Ololunga and the northern Loita plains, it extends eastwards in a band along the base of the Mau range as far as the western side of the Rift Valley. However, there is no firm basis to the assertion that it is spreading as a result of overgrazing (Talbot and Talbot 1961). In the study area Tarchonanthus bushland simply replaces, or is derived from areas of evergreen forest that have been destroyed by fire and elephants (Glover and Trump 1970). Thus, the Ol Kinyie hills, named after the Maasai for Euclea divinorum (the main constituent of Type 1(a) evergreen forest), no longer have any Euclea forest on them but are extensively covered by leleshwa bushland.

Another important characteristic of leleshwa bush is that it is confined to altitudes of between 1700 m and 2700 m (Pratt and Gwynne 1977). The restriction of leleshwa to the heavily utilized north eastern quarter of the study area, which is delimited by the 1800 m contour, would appear to reflect this dependence on altitude rather than the degree of grazing pressure.

Leleshwa is unpalatable to goats (Pratt and Gwynne 1977) except when they are accustomed to it (Pratt and Knight 1971). Where the cover of Tarchonanthus is high grass productivity is very low and annuals such as Eragrostis spp. predominate. The experiments of Pratt and Knight (1971) indicate that grass productivity, especially of Themeda triandra, is much enhanced following the temporary suppression of leleshwa by fire.

The composition by cover of this vegetation type is shown in Fig. 6:1a). The most common species associated with Tarchonanthus are Rhus natalensis, reported to be very palatable to stock, including cattle (Le Houerou and Corra 1980), and another palatable species Combretum molle (Walker 1980). Scattered Euclea divinorum are also present. Although Tarchonanthus is still numerically dominant in the Lemek valley, the leleshwa community in this area becomes very diverse. Other species include Acacia gerrardii, A. senegal, A. xanthophloea, A. seyal, A. nilotica, A. drepanolobium, Grewia spp, Teclea spp, Cadaba farinosa, Cordia ovalis, Ormorcarpum trichocarpum, Dichrostachys cinerea, Euphorbia candelabrum and Cussonia holstii. Of these only Acacia xanthophloea, Euphorbia candelabrum and Cussonia holstii attain a height of greater than about 7 m. Abundant smaller shrubs are Lippia javanica, Clutia spp, Hibiscus spp, and Hypoestes verticillaris. Cattle densities in the Lemek valley are very high, of the order of 60-80 cows.km^{-2} (Section 10:3:ii). Grass cover is very low, and in some parts of the valley over 3 m of topsoil has been lost.

The soils under leleshwa bush have been described as poor, being very low in calcium and nitrogen (Glover and Trump 1970; Taiti 1973), although sodium and potassium levels may be normal. In some parts of eastern Narok district so much soil has been lost that bedrock is exposed. In the study area _Tarchonanthus_ bushland coincides with areas of "reddish brown and black soils overlying basement system rocks" (Williams 1964). These soils are, in turn, mainly restricted to the north-eastern quarter of the study area and thus the confinement of leleshwa to this area may reflect soil as well as altitudinal conditions.

According to Glover and Trump (1970), "much of the country colonized by _Tarchonanthus_ is of little agricultural or pastoral potential, not because of the presence of this plant but because of the shallowness of the soil and the maltreatment these areas have received from man and his stock".

Type 2(c): Euclea Regeneration Community

This occupies only 2 km^2 of the study area, adjacent to Fig Tree Camp on the Talek river, although small patches occur further east along the Talek. This community consists simply of very regularly spaced _Euclea divinorum_ bushes, 3-5 m tall, forming a distinctive pattern with a cover of 20-25%. Like

Tarchonanthus. Euclea coppices readily from stumps (Taiti 1973; Pratt and Gwynne 1977), and these patches would seem to be the result of a decrease in fire frequency associated with heavy grazing. The Euclea bushes are presumably regenerating from root stock surviving from what was once (before 1950) Type 1(a) forest. Taiti recognizes this type as a community and concludes that "fire constrains its development into trees". A comparison with the 1974 aerial photography, however, reveals that this community is growing rapidly and may revert to Type 1(a) forest again. In any event, as Taiti later states, the Talek area - even in 1972 when his study was conducted - was too heavily grazed to burn, and this very pure community could therefore be classified as a 'bush encroachment' community. Its control by goat browsing is unlikely, since Euclea is unpalatable to stock (Walker 1980).

The slightly acidic soils are very similar in chemical composition to those of Type 1(a) forest (Taiti 1973).

3. Bushed and Wooded Grassland

Type 3(a): Acacia-Commiphora Community (Plate 6:4)

This community is relatively widespread, occupying some 9% of the study area and lying within the 1550-1800 m altitudinal range. Acacia-Commiphora woodland is usually associated with Ecozones V and VI, the semi-arid to arid areas of Kenya, receiving 300 -700 mm of rainfall (Lind and Morrison 1974; Pratt and Gwynne 1977). The Mara therefore represents the wet end of its climatic range. As indicated in Section 1:3:iii a weak climatic gradient of 800-1100 mm extends east-west across the study area. In the wetter, western portion of this community's range, the Enkikwe area, Commiphora species become less abundant.

This community is very diverse and Acacia and Commiphora species account for less than half the number of species present. The community is closely associated with the shallow erosion surface lying along the northern boundary of the Maasai Mara National Reserve (demonstrated in Fig. 6:4). This erosion surface extends from Enkikwe, through the Ilbaan area north of Talek (where it forms a small escarpment) to Oloiburmurt hill in the south west. The analysis of woody vegetation change described in the next chapter indicates that this community is relatively intact in the south-west of the study area, where fire frequency is reduced by heavy grazing. However, in areas between Ilbaan and Enkikwe this type has been almost completely eradicated by fire. At both ends of the erosion surface it falls within the 2-20% bushed grassland category of Pratt et al (1966) and has been mapped as such in Figs. 6:3 and 6:4.

Trump (1972) considers this type to have been derived from evergreen thicket, presumably of vegetation Type 2(a). Croton dichogamus and Acacia brevispica clumps still occur at the scarp edge and other rocky areas, but further from the edge these give way to a complex of the following species: Commiphora africana, C. trothae, Acacia gerrardii, A. hockii, A. nilotica, A. senegal, Cordia ovalis, Maytenus senegalensis, Lannea stuhlmannii, Grewia spp, Boscia angustifolia, Albizia petersiana, A. amara, Ormocarpum trichocarpum, Rhus natalensis and Dichrostachys cinerea.

This complex then grades into a subtype dominated by Acacia senegal, which gives way to vegetation Type 3(c), the Acacia drepanolobium community that extends out onto the plains. The composition of the Acacia-Commiphora community by density and colour is shown in Figs. 8:3a) and b).

Themeda triandra and Pennisetum mezianum are the common grassland species, although towards the rocky scarp edge Loudetia kagarensis, Hyparrhenia filipendula, Heteropogon contortus, Aristida adoensis, Eragrostis spp and Harpachne schimperi are also abundant. Justicia spp, Tephrosia spp and Indigofera spp are common herb genera.

This vegetation type also occurs on the east facing slopes of Ropile and Kaitapini hills (where Heeria reticulata, Combretum molle and Dombeya rotundifolia are also common as trees) and along the lower slopes of Bardamat hill. There is evidence from old photographs taken in the 1930s and 1940s, by the late Mr S Downey, a hunter who visited the area regularly, that Acacia-Commiphora bushland and bushed grassland dominated what are now the open grasslands of the Maasai Mara National Reserve. Plates 7:1a) and 7:1b) are photographs taken from the same small hill in the Mara Triangle in 1944 and 1983, showing the reduction in this woodland type, which has suffered particularly severe losses (Chapter 7).

Taiti (1973) describes the Acacia-Commiphora community as his "complex community" and notes that the soils are well drained and very shallow, with a hard pan at 5 cm; Commiphora roots apparently grow horizontally. Carbon, nitrogen and calcium levels are low, potassium and phosphorus levels moderate, and the soils closely resemble those of the Croton thicket community.

Type 3(b): Acacia gerrardii Community (Plate 6:5)

The results of the aerial photograph interpretation of woodland change, described in the next chapter, indicate that in the Enkikwe are north of Governor's Camp, and along the Mara river between the upper Mara bridge and Mara Buffalo Camp, there has been a very rapid increase in the cover of Acacia gerrardii. This very pure community forms a mosaic with relict Acacia-Commiphora bushed grassland (vegetation Type 3(a)), the latter on the more rocky hillslopes, the former on shallow slopes with deeper soils. It is the 'encroachment' of this species which has provided the building materials for the temporary livestock camps constructed in this area as wet season cattle bases and 'stopover' points (see Section 4:3).

This vegetation type was not recognized as a distinct community by Trump (1972), probably because at the time of his groundwork it was not extensive. However, it was described by Herlocker (1976) as forming "extensive stands on loamy soils of ridge tops and upper slopes in the north-east of the [Serengeti] Park". Herlocker noted its mosaic association with the Type 3(a) community and states that "small stands of evergreen to semi-deciduous bushland occured on a variety of soils throughout the [A. gerrardii] species type. They appeared to be relict stands with abrupt boundaries. The boundaries often appeared to be retreating. In these cases *Acacia gerrardii* trees were actively replacing the previous vegetation".

According to Glover and Trump (1970), "*Acacia gerrardii* is a common relict in fire-induced grassland" and Taiti (1973), recognising its apparent fire tolerance, suggests that "light fire .... seems to be a vigorous stimulant to its growth".

Acacia gerrardii has, in the past, been commonly associated with *Acacia hockii*, which has been described by both Herlocker (1976) and Taiti (1973) as forming a separate community. Harker (1959) describes *A. hockii* as a weed species in Uganda grasslands where it forms impenetrable stands. However, the *A. hockii* community was never identified as such in the study area, nor anywhere else within the reserve. According to Taiti, "on the phonolitic lava in the Mara Triangle, Loldurugi, Ongata Olduroroi, Enkikwe and upper Mara bridge, *Acacia gerrardii* .... replaces *A. hockii* in the succession".

The fire tolerance of *A. gerrardii* and *A. hockii* has been described in the Akagera National Park of Rwanda by Spinage and Guiness (1972), who constructed height-related survivorship curves for a number of species in common with those of the Mara. With good representation of all height classes up to 7 m, *A. gerrardii* and *A. hockii* showed much greater fire survival than *Ormocarpum trichocarpum*, *Commiphora africana* and *Dichrostachys cinerea*, all constituents of the Type 3(a) community. Of the three latter species, few reached heights of greater than 2 m.

Harrington and Ross (1974) found that in the Kidepo Valley National Park of Uganda, plots excluding browsing and burning did not stimulate an increase in *A. gerrardii*. They suggest that water table changes, or 'nursery thicket' conditions, are necessary for *A. gerrardii* regeneration to take place. Western and von Praet (1972) have shown that in the Amboseli area a rise in the saline water table has been responsible for the deaths of mature *A. xanthophloea* trees in the 1960s. However, the soils of the Mara are only weakly alkaline and it is unlikely that water table changes have influenced tree survival.

The dynamics of this community type are under investigation in the Mara by Dublin; her studies will shed further light on the fire tolerance of this species.

Other species associated with the *Acacia gerrardii* community in small numbers are *Dichrostachys cinerea*, *A. senegal* and *Ormocarpum trichocarpum*, but very few of these reach greater than seedling height. The common grasses are *Themeda triandra*, *Pennisetum mezianum* and *Hyparrhenia filipendula*.

The soils under this community are well drained, slightly acid (pH 5.7-6.1) at the surface, but increasingly basic with depth, with low carbon and potassium levels (Taiti 1973). Taiti suggests that moisture availability determines whether *A. gerrardii* or *A. hockii* becomes established. *A. gerrardii* appears to be confined to slopes of between 1:5 and 1:15 gradient although some apparently suitable sites were completely uncolonized by this type. The tree cover is usually less than 20%, but may increase to 40% in clumps such as those along the road leading down to the Mara bridge in the Mara Rienda area.

Type 3(c): Acacia drepanolobium Community (Plate 6:6)

The Acacia drepanolobium, or 'Whistling Thorn', community, covers 5% of the study area and, occupies a specific position between the Type 3(a) community and the edaphic grasslands of the Aitong and Bardamat plains (see Figs. 6:3 and 6:4). According to Dale and Greenway (1961), "A. drepanolobium forms pure stands in seasonal swamps on black cotton soil", but in the Mara the soils under this community are more well drained than this might suggest. Glover and Trump (1970) indicated that chemical factors may be just as important as soil drainage conditions.

The results of the next chapter indicate that the distribution of this community on the heavily grazed Aitong and Bardamat plains has remained remarkably constant since 1950. The same patches of A. drepanolobium are present in exactly the same places on the plains in both the 1950 and 1983 aerial photography. However, in the 1960s and early 1970s the game reserve area used to have extensive stands of this type (Glover and Trump 1970; Taiti 1973), but now has none at all.

Acacia drepanolobium stands have a very uniform cover of 10-15%, and a height of 2-3 m. They are heavily browsed by giraffe, which maintains the rather stunted growth form (Glover and Trump 1970). Acacia senegal and Ormocarpum trichocarpum may be present in small numbers. The grass layer is predominantly Themeda triandra and Pennisetum mezianum.

Soils are black (black cotton), neutral to slightly basic with low nitrogen and calcium levels (Taiti 1973).

Type 3(d): Balanites - Acacia seyal Community

This community, recognized by Herlocker (1976) and Taiti (1973), occupies about 15 km^2 of the study area in the Aitong-Koyage gap. The cover of the conspicuous large Balanites aegyptica trees is of the order of 5-10%, whilst in places Acacia seyal trees form impenetrable thickets of 60-70% cover. It has not been possible to determine quantitatively from the panchromatic aerial photographs available whether A. seyal is increasing, because this tree has pale bark and sparse foliage and cannot therefore be easily 'resolved' against the underlying grass layer (see Adams 1967). However, from a qualitative examination of the photography, it is clear that A. seyal is encroaching and that Balanites is slowly declining. Taiti noted in 1972 that Balanites stands in the Mara triangle appeared to be thinning.

This decline is probably due, in part, to heavy browsing by giraffe (Giraffa camelopardalis), which select heavily for Balanites (Pellew 1981). According to Glover and Trump (1970), "many [Balanites] were dying in the Mara area as a result of giraffe browing. At Ngirende, it looked as if the Balanites parkland would be gone within 5 years if the existing browsing pressure continued". No Balanites were found in the Ngirende area in the 1983 fieldwork studies.

It is likely that at Koyage, heavy browsing from goats is preventing the recruitment of Balanites, a highly palatable species (Le Houerou and Corra 1980).

Taiti (1973) describes the soils in the Mara Triangle Balanites community as black, well-drained and acid, with high carbon and nitrogen, and low calcium and potassium levels. However, in the Aitong-Koyage gap drainage of the Balanites areas drainage appeared to be rather poor and Pennisetum mezianum grass predominates.

Other bushland species found in significant numbers in this community are A. gerrardii, Cordia ovalis, Scutia myrtina and Grewia spp, and the composition by cover of a 5 km variable-plot transect through this type in blocks G3/G4 is shown in Fig. 6:1b).

Type 3(e): Cassine buchananii Community

As I have indicated in the description of Type 1(a) forest, the lone Cassine buchananii trees in otherwise open plains in the Mara Buffalo area are probably relicts of Type 1(a) forest. All trees are over 9 m in height and there is no regeneration of this species at all. Glover and Trump (1970) note that this species, which forms a very distinctive open 'parkland' community of 2-6% cover, is heavily browsed by giraffe; the trees have a very pronounced 'browse line'. This species is, however, very poisonous to stock (Verdcourt and Trump 1969).

Tree-cores have been taken by Dublin of this species, in an attempt to determine the fire-history of the area.

This community occupies only 0.5% of the study area.

4. Grassland

Grassland comprises about 40% of the study area. Both Talbot (1970) and Glover and Trump (1970) describe "tall grass plains" and "short grass plains", but in the Mara this difference usually reflects the degree of grazing pressure. Furthermore, Glover and Trump state that "all the plains in this region are fire-induced". However, much of the area consists of edaphic grasslands where the growth of trees is inhibited by poor drainage, low infiltration rates and the presence of a 'hard pan' beneath the soil surface (Vesey-Fitzgerald 1971; de Wit 1978). It is possible that these plains were covered by bush during the earlier part of this century. However, Pellew (1983) notes that "the elimination of mature trees could adversely influence the soil water dynamics resulting in an edaphic climax grassland in previously wooded areas".

Trump (1972) recognizes these edaphic grasslands and classifies them as "grassland on clay plains with impeded drainage", and contrasts them with "grassland derived from evergreen thicket". These two types are described below.

Type 4(a): Grassland on Clay Plains with Impeded Drainage

Themeda triandra, or "red oat grass", usually thought to be promoted by fire (Rattray 1960; West 1965; Lock and Milburn 1971; Bogdan 1977), is dominant in the western edaphic grasslands between Aitong and the Mara bridge. This perennial species is considered to be one of the most desirable components of grassland in southern Africa, because of its high productivity and palatability (Rattray 1960; Pratt and Gwynne 1977). Marshall and Bredon (1967) have shown, however, that its nutrient value drops significantly as it matures.

In the more heavily grazed grasslands immediately to the south and west of Aitong and Bardamat, Themeda is suppressed and the less palatable Pennisetum mezianum increases in frequency (Talbot and Talbot 1963) and forms 'tussocks' of very coarse and almost woody growth. Darling (1960) noted a close correspondence between areas available for grazing because of a lack of tsetse, and areas with an abundance of P. mezianum (which he appears to confuse with P. schimperi). In the early 1960s Heady (1966) measured grassland composition along a grazing gradient on the Kiloriti plains (block E2) and recorded that P. mezianum increased in frequency with increasing grazing intensity. Pennisetum species generally have a high fibre content (Dougall et al 1964) and are only palatable to stock when sprouting new growth (Pratt and Gwynne 1977). Along a series of three randomly located 100 m transects across the Kiloriti plain just north of Aitong, cover was measured using a 10-vertical-pin frame placed on the ground every 10 m. The cover of this grassland was 48% ± 10% (± S.E.: arcsine transformation: n=60). P. mezianum contributed 4% ± 1% to this cover, but because areas between the tussocks were grazed almost down to ground level P. mezianum contributed an estimated 50% to the total standing crop biomass. At another location mid-way between Talek and Aitong the total cover was 45% ± 2%, of which 13% ± 2% was contributed by Pennisetum mezianum.

Moving eastwards into Ol Kinyie Group Ranch dwarf shrubs become conspicuous, although their cover of 10-15% is not enough to place this grassland in the "dwarf shrub grassland" category of Pratt et al (1966). This grassland has in places a very characteristic 'peacock feather' like pattern, visible from the air but not readily apparent on the ground, of vegetation associated with termite mounds, (Glover et al 1964). Although the termitaria and vegetation patterns extend well into the central and southern parts of the study area, it is only on the Loita plains that dwarf shrubs, notably Achyropsis greenwayi and Justicia elliotii, become associated with the 4-7 m central zone of the mound area. The patterns are most pronounced along drainage lines. On the flatter plains Achyropsis greenwayi, Justicia elliotii and two other dwarf shrubs, Sida tenuifolia and Becium obovatum, are more regularly scattered over the grassland.

Dwarf shrub grassland is more often associated with the arid zone of Kenya than with the semi-arid to sub-humid zone (Pratt and Gwynne 1977), but it should be recalled that the Loita plains, receiving approximately 700 mm of rain per annum, lie at the low rainfall end of the rainfall gradient. Pratt (1966) considers that the presence of a high cover of dwarf shrubs is indicative of overgrazing; the palatable grass species are heavily selected for by livestock, dwarf shrubs invade, productivity decreases and further pressure is placed on the remaining grass. However Skovlin (1980), who monitored permanent vegetation transects at Olengerin on the Loita plains in 1970 and 1980, reports that there has been no further increase in dwarf shrub cover despite the heavy grazing on this area. On the other hand, perennial grass cover has declined and the cover of bare ground has increased. At permanent transects at Koyage, the cover of perennial grasses was reduced by 26% and less productive annual grasses had increased by 10% over the 1970-1980 period.

The common species of the flatter grasslands are Cynodon dactylon, Harpachne schimperi, Eragrostis spp, Sporobolus spp, Digitaria spp and Michrochloa kunthii, the latter an indicator of overgrazing (Napper 1965). Pennisetum schimperi forms thick tussocks around the termitaria, and Dyschoriste radicans is a very abundant low herb.

The soils are neutral to slightly basic, and nitrogen and potassium levels are normal for the Mara area (Glover *et al* 1964).

Type 4(b): Grassland derived from Bushland

This grassland type, occupying the greater part of the Maasai Mara National Reserve and northern Serengeti, appears to have originated from bushland, rather than, as suggested by Trump (1972), evergreen thicket. It is dominated almost exclusively by *Themeda triandra*, although *Hyparrhenia filipendula* and *Bothriochloa insculpta* are also common, especially on shallow slopes in the Ongata Oldururoi area. *Pennisetum mezianum* and *Setaria spp* are common in less well drained areas.

The productivity of these grasslands is very high, of the order of 7000-8000 kg.ha^{-1}.annum^{-1} (Braun 1973; Sinclair 1975; NcNaughton 1979; Onyeanusi 1983; Olang 1984). Although the passage through grasslands of this type by the Serengeti wildebeest migration may result in an 85% reduction in standing crop biomass in a few days (McNaughton 1976), the productivity of these grasslands may be enhanced by grazing pressure of this sort (McNaughton 1979). McNaughton indicates that, in the absence of grazers, above ground biomass declines spontaneously as a result of postflowering senescence.

In the growing season (November-May) the grassland cover is invariably 100%. Even after the passage of the wildebeest in 1983, the cover of the grassland plot on the Posee plains, measured using a pin-frame, did not drop below 75% ± 4% (± S.E.: n = 35).

As I shall show in Chapter 9, grassland biomass and cover changes can be mapped particularly well from LANDSAT imagery.

The soils of this grassland type are acidic (pH 6.1-6.2) with high carbon and calcium content (Taiti 1973).

In his thesis Taiti (1973) identifies a catenary vegetation sequence within the Mara but in the study area selected for this project this sequence was far from clear. Morrison, Hoyle and Hope-Simpson (1948) define a catena as "a grouping of soil and vegetation types linked in their occurrence by conditions of topography and repeated in the same relationship to each other and wherever the same conditions exist". As the description of the physical environment (Section 1:3) has indicated, the repetition of identical conditions at the catenary scale is not an important or common feature of the study area. A clearer, more large-scale relationship between topography, altitude and vegetation is shown in the 3-dimensional representation in Fig 6:4.

Talbot (1970) and Taiti (1973) both recognize a 'succession' from grassland, through bushland to evergreen thicket, but the course of this succession is greatly altered by climatic and topographic effects, and fire and animal impact. The maintenance of a 'stable state' ecosystem with clearly defined successional sequences, very often a management aim in conservation areas, may be a completely unattainable goal in savanna environments such as the Serengeti and Mara (Norton-Griffiths 1979; Pellew 1981).

It is interesting to note that some of the major species of the vegetation communities of the Mara have been designated 'weed species' by Ivens (1967) and Pratt and Gwynne (1977), in that they are undesirable components of pastoral rangelands. Tarchonanthus camphoratus, Euclea spp and Commiphora spp all fall into this category. Of Acacia gerrardii, A. drepanolobium and a number of other Acacia species Ivens (1967) states: "[these] Acacias are natural constituents of grassland communities and when the grazing intensity is increased by the introduction of cattle, their numbers tend to increase because of reduced competition'. This point illustrates the conflict between managing a rangeland for pastoralists and managing the same areas for conservation; in the former a highly productive pure grassland community is favoured, whilst in the latter woody vegetation and greater habitat diversity become the goals.

6:3 The 1983 Vegetation Map

The vegetation map for 1983 was prepared from the following sources:

a) the vegetation maps of Trump (1972) and Epp and Agatsiva (1980),

b) a stereo interpretation of the 1974 aerial photography, using a Wild ST4 stereoscope and x 3 magnification,

c) the oblique aerial photography of October 1983,

d) an acquired knowledge of the distribution of the vegetation types from extensive travels within the study area.

The oblique aerial photography was acquired because two of the major vegetation communities, the Acacia gerrardii and the Acacia drepanolobium community could not be mapped adequately from the 1:68,000 scale 1974 aerial photography. Much of the A. gerrardii has been regenerating since 1974, as the next chapter will show. On the 1974 photography A. drepanolobium appears as a very indistinct 'fuzzy' pattern which can be easily confused with photographic developing and printing imperfections. The 4 flight lines of the oblique photography, flown at an altitude of 500 m a.g.l. in a Cessna 182 light aircraft, were orientated with a prior knowledge of the approximate distributions of these two vegetation types (Fig. 6:2). Overlapping 35 mm frames were taken according to the recommendations of Fleming and Dixon (1981). It was fortunate that the weather was ideal for this photographic exercise.

The resulting vegetation map is shown in Fig. 6:3, and translated onto the 3-dimensional GINO-SURF topographic map in Fig. 6:4. In the latter the relationship between vegetation, altitude and topography is clearly defined.

With the exception of the small patches of evergreen forest along the Mara and Talek rivers, the 18% of the study area that lies within the Maasai Mara National Reserve has no woody vegetation at all.

6:4 Discussion

In this chapter I have attempted to classify the vegetation of the Mara into categories in line with the broad scale classification of East African vegetation of Pratt *et al* (1966). By doing so, it is hoped that the most meaningful use can be made of information from a number of studies of the Mara vegetation. At a recent workshop on "The Plant Communities of Kenya" organized by Environmental Training in Africa (a small group operating within United States agency for International Development) it was stressed that, before vegetation conservation strategies can be implemented, it is of vital importance that a universal system of classification be employed for inventory purposes. In addition, therefore, to providing a map of vegetation purely for the purposes of this study, a classification has been used which, it is hoped, will effectively update and improve existing vegetation inventory maps of Kenya.

Fig. 6:1a). The species composition by mean cover (%) of the Tarchonanthus camphoratus community in blocks H5/I5, determined by the variable-plot method (Cooper 1957).

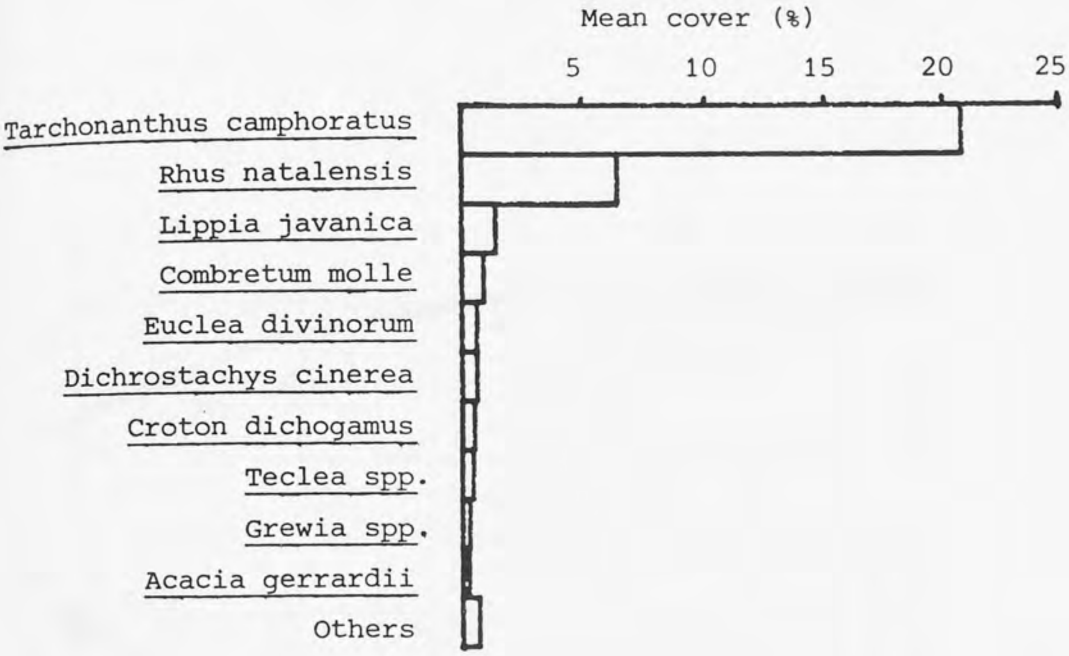


Fig. 6:1b). The species composition by mean cover (%) of the Balanites-Acacia seyal community in block G4.

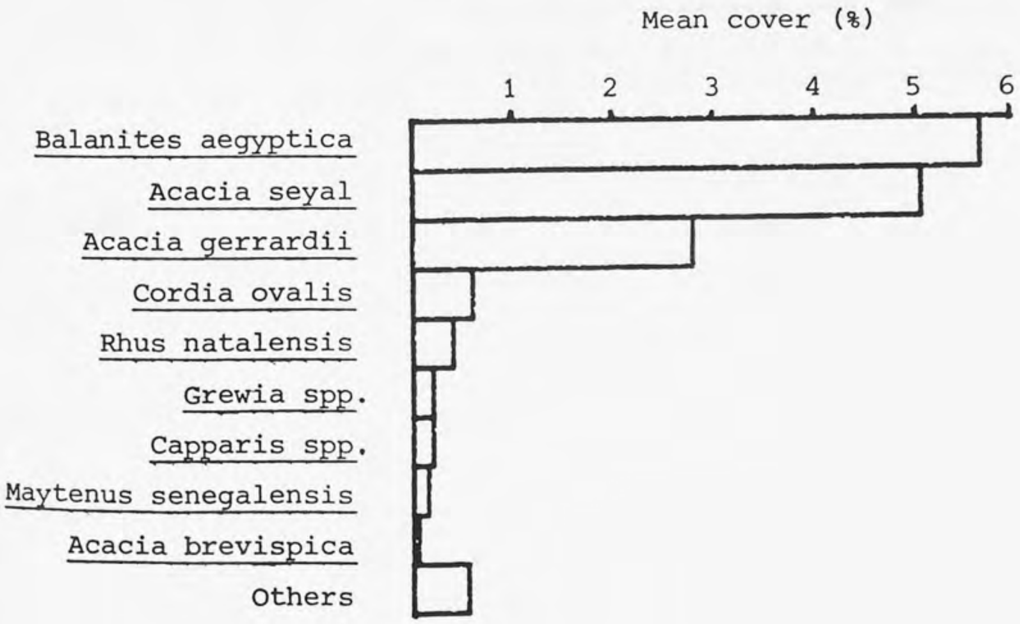
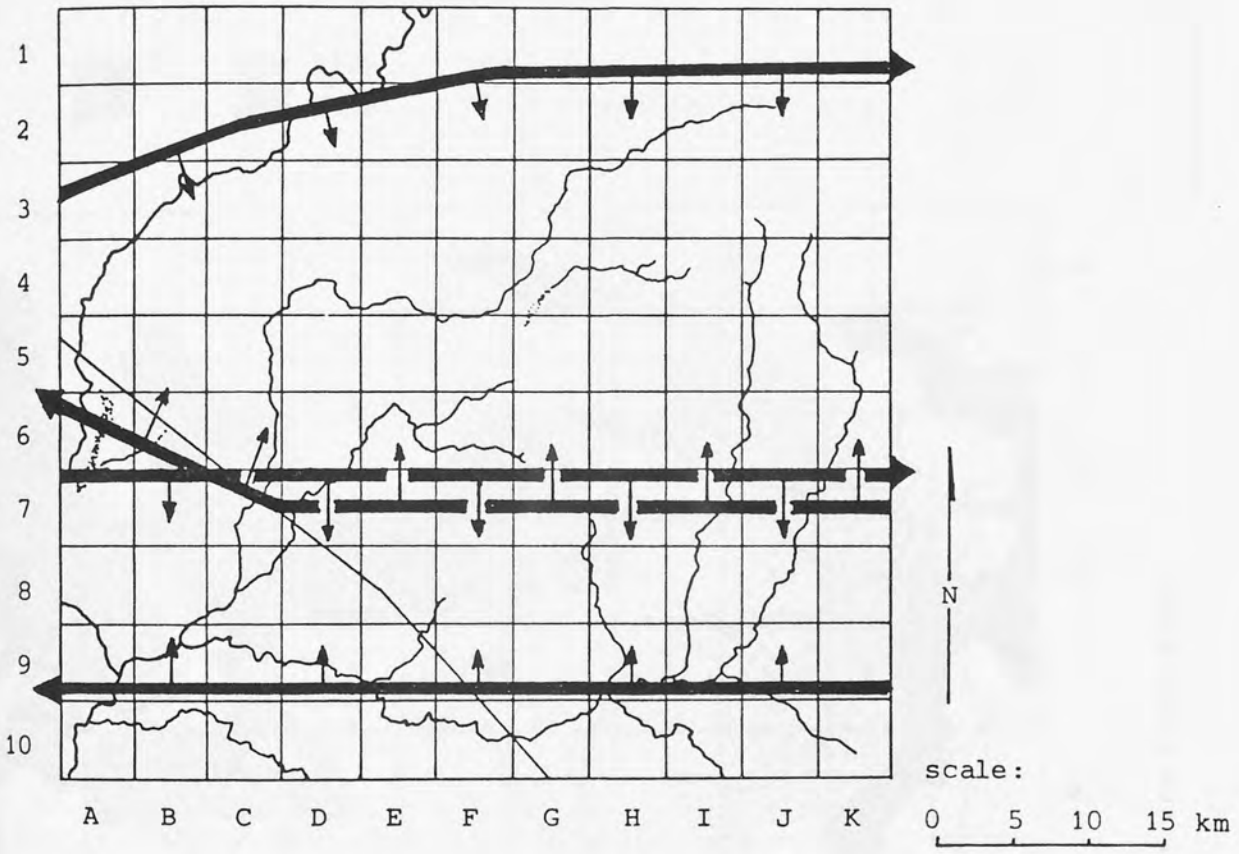


Fig. 6:2. The flight diagram for the 35 mm oblique aerial photography of October 1983. The small arrows show the direction of photography from the aircraft. The flying height was approximately 500 m a.g.l.



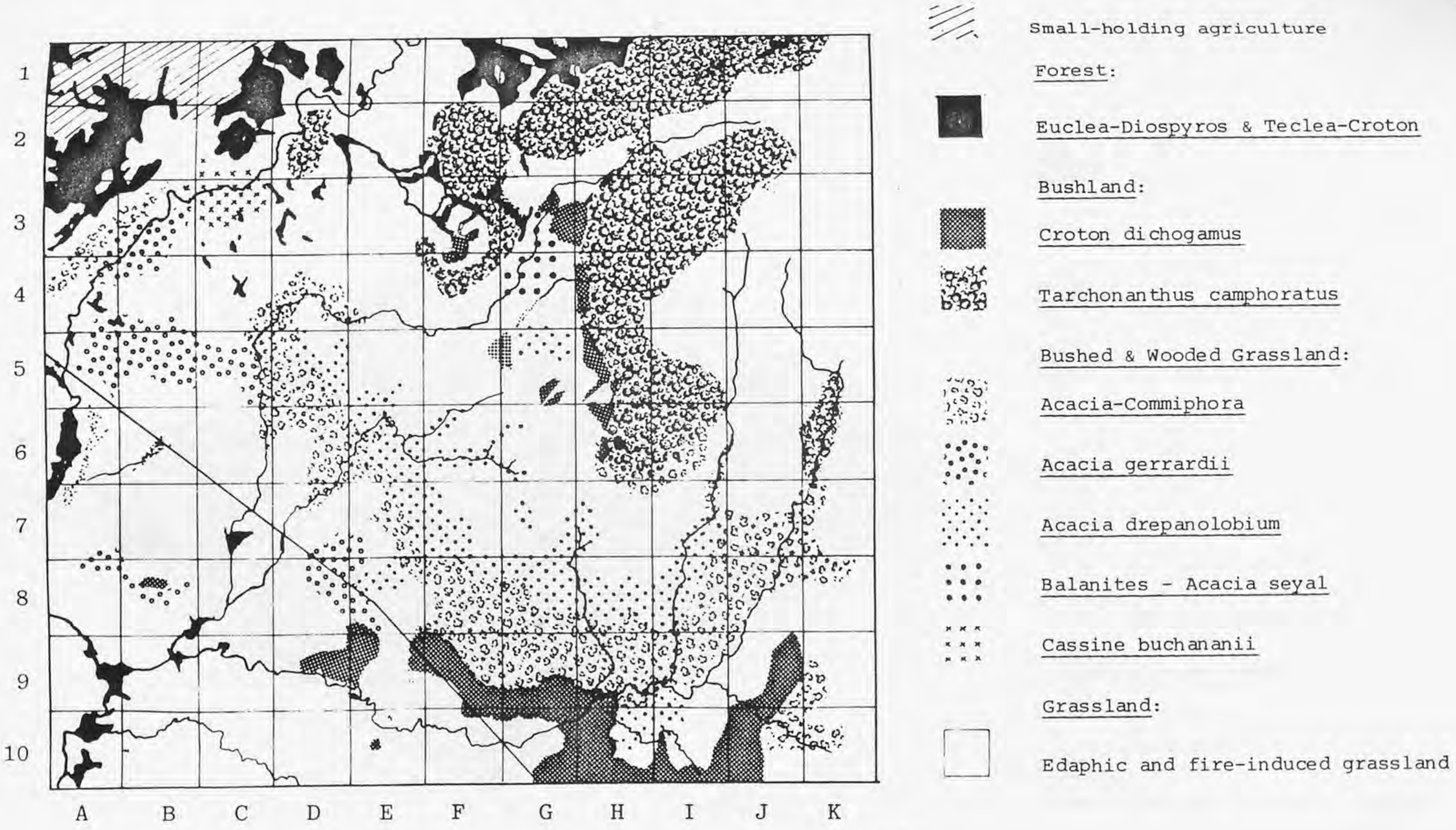


Fig. 6:3. Vegetation map of the study area.

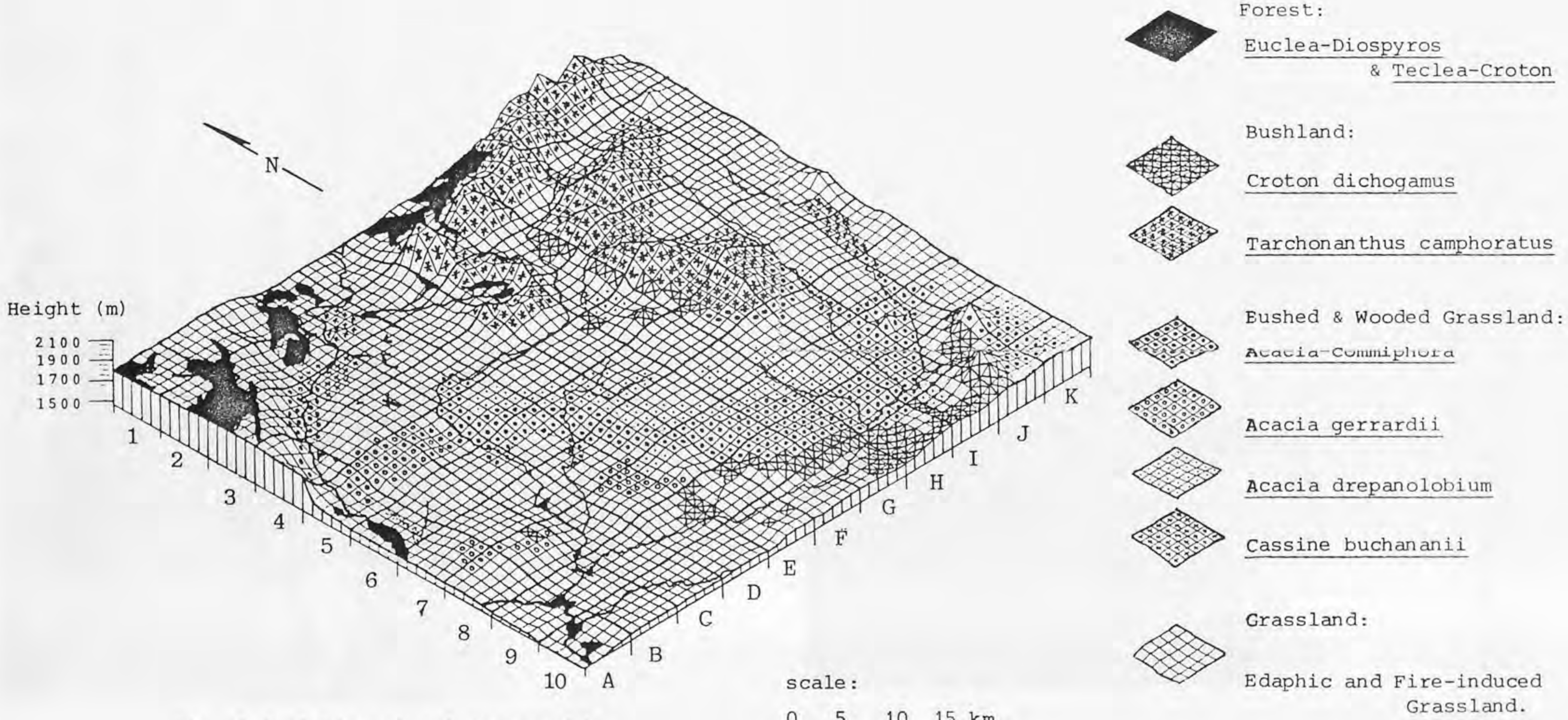


Fig. 6:4. 3-Dimensional topographic vegetation map of the study area.

Plate 6:1. Colour infrared vertical aerial photograph of a forest patch (vegetation Type 1(a)) in block C7, showing the open nature of the forest canopy. This canopy was completely closed in the 1961 photography.

Plate 6:2. Oblique aerial photograph, looking towards the junction of the Mara and Talek rivers (Talek in foreground), showing relic patches of forest (vegetation Type 1(b)): blocks A9/B9.

Plate 6:3. Oblique aerial photograph, looking north from Aitong hill (block F3) towards Kipleleo hill, showing Tarchonanthus (vegetation Type 2(b)) bushland on hillslope to left and a mix of Croton thicket and Euclea forest (Types 2(a) and 1(b)) to right. In this densely settled area small maize patches are associated with the many manyattas (foreground).

Plate 6:4. Oblique aerial photograph, looking south along the Kaimurunya river (block J7), with Acacia-Commiphora bushed grassland (vegetation Type 3(a)) in foreground. A permanent livestock watering pool can be seen in the middle distance. This area is relatively densely settled.

Plate 6:5. View in Enkikwe (block E7), with Acacia gerrardii bushed grassland (vegetation Type 3(b)) on the shallow hillslope in the background. This hillslope was completely open on the 1974 aerial photography. In the foreground a temporary livestock camp (TLC) with a small shelter.

Plate 6:6. Acacia drepanolobium bushed grassland (vegetation Type 3(c)) in block F7, along the road between Talek and Aitong (Aitong hill can be seen in the distance).

CHAPTER 7: THE AERIAL PHOTOGRAPH INTERPRETATION OF WOODLAND CHANGE

7:1 Introduction

Having defined the vegetation communities of the study area, changes in these communities can be measured from the aerial photography. The use of aerial photography for rangeland monitoring and evaluation is well documented, but virtually all of these studies refer to the interpretation of very large scale panchromatic, colour or colour infrared photography gathered specifically for the purposes of monitoring change, or assessing range condition, in small carefully selected sample areas (e.g. Harris 1951; Heller _et al_ 1964; Driscoll _et al_ 1970; Carneggie 1968; Carneggie and Reppert 1970; Carneggie _et al_ 1971; Anderson _et al_ 1978; Everitt _et al_ 1981; Curran 1980; Epp _et al_ 1982; van Zee and Bonner 1981).

A number of ecologists in East Africa have used smaller scale aerial photographs for the construction of vegetation maps of their particular study areas (Allaway 1969; Lamprey 1963; Western 1973) with classifications designed for their own specialist needs. Other studies, such as those of Astle _et al_ (1969), Howard (1965) and Scott _et al_ (1971) have employed small scale aerial photographs for 'landscape classification', a process whereby terrain is classified into homogeneous areas according to geomorphology, geology, hydrology and vegetation. Gerresheim (1974) used the hierarchial approach of Webster and Beckett (1970) to subdivide the Serengeti-Mara ecosystem into land facets (the smallest units), land systems and land regions. The study area lies within Gerresheim's Talek, Lamai-Lorogoti and Bardamat land regions and it is clear that for the Mara area, geology has been the most important factor in his Mara land classification. His classification has proved useful in, for example, the analysis of the Serengeti climate (Norton-Griffiths _et al_ 1975), in the study of wildebeest movements within the ecosystem (Maddock 1979) and in the selection of sample areas for herbivore counts (Pellew 1981). However, Gerresheim's classification has not provided any additional information to that available from my own airphoto interpretation, and it has not therefore been used in this study.

Most workers in East Africa who have measured woodland change from sequential aerial photography have recorded changes in tree numbers within small plots, or easily definable areas or 'polygons' (Croze 1974b; Field 1971; Western 1973). In this study a different approach to monitoring change has been required because of the vast difference in scales (1:3000-1:68,000) between the photography. Unlike the aerial photographic studies of rangeland trends mentioned earlier, the photographs available for this study were intended for map-making and not detailed vegetation studies. Tree counts would be heavily biased in that, due to differences in photographic resolution, smaller trees would be included in the counts from large-scale photographs that would not be visible on small-scale photographs. Meaningful results can only be obtained if trees above a certain size, that are visible on all the sets of photography, are included in the count. A system was therefore devised, adapted from the method of Norton-Griffiths (1979) and described in the next section, to record not tree numbers but the percentage cover of trees greater than 2.5 m diameter. Woody vegetation changes of the _Tarchonanthus_ community and the _Acacia_-_Commiphora_ community were measured in this way. Changes in the forest communities and the

Croton thicket communities were determined by measuring the change in area of the thicket or forest.

Prior to these analyses a more generalized and cruder assessment of change within the communities, using a systematic sampling procedure, was made to answer the question: over the whole study area, and between the vegetation communities of the study area, has there been an overall increase or decrease in woody vegetation? This analysis was conducted because the monitoring of a bushland plot from 1950 to 1983 gives no indication of whether 'bush encroachment' is taking place in areas that were initially grassland.

This chapter therefore aims to test hypothesis 1 in Section 1:1 in the following ways:

a) By monitoring changes over the whole study area using a systematic procedure to determine whether bush encroachment is a feature of both bushland and grassland communities.

b) By selecting bushland plots for a more detailed examination of cover changes in areas of low and high Maasai density.

c) By selecting forest or thicket patches to measure the change in area of the patch in areas of low and high Maasai density.

7:2 Methods and Results: The Systematic Point Sampling Procedure

The flight lines of the 1983 photography are shown in Fig. 7:1. The intervals of the 70 mm panchromatic photographs in flight lines 1, 2, 4 and 5 are surprisingly regular, the photographic centres ('principal points') being separated by about 500 m. There are approximately 110 photographs in each flight line. Due to a camera malfunction, there were no panchromatic photographs taken in flight line 3, but this flight line was successfully duplicated by the colour infrared photography, again with a photographic separation of 500 m. Line 1 was omitted from the analysis to systematically space the flight lines. The centre point of each 1983 photograph was located on the high quality 1961 1:50,000 photography and a visual assessment was made of the cover change at that point between 1961 and 1983. A table was set up to answer the following questions:

a) What is the vegetation type?

b) Has there been an increase, decrease or no change in the cover at that point?

Due to the orientation of the flight lines and the relatively coarse nature of the sampling method, the procedure could only be applied to the _Tarchonanthus_, _Acacia_-_Commiphora_, _Acacia drepanolobium_ and grassland communities, which by area (and excluding trans-Mara) accounted for 97% of all vegetation of the study area. On the 1961 photography the _Acacia gerrardii_ community could not be easily distinguished from the _Acacia_-_Commiphora_ community from which it is derived (Section 6:2). Points lying within this type have been included in the _Acacia_-_Commiphora_ type.

A total of 420 photograph principal points were examined and the results are shown in Table 7:1.

According to this procedure grasslands accounted for 54% of the cis-Mara portion of the study area. This can be compared with the estimate of 40% derived from the 1983 vegetation map (Fig. 6:3). On only 5 points of the 420 (or 1.2% of points) had an area of grassland become invaded by shrubs - in all these cases A. drepanolobium. This however, was offset by a decline in A. drepanolobium to grassland on 4 other points, giving a total 'loss' of grassland due to to bush encroachment of 0.2%. A further 21 points (5% of points) had degenerated to grassland from the Acacia-Commiphora community, resulting in an overall 4.8% increase in grassland.

The results have important implications for the understanding of bush encroachment. Only certain areas have soil conditions suitable for tree and bush growth. Areas with unsuitable soils as a result of, for example, poor drainage, are classified as the edaphic grassland vegetation type (see Section 6:2). 'Bush encroachment' is simply a reversion of the suitable areas to bushland once there has been a relaxation in the causes of woodland mortality.

Table 7:1 clearly indicates that between 1961 and 1983, the Acacia-Commiphora vegetation type has suffered severe losses, whilst the Tarchonanthus and A. drepanolobium communities have remained relatively unchanged, with some losses and some gains. As the next section will show, the few gains in cover of the Acacia-Commiphora community can be attributed to the regeneration of A. gerrardii in the Enkikwe area.

7:3 Methods: Cover Changes in Bushland

To record woodland changes at preselected points from 1950 to 1983 a 'dot-grid' technique has been employed, where woody vegetation cover is expressed as the proportion of the total number of dots that are touching trees or woody vegetation (Norton-Griffiths 1979). A grid of 49 dots, in the pattern shown in Fig. 7:2, was used and the grid was designed to cover 3.14 hectares 'on the ground' with a dot size of 2.5 m diameter (or 0.05 mm on a 1:50,000 aerial photograph). A number of grids were prepared, each grid size adjusted to cover the same area on each set of aerial photographs to minimize bias due to differing scales (and therefore differing dot size and grid area). Tree measurements from the photography using an Oben glass ruler with 0.1 mm gradations indicated that the smallest trees that could be resolved by the photography with the smallest scale (the 1974 photography with scale 1:68,000) were 2.5 m in crown diameter. Therefore, to 'filter' out from the count trees smaller than 2.5 m visible on larger scale photography, trees that were touched by, and smaller than, the 2.5 m dots were rejected from the count.

The grids were prepared photographically. A 35 mm SLR camera, loaded with 64 ASA slide film, was mounted on a tripod, the camera mirror was locked up to avoid vibration and photographs at a number of exposure settings were taken of a grid on a brightly illuminated sheet of paper. With the correct exposure, clear slides were obtained with the grid dots occupying the centre. These slides were used as the grids. The size of the grid could be adjusted to the scales of the aerial photography by geometrically calculating the appropriate distance between the camera and the target grid. This technique was employed to obtain grids for the 1950, 1961, 1967 and 1974 photography. With the large scale 1983 photographs clear cellophane sheets and 'Letraset' dots were used to construct the grids.

The slide grids, mounted on glass sheets, were almost invisible to the naked eye. A minimum of x 14 magnification, with very high illumination, was needed to make the counts. No stereoscope available provided sufficient magnification, illumination or convenience for the very delicate task of centreing the grid on the sample spot or counting the dots. A palaeontological binocular microscope with a x 20 and x 40 magnification was chosen instead. A test, however, was made to compare a stereoscopic cover estimate with a monoscopic estimate for 3 sample points on the 1961 aerial photography. A Zeiss Interpretoscope with a x 16 maximum magnification was used for the stereoscopic analysis and a battery of lights provided the illumination. Five randomly-rotated grid counts were made at each point. There was no significant difference between the mono and stereo cover estimates, indicating that with the scales of the 1950-1974 photography, no benefit could be obtained for this analysis from stereoscopic interpretation.

In any cover evaluation involving the use of a finite dot-size or pin-size, cover will be overestimated as a function of the diameter of the dot or pin (Goodall 1952; Kershaw 1964). In this study, extensive computer modelling of the dot grid technique revealed that cover correction factors varied with both the dot size and the tree size (Appendix F), but since the dot size remained the same for each set of photography, correction factors were not employed. It should, nevertheless, be noted that the use of 2.5 m diameter dots, the smallest that could accurately be obtained for the grids, overestimates cover by a factor of approximately 2.

The selection of the sample points was made using the following procedure. The 1983 flight lines were drawn on to the 1961 photography; 1950 photographs could not be used as the 'base' because of the limited time those photographs were available for my use. 5 km UTM grids that were crossed by the flight lines were selected for the sampling, the criterion for the selection being the degree of livestock usage of the grid cell and the presence of a large area of woodland in the cell. Grid cells from low livestock density areas (inside the Maasai Mara National Reserve) through to high density areas outside the reserve were chosen (Fig. 7:1). Each 1:50,000 1961 aerial photograph has a grid of small crosses called 'reseau-markers', spaced 1 cm (500 m) apart, that are used for cartographic measurement. These markers obscure trees beneath them. Five sample points in each 5 km grid square were therefore chosen from points lying exactly halfway between markers, to give a systematic sample within the woodland stratum (Fig. 7:3) (NRC 1962; Cochran 1963; McIntyre 1978). 5 points were generally the maximum number that could be obtained because:

a) A loss of contrast towards the edges of some photographs excluded some areas.
b) In the Lemek hills, shadows prevented an analysis of cover changes in <u>Tarchonanthus</u> bushland on westerly facing slopes.

Where move than five suitable sample points could be found by this procedure in clearly resolved, homogenous woodland, the number was reduced to five by random selection.

Each photographic sample point had, therefore, to have suitable contrast and resolution for cover changes to be monitored from the 1950 photography through to the 1983 photography. However, in 3 blocks, H3, E9 and J7, cover values for 1950 samples are missing because these criteria could not always be strictly adhered to.

Five dot-grid counts were made at each point by rotating the grid systematically on the sample point. By this method a mean cover and standard error estimate were obtained for each sample point for each year of photography. Some authors (e.g. Norton-Griffiths 1979; van Zee and Bonner 1981) have converted cover estimates to their arcsines to equalize sample variances for parametric statistical analysis. This transformation was attempted for this analysis but it was found that arcsine transformations had a rather small effect on sample variances, and even less effect on sample means. Trends were so significant without arcsine transformations that the transformation was rejected (Marriot pers. comm.).

In this analysis only cover changes within the <u>Tarchonanthus</u> and the <u>Acacia-Commiphora</u> communities have been monitored. On all photography <u>Acacia drepanolobium</u> appears as a grey 'fuzz' and its cover cannot be measured. However, as the previous section has shown its distribution has not changed significantly between 1961 and 1983.

Finally, the woodland cover values for 1983 for blocks A7, B10, C8 and E7 (all off the 1983 flight lines) were determined on the ground using the 'line-intercept' method (Canfield 1941) described in the next chapter. In none of the points investigated on the ground within the Maasai Mara National Reserve did the cover of trees greater than 2.5 m crown diameter exceed 1%. It was felt that too few sample points could be selected in this important sub-area from the 1983 aerial photography alone.

The results of this analysis are shown in Appendix G, in which cover values for each point for each year are presented with their 95% confidence limits.

7:4 Results: Cover Changes within Tarchonanthus Bushland

Cover changes in Tarchonanthus bushland lying within blocks I5, H3, F2 and D2 are shown in Figs 7:4a)-d) respectively.

Woodland cover in all Tarchonanthus blocks has been relatively stable between 1950 and 1983. A slight dip occurred between 1961 and 1967 but in I5, H3 and F2 - all heavily utilized areas in the Lemek hills - the cover after 1967 has increased again to the 1950 and 1961 levels. Only in the less utilized block D2, the Ngirende area, has the decline in cover slowly continued. These observations are entirely consistent with the recovery abilities of Tarchonanthus following burning, described in the previous chapter. In Section 7:10 of this chapter the evidence for increasing burning in the early 1960s will be reviewed.

In the study area Tarchonanthus is confined to altitudes above the 1800 m contour and therefore to the high Maasai density north-eastern quarter. The long-term trend in Tarchonanthus cover would tend to support hypothesis 1 in Section 1:1 - that cover is stable or increasing in areas of high Maasai density. However, this stability is an inherent feature of Tarchonanthus and, although it has been derived from the Euclea forest community by Maasai burning (Section 6:2), its restriction to the Lemek hills by altitudinal and soil conditions means that its cover response in areas of light grazing pressure cannot be examined.

7:5 Results: Cover Changes in the Acacia-Commiphora Community

The woodland blocks selected for examination of cover changes in the Acacia-Commiphora community lie along the broad band of this vegetation type that extends from the Mara bridge to Oloiburmurt hill. Although a grazing gradient extends along this band (the more utilized end to the east) it is not as pronounced as the gradient over the study area running north-east to south-west. However, with the exception of small patches of Acacia-Commiphora woodland along the southern base of Bardamat hill, that were selected for tree recruitment analysis (see Chapter 8), this community does not occur in the high Maasai density north eastern quarter. It has not therefore been possible to examine its response to heavy grazing pressure at the very high end of the grazing scale.

Cover changes in this community for blocks B3, B5/C5 (combined), E7, E9, J7 and I9 are shown in Figs. 7:4e)-j) respectively; B5 and C5 have been combined because they are adjacent to each other in the Enkikwe area. The trends in all these figures are apparent and are consistent with the systematic sample results of Section 7:2. The Acacia-Commiphora community has declined rapidly between 1961 and 1967 in all areas. In blocks J7 and I9, with a higher grazing intensity, this cover has stabilised. However, the remaining cover at the Talek block E9 is still declining slowly.

In blocks B3, B5/C5 and E7 in the Enkikwe area a more unusual pattern emerges. Cover at all sample points declines until 1967 or 1974 and although these declines continue in some points, the cover at others increases rapidly to the 1961 level. These points lie in patches of colonizing Acacia gerrardii which, as described in the community description of this type (Section 6:2), forms a mosaic of patches associated with declining Acacia-Commiphora bushland. This colonization can almost be regarded as a stochastic process. Nevertheless, the association of Acacia gerrardii with well drained soils on gentle slopes was clear from both stereo air photo interpretation and from ground observations.

The course of woodland change has also been monitored in blocks A7, C8 and B10 within the game reserve, which can be considered to have (or have had over the 1961-67 period) virtually no cattle grazing pressure. Early photographs of these areas (see Plate 7:1a), taken by the late Mr S Downey, strongly suggest that Acacia-Commiphora woodland was the dominant community in these areas in the 1930s and 1940s. The results of these block cover changes are shown in Fig. 7:4k)-m), which indicate that, inside the game reserve, woodland areas have declined completely into grassland with no recovery (see Plate 7:1b)).

7:6 Rates of Cover Change in the Tarchonanthus and Acacia-Commiphora Communities

In order to examine the rates of change of cover of the *Tarchonanthus* and *Acacia-Commiphora* between consecutive years of photography, sampling block data have been aggregated into 3 categories:

a) *Tarchonanthus* blocks (blocks I5, H3, F2 and D2)

b) *Acacia-Commiphora* blocks outside the game reserve (blocks I9, J7, B5, C5, B3, E7, E9)

c) *Acacia-Commiphora* blocks inside the game reserve (blocks B10, C8, A7).

Mean relative and absolute rates of change have been calculated, using the data manipulation facilities in the MINITAB statistical package (Ryan *et al* 1981). Relative change refers to the proportion of the previous photographic years' cover that remains in the next year of photography. A change in woody vegetation cover density from 50% in 1961 to 25% in 1967 will represent a relative change of 25/50 or -50% (-8.3%.annum^{-1}) and an absolute change of 50% - 25% or -25% (-4.2%.annum^{-1}). Relative and absolute rates of change of the three vegetation categories are shown in Table 7:2. The dot-grid analysis overestimates cover by a factor of approximately 2 (Appendix F), and therefore in Table 7:2, absolute changes have also been divided by 2 to give a more realistic estimate of absolute cover change (estimates of relative cover change will be unaffected).

There is no significant difference in the rates of change of the Acacia-Commiphora community inside and outside the reserve until the period 1974-1983, when the colonization of Acacia gerrardii, although patchy, significantly increases the overall cover in the outside blocks ($d = 2.386$: $p < 0.05$). Of the three vegetation categories, Tarchonanthus shows the greatest stability. Although declines in this community occurred over the 1961-67 period, the rate of this decline, in terms of absolute cover, was significantly 'slower' than in the Acacia-Commiphora community outside the game reserve ($t = 4.767$: d.f. = 11: $p < 0.001$). After 1967 the cover of this community has increased again.

At the peak period of vegetation destruction, 1961-67, the cover of the Acacia-Commiphora community was decreasing at a relative rate of 9-12%.annum^{-1}, and an absolute rate of 2-3%.annum^{-1} (or 1-1.5%.annum^{-1} by the application of the x 0.5 correction factor). These estimates are slightly greater than those calculated for the Serengeti by Norton-Griffiths (1979). In the Mara area, therefore, 50-70% of the Acacia-Commiphora cover disappeared over just six years, between 1961 and 1967.

7:7 Methods: Area Changes in Forest and Thicket

The 1983 flight lines shown in Fig. 7:1 did not cover extensive areas of either Type 1(a), Type 1(b) (Forest) or Type 2(a) (Croton thicket) vegetation. Thicket areas that were photographed were too small to be of much use in assessing large scale changes in thicket area. A thicket type that might appear as a large patch or strip on the 1:5000 1983 enlarged aerial photography was perceived as an almost invisible patch on the 1:68,000 1974 photography. Scale manipulation was attempted but errors in boundary alignment crept in with the necessary repeated redrawings of the same patch. Similarly, there were severe limitations in using 1980 LANDSAT imagery from which to determine areas. With the low 80 m resolution, the fine detail of the thicket boundaries was lost and comparisons with previous years were generally unsatisfactory.

For these reasons whole 5 km UTM blocks with extensive patches of forest and thicket were selected from the 1950 photography and the total area of the patches in that block was monitored through until 1974. Where a patch extended slightly beyond the borders of the block it was included. The small portions of these thickets on the 1983 photography could be examined to give a more qualitative estimate of change between 1974 and 1983. The 5 km blocks used in this analysis are shown in Fig. 7:5, and the vegetation community types predominating within the blocks are indicated in Table 7:3.

The following procedure was chosen to measure area change, because it avoids area measurement difficulties associated with differences in photographic scale. The 5 km block and the thicket areas within it were traced off the 1950 photography. The resulting overlay was used as the 'sample base'. The area of forest was measured using an EROS Data Centre Area Dot Grid, a method preferable to using a Digitizer when measuring small irregular areas (Norton-Griffiths pers. comm.). Each aerial photograph of that 5 km block from 1961 through to 1974 was fitted to the sample base using the scale manipulation and 'stretch' facility on a Bausch and Lomb Zoom Transferscope, such that the same forest or thicket patches were exactly superimposed. The thicket areas that were 'missing' through thicket loss were drawn onto the 1950 sample base, measured using the Area Dot Grid and subtracted from the 1950 thicket area.

Each Area Dot Grid count was repeated at least three times to obtain a standard error/mean ratio of less than 15%.

7:8 Results: Changes in the Forest Communities

The area changes of the Type 1(a) and 1(b) forest samples are shown in Figs. 7:6a) and b). Regardless of whether the forest patches are in areas of high or low Maasai density, all forest areas have declined, some much more so than others. Where significant declines have taken place, they tend to occur in 'steps', some between 1950 and 1961 (block C3), some between 1961 and 1967 (block C7, blocks A9/B9) and others between 1967 and 1974 (blocks F3/G3). Changes in the area of the forest at the junction of the Mara and Talek rivers between 1950 and 1974 are shown in Fig. 7:7. However the area of the Mara River forest, in block A6 has hardly changed at all, although an extension to this forest that lies along the Safaringo tributary has almost completely disappeared. The north Lemek forest in block G1 has declined very little.

In the north eastern quarter, Tarchonanthus soon colonizes cleared evergreen forest (see Section 6:2). In lower areas these cleared forest patches revert to grassland although, as in the Mara Buffalo area, there may be extensive stands of small, coppicing Euclea bushes in areas that were previously forest.

The 1983 aerial photography indicates that there have been no more significant changes in forest area, either within or outside of the reserve, since 1974. However, inside the reserve the canopy is being cleared within forest areas. Plate 6:1 (in Chapter 6) is a colour infrared photograph taken in 1983 of the northern edge of the forest patch in block C7. This clearing is apparent as early as 1967 and is now particularly pronounced.

The interpretation of these observations is that the most significant impact on the forests has been fire, which through the 1950s and 1960s attacked the forest edges. More recently, fire damage has been replaced by another form of damage, in which forest areas are cleared from within. It is possible that this clearing may represent the natural senescence of even-aged forest trees, with little replacement because of elephant damage to the regeneration. However, further studies would be required to understand the clearing processes.

7:9 Results: Changes in Croton Thickets

It has not been possible to find many large, unbroken areas of Croton thicket for accurate area change measurement. This analysis is confined to two blocks F4 and G5/H5. However, the fate of a large thicket on the west side of Kaitapini hill has been traced through to 1983 and the changes in a 5 km block dominated by small interlocking thicket patches (block G10) have been recorded qualitatively, again using the 'zoom transferscope overlay' method.

The results are shown in Table 7:3. Changes in Croton thickets have been almost insignificant over the period 1950-74 and, where the photographs exist, to 1983. Even in the very heavily utilized blocks F4 (Aitong) and G5/H5 (Ol Doinyo Orinka), the removal of Croton bushes for the construction of manyattas has not had an important effect on the thicket areas. Similarly, within the reserve, an overlay of small Croton patches reveals virtually no change over the past 30 years.

Croton dichogamus is evidently resistant to fires and has a relatively high capacity to regenerate. Langridge et al (1970) noted this fire resistance and Dublin (pers. comm.) has recorded that, in experimental fire plots, fires appear to stop dead at the edges of Croton thickets.

7:10 Conditions for Woodland Change in the 1960s

The Maasai have long held a tradition of grass burning. Fires are lit to remove rank and unpalatable grass, promote the sprouting of fresh grass shoots and to clear bush and with the bush, tsetse-flies. Fires are also lit to kill ticks.

A number of authors have reported that extensive burning took place in the Mara area, and in Narok District as a whole, in the 1950s and 1960s (Betts 1952; Darling 1960; Grimwood 1960; Glover and Gywnne 1961; Talbot and Talbot 1963; Glover and Trump 1970). With special reference to the Talek and Aitong areas Langridge et al (1970) noted that "as soon as they are dry enough, the grassy plains are fired by the Maasai. Sometimes conditions are such that the new growth of grass after a fire is ready for burning within the same season. Thus a single area may be burned twice within a season or even three times during a year".

Conditions in the late 1950s and early 1960s were ideal for burning for the following reasons:

a) According to climatic records from Narok, the rainfall over the area in the late 1950s and early 1960s increased dramatically, leading to a very high grass production and suitable conditions for fires. Fig. 7:8 represents a five-year cumulative average (Barry 1976) for rainfall at Narok. The national drought of 1961 and 1962, in which the **Kaputiei, il-Matapato** and **il-Kisongo** Maasai of eastern Maasailand lost all but 210,000 of their 740,000 cattle (Prole 1976), did not affect Narok District at all. In fact the rainfall at Narok for these two years, totalling 1032 mm and 1097 mm respectively, was well above the 63 year average of 753 mm.

b) The Maasai could not take advantage of the increased productivity in the Mara because of the tsetse.

c) Grazing wildlife densities were much lower in the 1950s and 1960s than they are now, and grass biomass levels would have remained high throughout the year. The Serengeti wildebeest migration that comes into the Mara every dry season (July-October) is, as explained in Section 1:4, a comparatively recent phenomenon; the first migration to use the Mara arrived in 1969 (Pennycuick 1975).

The process of vegetation destruction in the Talek area over the period 1959-1963 was monitored by Langridge *et al* (1970). As part of the tsetse survey and control programme in the Mara, vegetation plots were established at Talek. 100 trees (referred to as 'tsetse resting places') were marked in each plot. Langridge *et al* report that "between 1961-1963 rainfall was very heavy throughout the district and produced a luxuriant grass cover which allowed the bi and tri-annual burning described above .... The very fierce fires caused accelerated destruction of the vegetation with marked changes in numbers of trees and shrubs in plots. In Plot No 1 [in 1963] only 53 of the original [1959] marked resting places were found again, and of these most had suffered extensive damage. In Plot No 2 only 31 of the original marked places remained. In Plot No 3 only 6 of the original resting places were found .... The vegetation changes in the [Ilbaan] escarpment woodland were due more to the actions of elephants than fire. In Plot No 4 24 resting places had been smashed down to the ground and 16 had been burnt".

Glover and Trump (1970) and Lamprey *et al* (1967) also describe increased elephant damage at this time. Vesey-Fitzgerald (1969) discusses the role of elephants in opening up paths in the thicket areas enabling fires to penetrate further into the thickets.

In the very useful report of Langridge *et al* (1970), the 'popularity' of the different tree species to tsetse was recorded and it is interesting to note that *Grewia spp*, *Cordia ovalis*, *Acacia spp* and *Commiphora spp*, all major constituents of the *Acacia*-*Commiphora* community, were all described as being popular to tsetse flies. The destruction of this community would therefore have led to an eradication of tsetse.

7:11 Evidence for Long-Term Vegetation Cycles in the Mara

In his expedition to the Mara area before the tsetse advance, Woosnam (1914) described the Mara Triangle as "a broad plain of park-like country, fine grazing land, studded with occasional yellow-barked *Acacia* trees". The only species he could have been referring to are *Acacia xanthophloea* or possibly *A. seyal*, the latter a more thicket forming community. Neither of these species are found in the Triangle today. Looking across the Mara river to Enkikwe he observed that "the ground is more rocky and arid, more undulating, and rises higher and more abruptly above the river. The grass is less luxuriant and the country cannot be described as park-like, being extensively covered with thinly scattered thorn scrub of several dark rough-barked varieties of *Acacia* and not the tall yellow barked species". *A. gerrardii*, *A. nilotica* and *A. clavigera* are all "dark rough barked varieties" and Enkikwe (blocks B5 and C5) is now extensively colonized by *A. gerrardii* (see Fig. 6:3). He continues, "at the bend of the river at Judd's lower store [the junction of the Mara and the Talek] the Amala [Mara] flows fairly swiftly over a rocky bed and the banks, particularly on the east side, have little or no bush upon them, only a fringe of trees along the water's edge and scattered thorn trees further from the river". These observations suggest that the Mara was relatively open. White (1915), a hunter, describes the Mara in 1913 in similar terms: "a very thin growth of thorn trees covers what may be considered open, grassy, rolling country. Here and there are low, rocky, circular, outcropping hillocks crowned with green thickets". The latter are presumably the Croton thickets communities.

In 1932 Lewis E.A. (1935) reports that "the plains of Angata le Malta and Angata Bossi [the Meta and Posse plains] with 'black cotton' soil and a long growth of Themeda triandra grass are broken into a meshwork pattern by numerous intersecting and narrow belts of thorn bush ... In order to reach the Mara River it was necessary to cut a path for the vehicle to pass through densely growing A. seyal and other species known to the Maasai as 'Ol-jerai'". Further observations from his report suggest that the vegetation was, by 1932, quite dense although he describes numerous glades that "give the observer the impression of the beautiful parks in England".

Plate 7:1a) shows that, by 1944, much of the Mara Triangle consisted of Acacia-Commiphora bushland, which has now been cleared to grassland (Plate 7:1b). Extensive areas of the Meta and Posee plains were tsetse infested in 1944 (Downey pers. comm.).

Talbot (1970) presents evidence that around 1915 the northern Serengeti was open. He noted that on early German maps of the area that had been prepared in 1911-1915 a small rock outcrop ('kopje'), called Njamageti, was shown as a very prominent marker in an identifiable and accessible part of the Kenya-Tanzania border. For many months in 1957 the Talbots were unable to find this hill but eventually it was located. The reason why it had become invisible was that very tall Acacia trees, that had grown in the area, effectively screened it from view. They argue that the country must have been very open in 1915 to allow the outcrop to have been so conspicuous.

The evidence presented in this section tentatively suggests that there has been an increase in woody vegetation in the Mara from the early to mid part of this century. Woodlands then declined rapidly between 1961 and 1967.

7:12 The Impact of Tree Cutting on the Woodlands of the Mara

By measuring the radius of cleared areas around manyattas and temporary livestock camps on aerial photographs, it has been possible to estimate how much woodland, over the period 1961-1967, has been lost to tree-cutting. The mean radius of clearing around a TLC is 75 ± 21 m (± S.E: n = 12), around a manyatta 200 ± 48 m (± S.E: n = 7). Woodland loss can be measured by assuming that:

a) the maximum density of TLCs in an Acacia-Commiphora block is 9 (see Fig. 4:2b)), that the TLC is used for one year only, that only 50% of the block constitutes woodland, and that TLCs are present at this maximum density in all Acacia-Commiphora blocks for each year between 1961 and 1967.

b) the maximum density of manyattas in an Acacia-Commiphora block in 1961 is 4 (see Fig. 4:2a)), that the manyattas are used for 4 years, that 50% of the block constitutes woodland and that between 1961 and 1967 a maximum of two 5 km Acacia-Commiphora blocks out of a total of 14 actually had manyattas in them.

On the basis of these assumptions, an absolute maximum of 7% (or

$1.2\%.\mathrm{annum}^{-1}$) of Acacia-Commiphora woodland in the study area will have been cleared between 1961 and 1967 for TLC construction. However, the assumptions represent the worst possible impact and the figure is more likely to lie between 0.3-$0.7\%.\mathrm{annum}^{-1}$.

Similarly, over the whole Acacia-Commiphora area, manyatta building contributed $0.1\%.\mathrm{annum}^{-1}$ to the overall loss of this community type, although within the two Acacia-Commiphora blocks in which mayattas occurred, manyatta construction resulted in a maximum rate of loss of $0.7\%.\mathrm{annum}^{-1}$.

Manyattas are rarely built, however, in Acacia-Commiphora woodland because of the presence of the tsetse-flies. Favourite sites are adjacent to Croton thickets with an abundance of building material. In some areas, such as at Talek, the small thicket areas may be decimated. However, young Croton bushes less than 1 m tall are left and so the potential for regeneration remains. In the Talek area the proportion of total woody vegetation that is removed for manyatta construction is insignificant, and at Ol Doinyo Orinka, as was indicated in Section 7:9, the hilltop Croton thicket has hardly changed in area over the past 30 years, despite the very high manyatta density in this area.

However, some tree species that are favoured for hut construction are removed from thickets some distance from the manyatta. Examples are Grewia spp, Teclea spp, Euclea divinorum and Tarchonanthus camphoratus. Strychnos henningsii provides very durable hut centre poles but because of the shortage of Strychnos trees in high Maasai density areas, the centre poles are often reused in new manyattas. Olea africana, the "african olive", being resistant to termite attack, also provides hut poles, but its more important function is in the treatment of milk. A burning twig of O. africana (Maasai: **ol-oirien**) is inserted into the milk gourd before the milk is poured in; apparently this prolongs the life of the milk. A more detailed examination of the domestic uses of different plant species by the Maasai is given by Glover et al (1966).

The Maasai of the Mara use only dead trees for firewood and after the woodland losses of 1960-1974 there has been a surplus of this commodity in the southern part of the study area. Dead Dichrostachys cinerea and Grewia spp trees remain standing for a long time and make excellent firewood. However, with the local depletion of firewood in the Talek area by tourist lodges and camping visitors to the game reserve, the Maasai women may walk as far as 5 km from the manyatta to obtain wood.

As found for the **il-Kisongo** Maasai by Western (1973), the impact of tree cutting by the Maasai on the vegetation of the Mara has been relatively insignificant, a conclusion supported by Glover and Trump (1970).

7:13 The Recovery of Woody Vegetation on Abandoned Settlement Sites

In her detailed study of vegetation recovery on old **il-Kisongo** manyatta sites in the Amboseli area, Jensen (1982) found that on manyatta sites as old as 70 years, no shrub recolonization took place if there was evidence that the site had been burned. She concludes that "even though shrubs regrowth and/or recolonization does occur to a greater extent on unburned sites, there is nevertheless no significant trend of increasing shrub density through time on unburned sites".

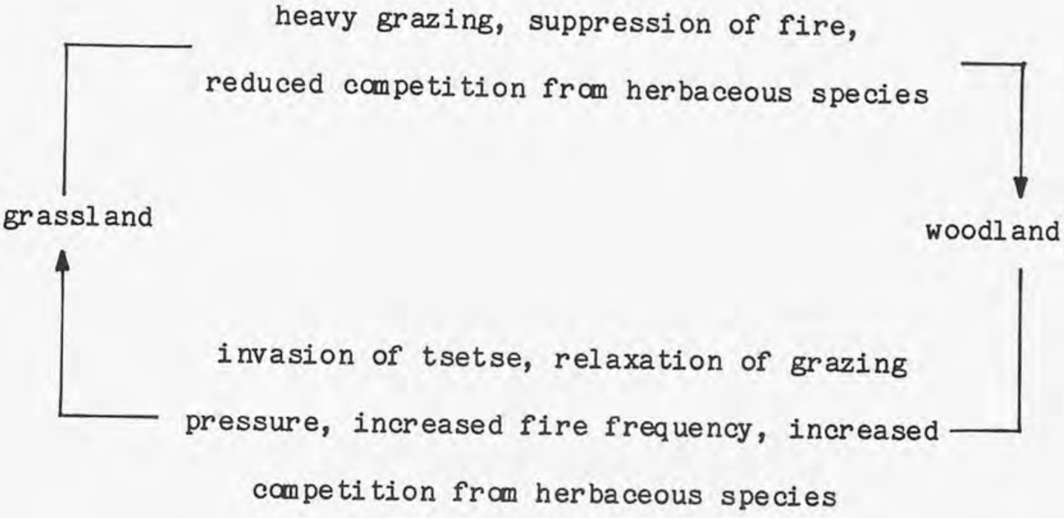
These observations hold true for the Mara area. Six sites were chosen in the Lemek valley for revisiting. All were on the edge of *Tarchonanthus* bushland and none showed any bushland recovery whatsoever. Because the penetration of manyattas into and through the *Acacia*-*Commiphora* belt is a comparatively recent phenomenon (Chapter 4), it was not possible to find sites in this vegetation type that were older than 16 years. Again none of the three 1967 sites visited had been recolonized and all three had disappeared so completely that it was difficult to find any sign of them at all. The first very large manyatta at Talek, which appears in 1967, was located 200 m from the authors camp. Not only could no trace be found of this site on the ground but it was virtually invisible from the air as well. In moister areas, however, old sites could be recognized by their dense sward of *Cynodon dactylon* grass. No signs were ever found of 1961-67 temporary livestock camps in the Enkikwe area.

Despite these observations, there was tentative evidence that recolonization had taken place in some areas. Small, circular, even-aged stands of *Acacia senegal*, *A. gerrardii* and *Dichrostachys cinerea* were occassionally encountered. According to Thomas (1945) *Dichrostachys* colonizes abandoned Karamajong settlement sites in Uganda. However, even with reference back to the early aerial photography, the stands in the Mara could not be confirmed as old manyatta or TLC sites. Woosnam (1914) indicates the position of two manyattas in the Mara Triangle in 1913 but they could not be visited.

From these findings, the recovery of shrubs and old settlement sites cannot be considered a significant factor in overall woodland trends in the area, but there are indications that such recovery was once much more conspicuous. Lewis E.A. (1935) noticed circular _Acacia_ stands in 1932; "in the course of my journeys through Osero [the old Maasai name for the Mara meaning 'bushland'], I observed many circular patches of young thorn trees. My Maasai guide informed me that the trees had grown on the sites of Maasai bomas [settlements] when the area was occupied many years ago". He continues "There is evidence (Sandford 1919) that a large number of Maasai, including Purko, moved into the trans-Mara country in September 1919 after Woosnam's discovery of _Glossina fuscipleuris_ [tsetse] and his suspicion of the existence of another species". Perhaps, in their hurry to move, they did not burn their settlements, and shrubs were able to recolonize.

7:14 Conclusions

In this chapter I have described the woodland changes in the Mara which enabled the Maasai to move south from the Lemek hills into areas directly adjacent to the Maasai Mara National Reserve. Over the period 1961 to 1974, declines in the tsetse-infested _Acacia_-_Commiphora_ belt, which had previously 'shielded' the southern areas from the Maasai, allowed this southward shift of Maasai and their livestock (see Chapter 4). However, in some areas outside the reserve, _Acacia gerrardii_ is regenerating very rapidly, leading to an increase again in the tsetse _Glossina_ *pallidipes*. Surviving areas of *Acacia*-*Commiphora* bushland in the south eastern quarter of the study area have also become reinfested with tsetse, this time by *Glossina swynnertoni*. It could be postulated that, over this century, a woodland-grassland-woodland cycle has taken place with the following mechanism:



It is interesting to note that a similar process, on a very much larger scale, has been described for the Ankole region of Uganda (Ford and Clifford 1968) where, between 1944 and 1953, 600 square miles of country became tsetse infested following the extensive regeneration of *A. gerrardii*. Ford and Clifford (1968) believe that A. *gerrardii* represents a seral stage in the succession back to the woodland 'climax' of an *Acacia*-*Commiphora* vegetation type. However, the course of this succession in the Mara (if indeed it can be considered as a succession) is masked by complex patterns of herbivore and fire impact.

Having described Maasai movements and woodland losses, an important question remains. With the heavy grazing offtake by wildebeest in the dry season, and the lower fire frequency associated with areas of high wildebeest utilization (Norton-Griffiths 1979), why has there been no recovery of bushland inside the reserve? The possible reasons for this will be discussed in the next chapter.

Fig. 7:1. The flight diagram of the 1983 photography. The stipled areas were chosen for the analysis of woodland cover change through the entire range of aerial photography. Blocks A7, B10 and C8 were sampled on the ground to determine 1983 cover values for the five sample points in the blocks (see Chapter 8). Part of the north-eastern corner of the study area was obscurred by cloud during the 1983 aerial photographic flight.

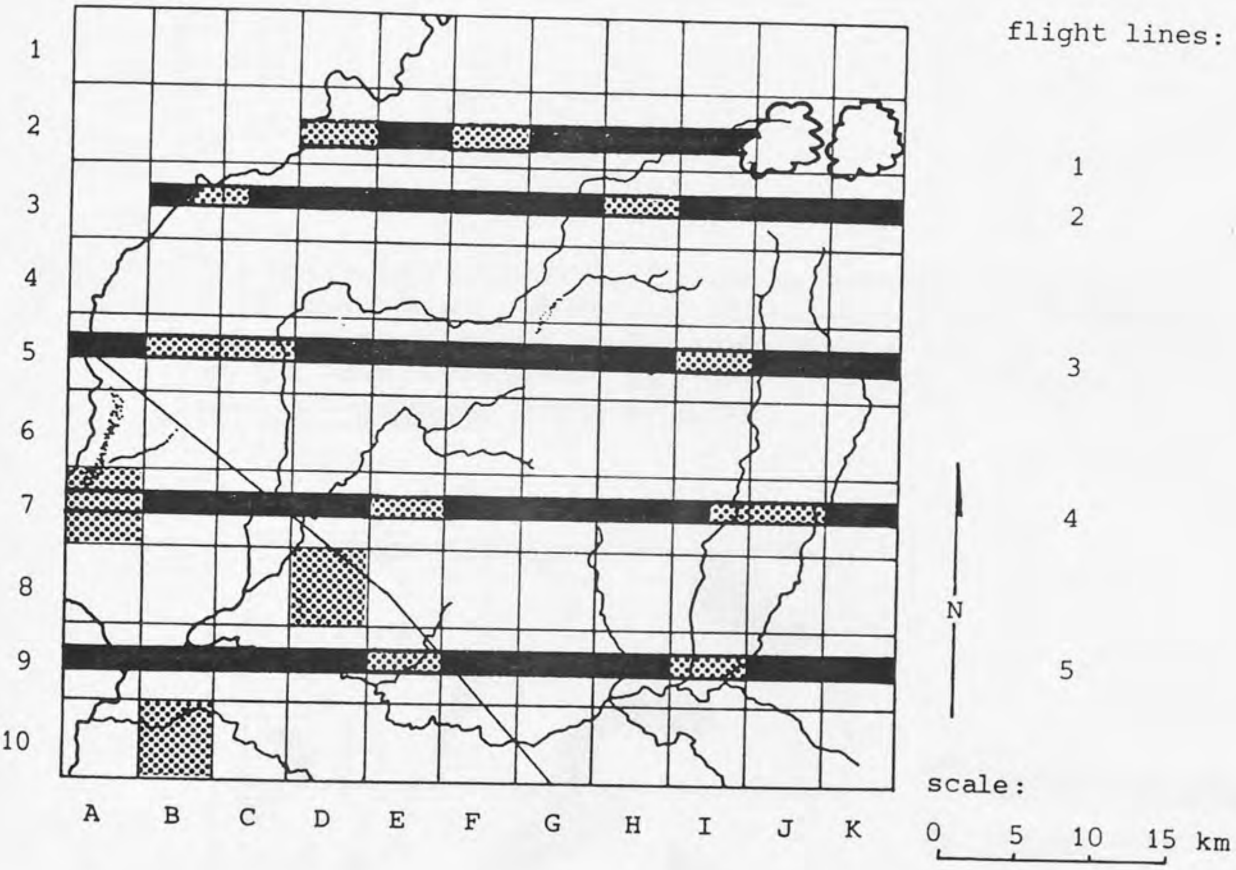


Fig. 7:2. The dot-grid pattern used to determine the woodland cover at each sample point. Five cover counts were made at each sample sample point by rotating the grid systematically around the centre-dot.

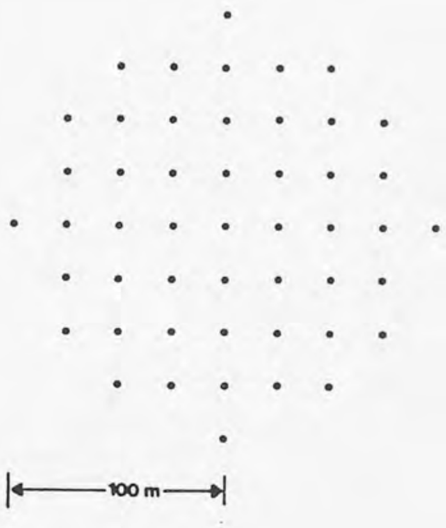
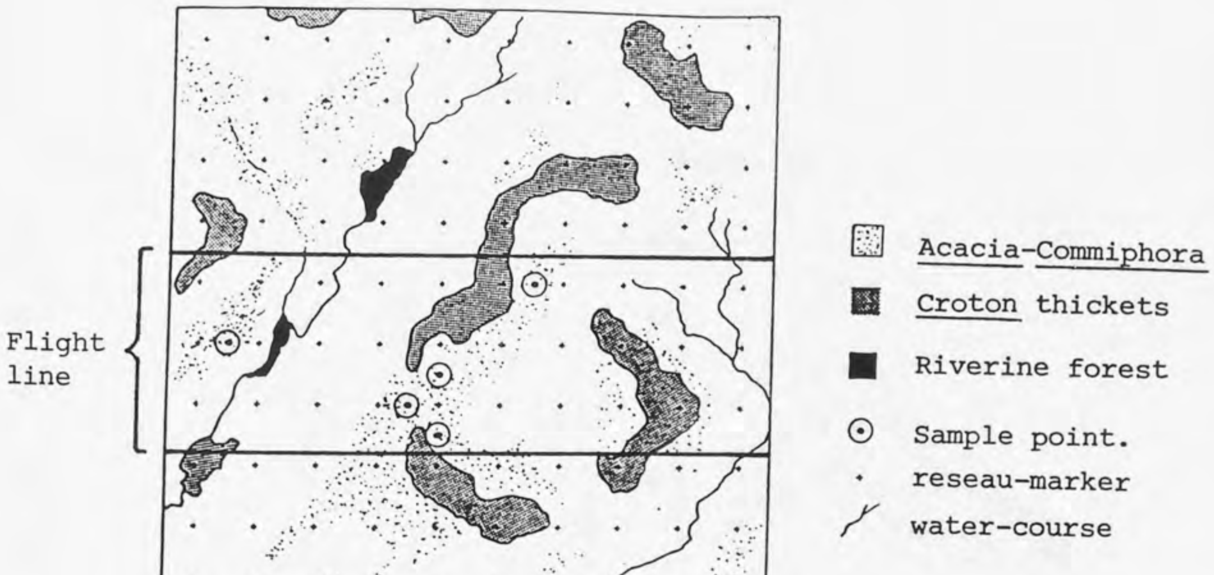
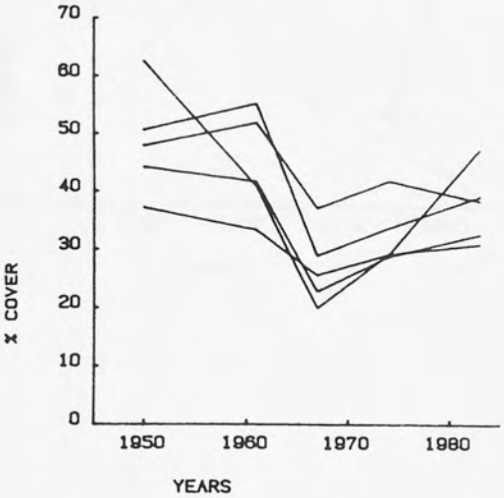


Fig. 7:3. The systematic selection of cover sample points along the 1983 flight lines, which were drawn onto the 1961 photography. The sample points all lie half-way between the reseau-markers on the 1961 photography, in areas of regular, homogeneous Acacia-Commiphora bushed grassland.

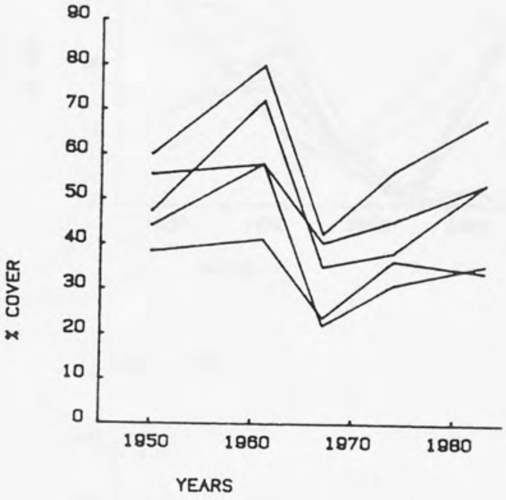


Figs. 7:4a)-d). Cover changes in the Tarchonanthus blocks I5, H3, F2 and D2.

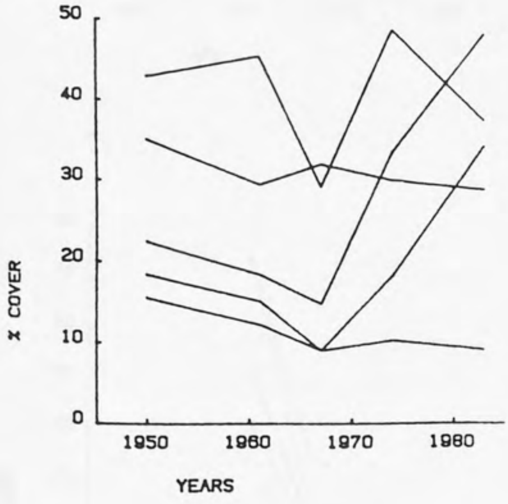
7:4a). I5



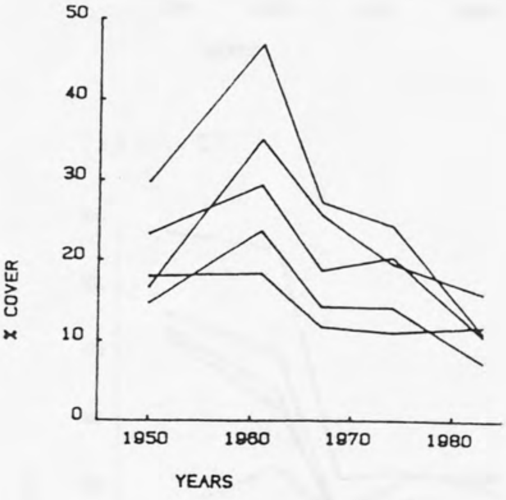
7:4b). H3



7:4c). F2

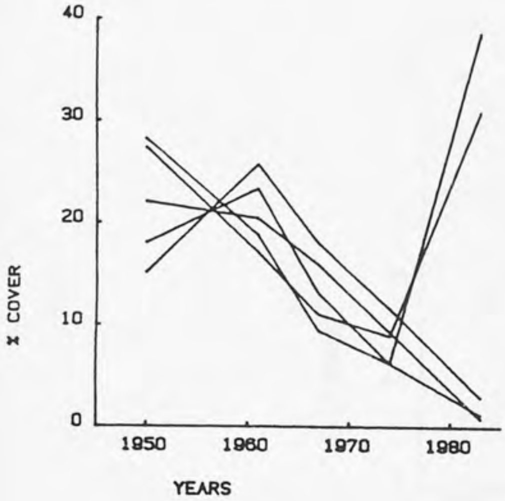


7:4d). D2

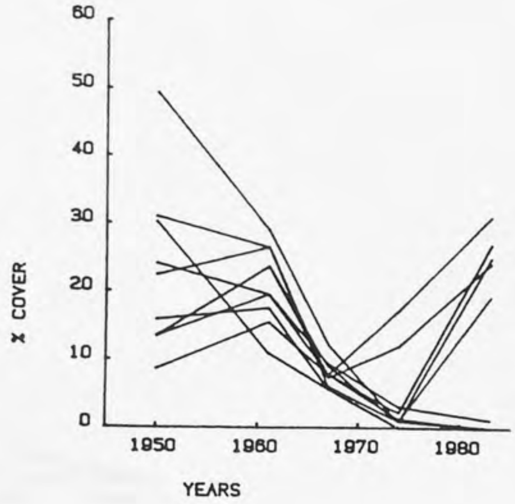


Figs. 7:4e)-j). Cover changes in the Acacia-Commiphora blocks B3, B5/C5, E7, E9, J7 and I9, all located outside the Maasai Mara National Reserve.

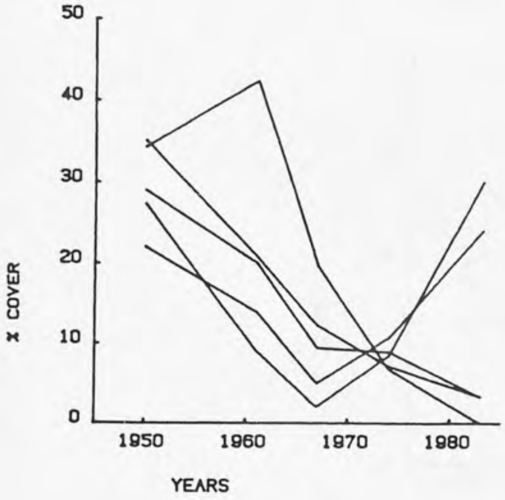
7:4e). B3



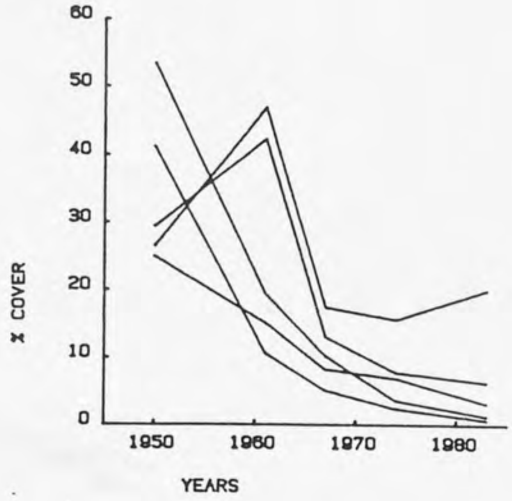
7:4f). B5/C5



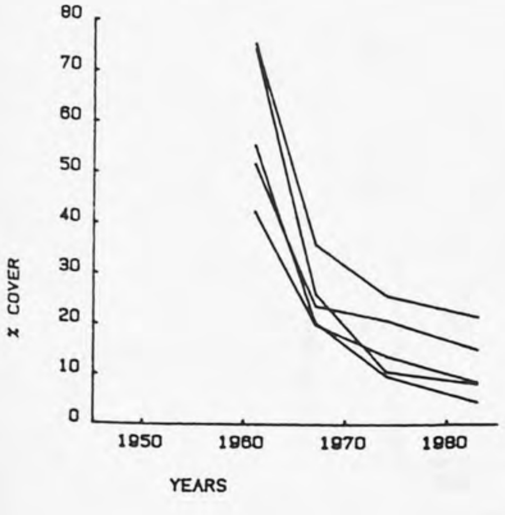
7:4g). E7



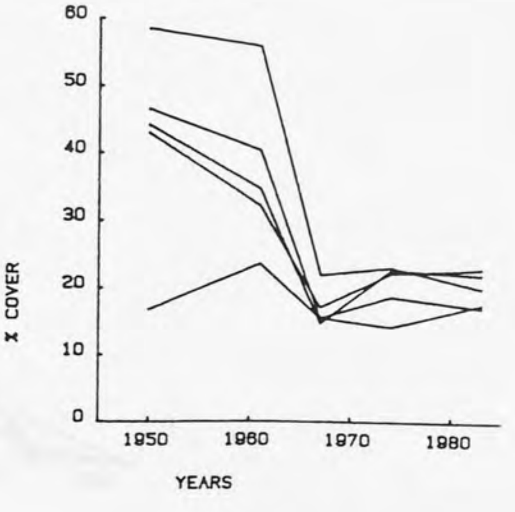
7:4h). E9



7:4i). J7

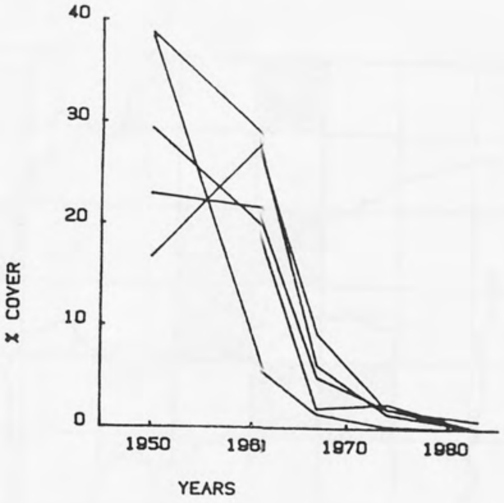


7:4j). I9

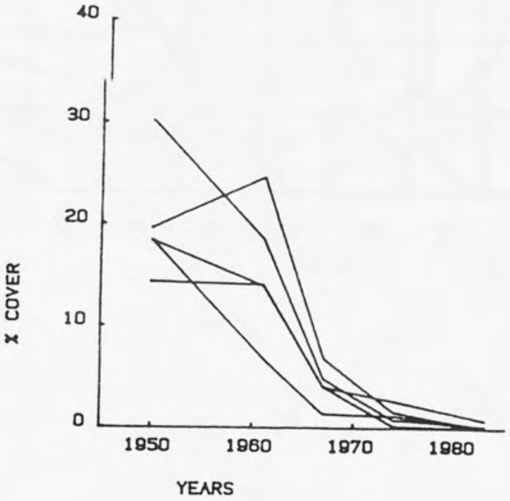


Figs. 7:4k)-m). Cover changes in *Acacia-Commiphora* blocks A7, C8 and B10, all located inside the Maasai Mara National Reserve.

7:4k). A7



7:4l). C8



7:4m). B10

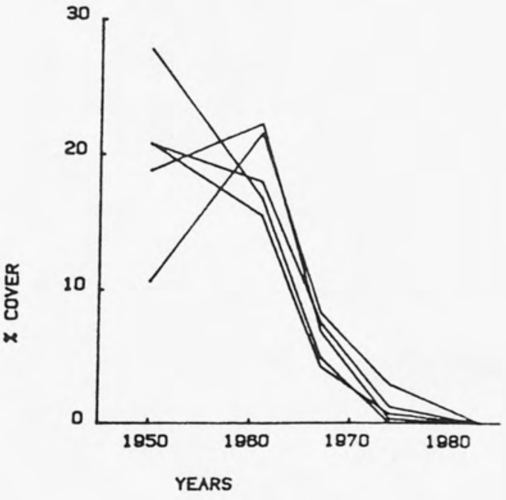
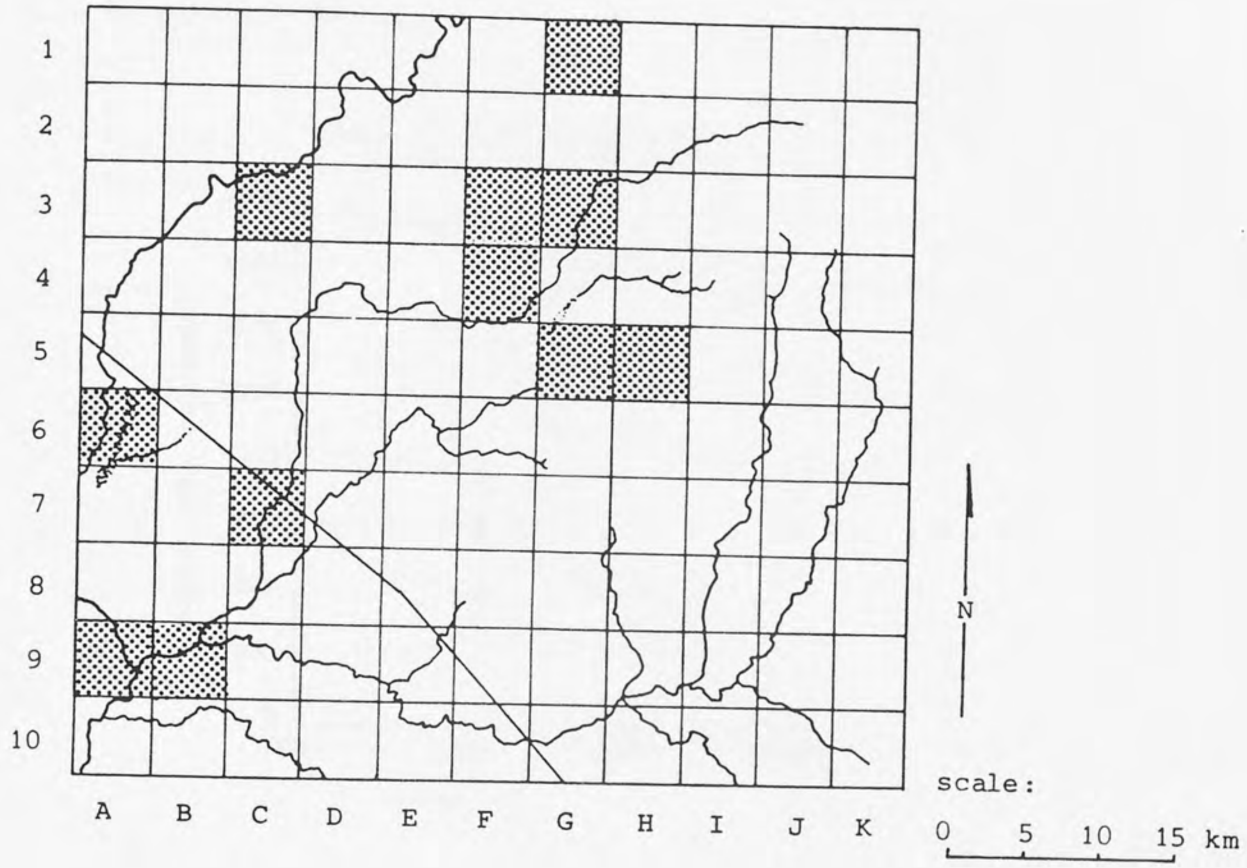


Fig. 7:5. The 5 km blocks (stipled areas) selected for forest and thicket monitoring.

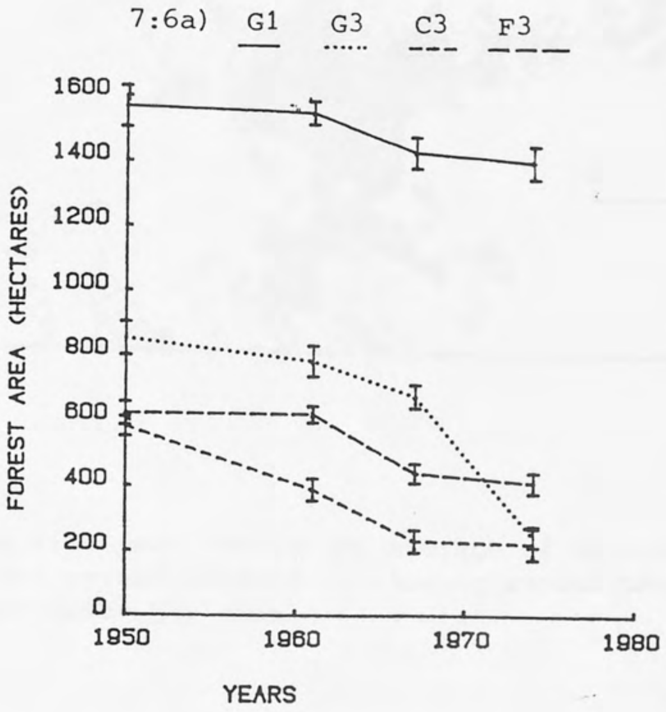


Figs. 7:6a) and b). Forest area changes between 1950 and 1974 for the specified 5 km blocks.

Fig. 7:6a). Blocks G1, G3, C3 and F3.

Fig. 7:6b). Blocks A9/B9, A6 and C7.

Bars represent ± 95%c.l.



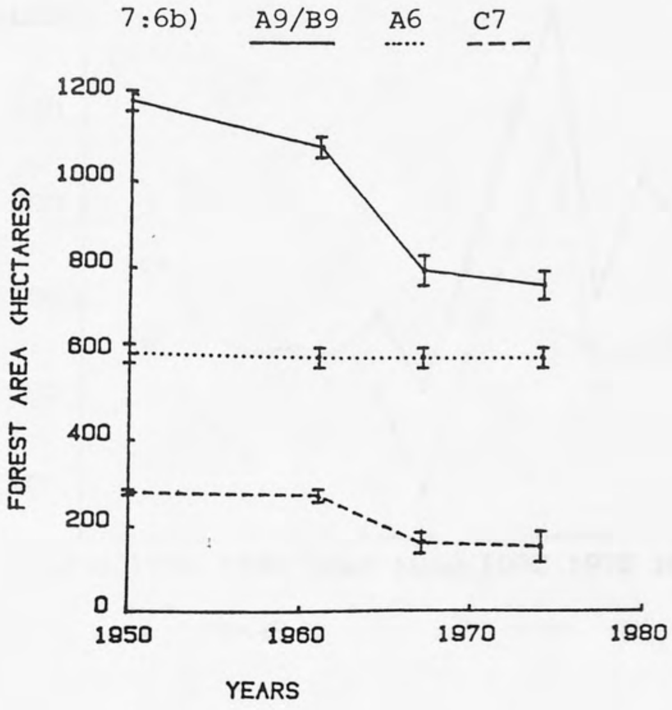


Fig. 7:7. The change in area of riverine forest (vegetation Type 1(b)) at the junction of the Mara and Talek rivers (5 km blocks A9/B9) between 1950 (hatched area) and 1974 (black area). The blocks are distorted because of photographic distortion and the scale rectification procedure.

Fig. 7:8. A five-year cumulative average of rainfall at Narok for the period 1914-1979, showing annual totals (•—•) and November-May totals (•·····•).

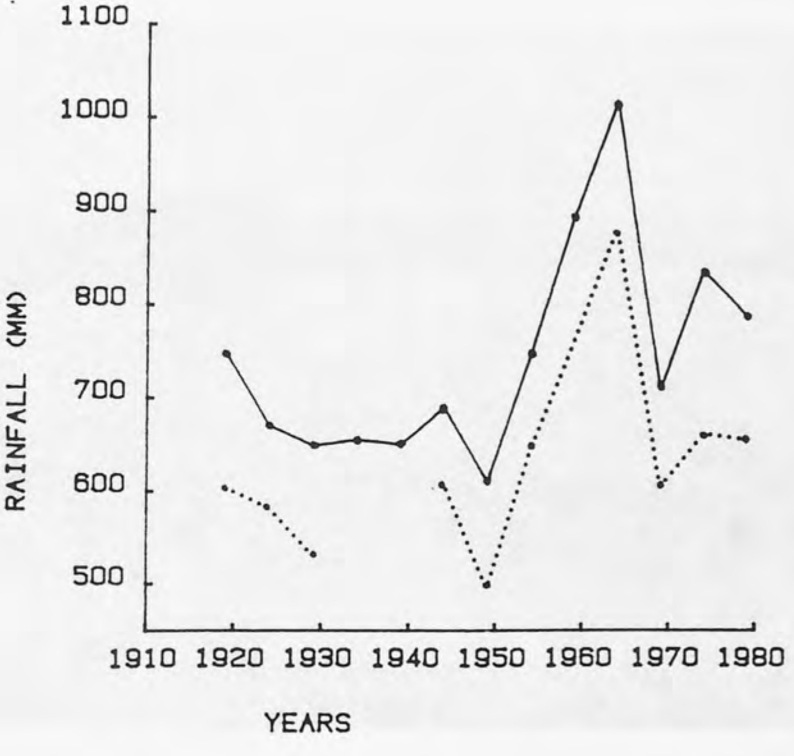


Plate 7:1a). View from a small hill in the Mara Triangle taken in 1944, showing the extent of the Acacia-Commiphora bushland. The Siria escarpment can be seen in the distance to the right. Photograph courtesy of the late Mr S Downey.

Plate 7:1b). The same view as in Plate 7:1a) taken in 1983. The Acacia-Commiphora bushland has been completely cleared to grassland.

Table 7:1. The results of the exercise to record vegetation change between 1961 and 1983 at 420 systematically spaced points in the study area, chosen as the centre points of the 1983 photography. The numbers in brackets refer to the percentage of the total number of sample points showing that change.

Vegetation type	Cover No change	Increasing	Decreasing	Converted to grassland[a]
Tarchonanthus	23 (5.5%)	2 (.5%)	4 (1.0%)	0
Acacia drepanolobium	35 (8.3%)	5 (1.2%)	4 (1.0%)	4 (1.0%)
Acacia-Commiphora[b]	23 (5.5%)	5 (1.2%)	56 (13.3%)	21 (5.0%)
Grassland	221 (52.6%)	5 (1.2%)	-	-

Remaining cover (8.9%) accounted for by the Forest and *Croton* thicket communities.

[a] :these points are incorporated into the 'Decreasing' category.

[b] : The *Acacia gerrardii* community is incorporated into the *Acacia-Commiphora* community.

Table 7:2. Rates of change of woodland in the study area, between the years of aerial photography. Woodland sample points have been grouped into 3 categories: a) *Tarchonanthus* blocks in the northern areas (blocks I5, H3, F2, D2): b) *Acacia-Commiphora* blocks outside the game reserve (blocks I9, J7, C5, B5, B3, E7, E9): c) *Acacia-Commiphora* blocks inside the reserve (blocks B10, C8, A7). Absolute change and relative change are presented; absolute change represents the mean annual loss in cover density between the years, and relative change the mean annual percentage loss from the previous photographic year's cover. All rates ± S.E. Bracketed numbers are the mean corrected absolute rate of change assuming that the dot-grid cover-measuring technique overestimates cover by a factor of 2 (see section 7.3). d-tests have been conducted to test the null hypothesis that there is no significant difference in the absolute rate of change in the *Acacia-Commiphora* community inside and outside the game reserve. In the table a negative change represents a loss.

Category	change	1950-1961	n	1961-1967	n	1967-1974	n	1974-1983	n
a) *Tarchonanthus*	relative	1.21 ± .75	19	-6.02 ± .56	20	3.82 ± 1.20	20	.56 ± .89	20
	absolute	.30 ± .22	"	-.264 ± .43	"	.79 ± .22	"	.26 ± .23	"
	(absolute/2)	(.15 ± .11)	"	(-.138 ± .21)	"	(.39 ± .11)	"	(.13 ± .12)	"
b) *Acacia-Commiphora* outside reserve.	relative	-.12 ± .79	30	-9.11 ± .36	35	-2.60 ± 1.90	35	20.50 ±11.80	35
	absolute	-.36 ± .21	"	-2.79 ± .31	"	-.48 ± .14	"	.35 ± .21	"
	(absolute/2)	(-.18 ± .11)	"	(-1.40 ± .15)	"	(-.24 ± .07)	"	(.18 ± .10)	"
c) *Acacia-Commiphora* inside reserve.	relative	-.83 ± 1.13	15	-12.08 ± .33	15	-9.63 ± 1.28	15	-10.21 ± .42	15
	absolute	-.42 ± .25	"	-2.22 ± .21	"	-.55 ± .09	"	-.13 ± .02	"
	(absolute/2)	(-.21 ± .13)	"	(-1.10 ± .11)	"	(-.28 ± .04)	"	(-.06 ± .01)	"
	d:	.117:NS		1.610:NS		.484:NS		2.386: $p < .05^a$	

NS: not significant.

[a]: this significance can be attributed to the replacement of the degraded *Acacia-Commiphora* areas outside the reserve with *Acacia gerrardii*.

Table 7:3. Forest and thicket areas (hectares ± 95% confidence limits) in selected 5km blocks from 1950 to 1974.

Vegetation type	5km block and location	1950	1961	1974	1983	1950-1974 loss per annum (ha)
Forest types 1a), 1b)	G1: forest north of Lemek	1566 ± 63.5	1551 ± 35.1	1432 ± 48.2	1406 ± 50.9	6.7
	G3: Aitong-Koyage gap.	851 ± 50.4	784 ± 47.2	678 ± 36.3	247 ± 33.4	25.2
	E3: Mara Buffalo camp area.	581 ± 29.7	390 ± 33.9	232 ± 35.1	224 ± 49.2	14.9
	F3: Aitong-Kipleleo area.	621 ± 35.1	620 ± 24.9	442 ± 29.9	414 ± 32.1	8.6
	A9/B9: Mara-Talek junction.	1185 ± 24.5	1079 ± 23.5	795 ± 40.2	761 ± 33.1	17.0
	A6: Mara River forest.	601 ± 21.7	592 ± 22.7	592 ± 22.7	592 ± 22.7	.4
	C7: Olare Orok river.	279 ± 9.4	272 ± 14.6	161 ± 24.7	152 ± 36.1	5.3
Croton dichogamus thicket type 2a)	G5/H5: Ol Doinyo Orinka.	562 ± 31.6	523 ± 30.6	523 ± 30.6	523 ± 30.6	1.6
	F3/4: Aitong.	550 ± 15.8	550 ± 15.8	536 ± 20.0	531 ± 19.3	.8

CHAPTER 8: CATTLE GRAZING INTENSITY AND TREE AGE DISTRIBUTION

8:1 Introduction

In the previous chapter a study was made of woody vegetation cover changes in areas inside and outside the game reserve. In this chapter a programme of ground sampling is described, which was conducted to examine the relationship between livestock grazing intensity and the recruitment of trees in the Acacia-Commiphora community. Tree recruitment rates in Tarchonanthus bushland were not analysed, firstly because a grazing gradient does not extend across this community, and secondly because it was very difficult to distinguish between individual Tarchonanthus seedlings and multi-stemmed coppicing regrowth from root stock below ground level (see Section 6:2).

In this chapter the following sub-hypotheses are tested, all derived from hypothesis 1 in Section 1:1:

1) That tree recruitment rates increase with increasing livestock grazing intensity.

2) That seedling densities are greater outside the reserve than inside. Throughout this programme of groundwork no distinction could be made between seedlings and shoots sprouting from underground root stock; both are termed 'seedlings'.

3) That areas of high cover Acacia-Commiphora bushland are confined to areas of high cattle densities.

8:2 Methods

Before this vegetation analysis was started it was envisaged that funds would not be forthcoming for a 1983 aerial photographic survey. Therefore, to obtain estimates of cover for 1983 for the airphoto plot points (see previous chapter) a method had to be used that recorded cover. At the same time this method, or an alternative, was required to provide density estimates of different size classes for the recruitment analysis, bearing in mind that if tree crown diameter is not taken into account, cover and density may be considered unrelated. For example, a very high density of small seedlings may have a cover of only 1-2% whilst a relatively low density of mature trees may have a cover of 10-20%. The distinction between cover and density has been clarified by Pratt et al (1966).

In vegetation studies in East Africa the following methods have been adopted to determine cover and density:

a) The variable plot method (Cooper 1957, 1963): this simple method, although accurate, measures cover only and does not allow the investigator to 'filter out' trees under 2.5 m canopy diameter, a necessary requirement when comparing estimates of cover from aerial photographs and ground plots. Although it was used for the community composition-by-cover assessment (Chapter 6) it was not used in this analysis.

b) The point-centred-quarter (PCQ) method (Cottam and Curtis 1956; Dix 1961; Heyting 1968). The PCQ method measures tree densities of different height classes but it does not record cover. It was tested for the recruitment analysis but was rejected, for reasons explained below.

c) Fixed area plots (see Greig-Smith 1964): as with PCQ this method records density but not cover.

Eventually a technique was selected that has been little used in Africa, the line-intercept method (Canfield 1941; Meeuwig and Budy 1981). This method, favoured by Walker (1970) for sampling tufted grassland communities in Zimbabwe, provides accurate estimates of both cover and density of different size classes and is described below.

The decision to use the line-intercept method followed extensive tests of all methods on a test plot on the side of En Doinyo Oloip hill (Maasai: the 'hill of the shade') in the Talek area, chosen for its complex vegetation structure and composition. In these tests circular 'quadrats' of 10 m^2 area were placed at 10 m intervals along each arm of the star-shaped plan shown in Fig. 8:1. 120 quadrat samples were taken. All species within the quadrat were identified, measured for height and canopy diameter, and counted, to provide estimates of the tree age distributions against which quicker sampling methods could be tested. The PCQ method (and other methods that rely on distance measurements) significantly underestimates density when plants are aggregated in clumps (Risser and Zedler 1968; Lyon 1968; Good and Good 1971; Poissonet _et al_ 1973; Peden and Olang 1982). On the test plot, clumps of _Dichrostachys cinerea_ seedlings were recorded by the 10 m^2 plot method as having an overall density of 1400 $seedlings.ha^{-1}$. The PCQ method with a sample point every 10 m along each arm gave an estimate of $400.ha^{-1}$, although a better approximation of density was obtained for less aggregated species. The line-intercept technique gave a Dichrostachys seedling density of 1200.ha^{-1} and line-intercept density estimates for other species were very close indeed to the 10 m^2 plot estimates.

The overall plot plan of Fig. 8:1 was used to resemble as closely as possible the airphoto plot plan of 100 m radius and 3.14 ha area (Fig. 7:2). The line-intercept transects, organized according to this plan, provided the ground cover estimates for the photo plots in blocks A7, B10, and C8 (see Section 7:3). These cover values were doubled to compensate for the x 2 overestimation of cover by the airphoto dot-grid technique (see Appendix F). Although the ground plot plan significantly oversamples the centre area of a plot, a greater efficiency of transect alignment and speed was achieved by orientating transects with respect to a centre pole, especially since an assistant was not available to help with the procedure.

At each sample point or plot, the total transect length was 1200 m, although in dense vegetation this was shortened to 800 m, or, in a few cases, 400 m. The transect direction away from the pole was fixed by 30° or 45° incremental compass bearings. Starting at the centre pole, a distant conspicuous feature such as a tall tree or hilltop was used to mark the bearing and each 100 m transect was paced out in that direction pushing a 'line-marking stick' with a curved skid at its head. Each seedling, bush or tree that vertically intercepted, by its canopy, the line drawn by the head of the stick was species-recorded and measured for height and mean canopy diameter. Thick bushes were measured and paced around, being careful to start in the correct position on the other side.

The crown diameter and height were assigned to the classes 0-1 m, 1-2 m, 2-3 m, and so on, and for all calculations the mid values of the classes 0.5 m, 1.5 m, 2.5 m, etc. were used. The density of each tree species, for each canopy class, can be calculated according to the formula (Meeuwig and Budy 1981):

$$\text{No. trees.ha}^{-1} = \frac{10{,}000}{L} \times \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots\ldots \frac{1}{C_n}\right)$$

where L is the total transect length (1200 m, 800 m or 400 m) and C_1, C_2 and C_3 are the diameters of each canopy intercepted.

Similarly, the cover of each species, for each canopy class, can be calculated thus:

$$\text{Cover \%} = \frac{25\pi}{L} \times (C_1 + C_2 + C_3 + \ldots\ldots C_n)$$

If each 100 m transect away from the centre pole is considered as a single sample, 12 such samples gave, for tree density, a standard error/mean ratio of 10-15%. This was felt to be sufficient for the accuracy required. In thick bush the plot dimensions could be reduced to eight 100 m transects or eight 50 m transects.

60 points were chosen for sampling, selected in exactly the same way as the airphoto woodland cover sample points; the ground plots were originally intended as the 1983 continuation of the photo plots. Thus the points lay in homogeneous woodland, between the 'reseau-markers' on the 1961 photography in selected 5 km blocks of known grazing intensity. All points lay in

Acacia-*Commiphora* woodland within Koyake Group Ranch and the selected 5 km blocks are shown in Fig. 8:2. Block H6 contains a narrow band of *Acacia*-*Commiphora* bushland adjacent to the *Tarchonanthus* bushland on the southern end of Bardamat hill.

As many as 10 points could be fitted into a block, although in the more inaccessible blocks or those with a smaller area of bushland, such as blocks E7 and H6, this had to be reduced to as few as 4.

Tree size is often regarded as an indicator of tree age (Philip 1983) and in the Serengeti height has been the most commonly recorded size variable (Croze 1974b; Herlocker 1976; Pellew 1981). In the *Acacia*-*Commiphora* community of the Mara, however, canopy diameters are closely related to height for all species (Table 8:1). The canopy size distribution, to which the line-intercept method is sensitive, has therefore been adopted as the indicator of recruitment rates. The calculation of height recruitment from line-intercept data is somewhat laborious and has only been performed in one instance (see Fig. 8:4).

Pellew (1981) has demonstrated that height growth rates for *Acacia tortilis* and *A. hockii* in the Serengeti are roughly constant at 11-23 cm.annum^{-1} until a height of 5 m is attained and the trees begin to 'escape' from giraffe browsing. Tree growth rates in certain component species of the *Acacia*-*Commiphora* community are currently under study by Dublin, but for the purpose of this analysis growth rates will be treated as being constant when the community is analysed as a whole. Thus canopy diameter and tree height are considered directly proportional to age.

8:3 Results: Tree Age Distribution and Recruitment

The total of 60 km of transects using the line-intercept method provides a copious quantity of data that can be analysed in a number of different ways. For example, tree age distribution can be examined in terms of density or cover for one species or all species combined. The composition by density and cover of the relatively 'intact' Acacia-Commiphora community in block I9 is presented in Figs. 8:3a) and b). In all 5 km blocks sampled on the ground the vegetation structure represented some stage of the destruction or regeneration of this type.

In the recruitment analysis, the percentage canopy diameter recruitment between the 0-1 m seedling class and the 1-2 m class can be considered a particularly important indicator of fire frequency because seedlings are the class most vulnerable to fire (Trapnell 1959; Hopkins 1965; Spence and Angus 1971; Herlocker 1976; Pellew 1981). For every sample point, seedling recruitment is expressed thus:

$$\text{Seedling recruitment (\%)} = \frac{d1}{d0} \times 100$$

d0 and d1 are the relative densities of trees in the 0-1 m and the 1-2 m categories respectively. The results for each sample block are shown in Table 8:2. In Figs. 8:4a) and c) seedling height and canopy recruitment data are plotted against the mean cattle density for the eight 10 km blocks in which the eight 5 km sample blocks lie. The mean cattle density has been calculated from all SRF data (see Table 5:2). In Figs. 8:4b) and d) the same recruitment data are plotted against the 1974-83 10 km Model 1 'mid-value' data (see Table 5:1). It will be recalled from Chapter 5 that cattle densities are proportional to the number of manyattas within 10 km of the block. The 1974-1983 Model 1 'mid-value' therefore provides an index of grazing pressure over the last 10 years (the mid-value is highly autocorrelated with both 1974 and 1983 models). The relationships presented in Fig. 8:4 are all highly significant ($p < 0.01$) indicating that in the Acacia-Commiphora community the recruitment of all seedlings from the 0-1 m canopy class and height class into the 1-2 m class is directly proportional to cattle grazing intensity.

This analysis 'lumps' all species together, but it is unlikely that different species will have the same growth or survival rates. Therefore, seedling canopy recruitment data for four of the most abundant species or genera have been 'extracted' from the line-intercept data set and tested separately against SRF cattle density and Model 1 data. These species are Commiphora spp, Acacia gerrardii, A. senegal and Grewia spp. The Spearman rank correlation coefficients of the relationships are shown in Table 8:3. All except Grewia spp show a significantly higher seedling recruitment at higher cattle densities. Growth rates of the individual species of the Acacia-Commiphora community, and the responses of those species to the actions of fire, elephants and other major agents of mortality are currently being studied by Dublin. Her work will clarify the survival characteristics of the separate species.

The line-intercept data can be analysed in a second way that takes into account not only the recruitment from the 0-1 m to 1-2 m categories, but the continuing recruitment into larger categories. The mean relative densities of each canopy size class for the sample points in each 5 km sampling block are shown in Figs. 8:5a)-h). The mean relative density, absolute density and cover of each size class in each block are presented in Appendix H. In Appendix I the canopy size classes are plotted against their $\log_{10}$ relative abundances (% frequencies), a transform which effectively straightens the age distribution curves. The resulting linearity indicates that in the Acacia-Commiphora community the tree age distribution follows the negative exponential commonly seen in natural, undisturbed tree populations (Philip 1983) where survival rates are approximately constant from one size class to the next. This age structure differs markedly from the Serengeti woodland age structures reported by Lamprey et al (1967), Croze (1974b) and Pellew (1981), where even-aged stands predominate. Norton-Griffiths (1979) suggests that the Serengeti tree age distributions indicate ecological instability. A predictable age structure such as that of the Acacia-Commiphora community in the Maasai areas would therefore indicate that woodland stability is increased in areas where grass cover, fire, wildebeest densities and elephant densities are reduced (see Chapter 10 and Section 8:13). With these complex patterns of impact on vegetation in the Mara it is difficult to determine what is a 'natural' tree age structure.

The negative exponential follows the function:

$$f(x) = \theta e^{-\theta x}$$

The term $e^{-\theta}$ is the proportion surviving each growth unit or size class. The estimate of θ ($\hat{\theta}$) is given by:

$$\hat{\theta} = \frac{2}{\bar{x}}$$

where $\bar{x}$ is the mean canopy diameter of all trees. The standard error of $\hat{\theta}$ is given by:

$$\text{S.E. } (\hat{\theta}) = \frac{1}{\bar{x}} \sqrt{\frac{2}{n}}$$

and the standard error of $e^{-\hat{\theta}}$ by:

$$\text{S.E. } (e^{-\hat{\theta}}) = \frac{\hat{\theta} e^{-\hat{\theta}}}{\sqrt{2n}}$$

Using this procedure (Marriot pers. comm.), the proportion surviving from one class to the next has been calculated. These data are presented in Table 8:4.

The means of the proportions of trees that survive from one canopy size class to the next, for each 5 km block sampled are plotted against cattle density and Model 1 data in Figs. 8:6a) and b). Recruitment rates vary from 2.6% inside the reserve to 31.6% in those areas heavily used by livestock. These results demonstrate that the increased tree survival in areas of high grazing intensity is not just a feature of seedlings but of trees in larger size classes as well.

It is clear that inside the game reserve woodland regrowth is greatly inhibited. With a tentative estimate of the mean growth rate of trees in the <u>Acacia-Commiphora</u> community of 20 cm.annum^{-1}, one large fire every 5 years is sufficient to effectively suppress the regeneration of this community. Herlocker (1976) suggests that a fire every 6-7 years is sufficient to suppress <u>Acacia senegal</u> regeneration in the Serengeti; <u>A. senegal</u> is an important component of the Acacia-Commiphora community (see Section 6:2). Similarly, from his computer simulation of woodland changes in the Seronera area of the Serengeti, Pellew (1981) calculated that a fire every four years would send the Acacia tortilis woodlands into a decline.

In this section a close correlation has been demonstrated between tree recruitment rates and livestock grazing intensity. However, it is a well known dictum of statistics that correlation does not necessarily imply causality (Bailey 1959; Sokal and Rohlf 1969). In the Mara, for example, elephants, another important agent of tree mortality, may actively avoid areas of high livestock concentration and allow bushland to recover. This, and other possibilities, are explored in Section 8:7.

8:4 Results: Seedling Densities

The mean absolute seedling densities for the more important species and genera of the Acacia-Commiphora community in each sampling block are shown in Table 8:5. The mean density of seedlings for all species combined combined is significantly greater for all sample blocks outside the reserve (I9, H6, E9/8, E7/6, C5) at 856 ± 165 seedlings.ha^{-1} (95% c.l.) than for blocks within the reserve (B10, C8, A7) at 547 ± 143 seedlings.ha^{-1} (95% c.l.) ($t = 3.28$: d.f. = 56 : $p < 0.01$). Clearly within the reserve not only is seedling recruitment into larger size classes repressed, but seedling germination, or growth from root stock, is inhibited. This may be the result of repeated burning leading to an exhaustion of root stock reserves, or the increased selection for this browse size class, in the absence of other sizes, by elephants in the dry season (see Section 8:7). Also to be examined in Section 8:7 is the possibility that a significant proportion of seedling mortality is due to trampling by wildebeest in the dry season. It can be seen from Table 8:5 that Commiphora spp densities are very signficantly lower inside the game reserve than outside. This can be explained by the observation of Glover and Trump (1970) that the Commiphoras are particularly sensitive to fire.

8:5 Results: The Relationship between Remaining Woodland Cover and Cattle Density

In Figs. 8:7a) and b) the remaining cover of the Acacia-Commiphora community in each block (Appendix H) has been plotted against cattle densities, calculated from all SRF data, and against the 1974-1983 Model 1 'mid-values'. The remaining cover is significantly correlated with cattle densities, a result which is consistent with the lower tree mortality associated with areas of high cattle densities.

8:6 The Impact of Fire in 1980 on the Acacia gerrardii Community

In 1980 unusually fierce fires swept through the northern Serengeti and much of the Mara area (Epp pers. comm.) In the Enkikwe area, less utilized by cattle, sufficient grass biomass remained well into the dry season to be burned. The distribution of these burns has been mapped from LANDSAT false colour composites dated 17th August and 10th October 1980 (Fig. 8:8). If this burn distribution map is compared with the woody vegetation map in Fig. 6:3 the very close correspondence of burns with the Acacia-Commiphora, Acacia drepanolobium and A. gerrardii communities of the west-central areas is apparent. This association is highly significant ($X^2 = 14.70$: d.f. = 1 : $p < 0.001$: analysis excludes north-eastern quarter). Clearly, if enough grass biomass remained for burning in these woodland areas as far into the dry season as September or October, the grazing pressure in the woodlands must have been reduced. By 1980 the growth of A. gerrardii trees in Enkikwe would have been well advanced. Presumably the Maasai and their livestock would have avoided these areas, with their increasing tsetse fly densities, if sufficient grazing was available elsewhere.

To examine the effect of this fire on the tree age distribution structure of the A. gerrardii community, three randomly located line-intercept plots were conducted in this vegetation type in the Enkikwe area. As a control, three further plots were established in small patches of A. gerrardii in the south-eastern corner of the study area (blocks I9 and J10) that had not been burned. The tree age distribution in these respective areas is shown in Figs. 8:9a)-f). The characteristic 'dip' in density in the 1-2 m class in woodlands which had burned would appear to reflect high mortality in the seedling class due to the burn which occurred three years prior to the sampling.

The effect of this seedling mortality is now moving through the age distribution, which suggests that canopy diameters increase at the rate of 50 cm.annum^{-1}, a figure entirely consistent with the growth rates of the very similar A. hockii in the Serengeti (Pellew 1981). Pellew recorded a browsed and unbrowsed height growth rate for this species, at this seedling size, of 20 cm.annum^{-1} and 50 cm.annum^{-1} respectively. In the unburned areas there is a relatively high representation of smaller height classes with greater survival between classes. In these areas of high livestock grazing pressure, A. gerrardii is forming almost impenetrable stands.

8:7 Aspects of the Interactions between Wild Herbivores and Woody Vegetation

The results of this chapter have indicated that tree survival rates inside the game reserve are very much lower than survival rates in the Maasai areas. It can be suggested that fire frequencies and intensities are greater in the reserve, because the reserve is not utilized by cattle. However, the area is subjected to very heavy grazng in the dry season by the wildebeest migration. Norton-Griffiths (1979) has demonstrated that in the northern Serengeti fire frequency has declined in response to increasing grazing pressure from the wildebeest migration. Why, therefore, has no bushland recovery taken place in the Mara reserve? The first possible reason is that most of the damaging fires now occur in the February-March period, after the 'short rains' when the grass has grown and dried slightly, and before the wildebeest migration has arrived. In 1983 much of the southern area of the reserve was burned at this time.

It is unlikely, however, that fire is the only factor responsible for the decline in woodlands in the Mara. Increased competition for nutrients by herbaceous species is likely to have played a part. Furthermore, recent research has shown that signficant damage is caused to seedlings by the sheer densities of the wildebeest in the dry season. Elephants and giraffe have also responded to changing environmental pressures in the Mara in such a way as to differentially affect woodland mortality. The impact of these three major herbivores is discussed below.

a) Wildebeest: it will be shown in Chapter 10 that during the dry season wildebeest densities may rise to as high as 250-300 animals.km^{-2}, and that the wildebeest avoid areas of high cattle density. On their arrival in new areas the wildebeest often form grazing 'fronts' or dense, advancing concentrations, and Dublin (pers. comm.) has shown that seedlings are frequently destroyed by trampling or by the accidental 'nipping off' of stems. In her experimental plots Dublin attached tags to seedling stems and recorded that after a single passage by the wildebeest 15-50% of stems had been killed. Further mortality to older saplings in the 1-3 m class is caused by the 'thrashing' of the trunks by bull wildebeest (Estes pers. comm.). Cattle do not appear to damage seedlings to the same extent because they are never present in such high densities at any one time.

b) Elephants: in a recent total count of all elephants in the Mara from the air, a population estimate of 1300 elephants was obtained (Dublin pers. comm.). These elephants were mainly confined to the reserve. The population density can be calculated as 0.75 elephants.km^{-2}, a density much greater than the 0.26 elephants.km^{-2} calculated for the northern Serengeti by Watson and Bell (1969). Norton-Griffiths (1979) provides an estimate for the northern Serengeti of 0.2 elephants.km^{-2}. However, the densities are lower than in other areas which have suffered woodland damage by elephants.

For example, in the Kabalega National Park in Uganda Laws _et al_ 1975 have recorded a density of 2.7-3.5 elephants.km^{-2}, whilst in the Tsavo National Park of Kenya elephant densities are of the order of 1.7-2.0 elephants.km^{-2} (Laws and Parker 1968; Leuthold and Sale 1973). The 1983 Mara survey was extended into the northern Serengeti but no elephants were encountered, presumably becaue of the heavy poaching in this area.

In this study KREMU SRF data has been used to determine which areas are most heavily utilized by elephants. Elephant distribution data are presented in Fig. 8:10a), in which the symbols in each 5 km block refer to the number of times an elephant, or elephants, were encountered in the block for 12 SRFs in 1979-80. The numbers therefore represented 'occupance' (see Chapter 5), unconverted to percentages. The elephants generally remain within the reserve and appear to 'know' where the unmarked northern border lies.

In the dry season elephants usually switch from a grass to a browse diet (Laws _et al_ 1975; Field 1971; Guy 1976) and this change has been observed in the Mara elephants (Dublin pers. comm.). However, because there are so few large trees remaining within the reserve the elephants have turned their attentions to seedlings. Dublin has recorded that in the dry season an elephant may pull up as many as 60 seedlings every hour, although there are marked differences in seedling feeding rates between individuals. The relationship between seedling survival and cattle density (Fig. 8:4) may therefore reflect the tendency of elephants to avoid Maasai areas. However, the linearity of this relationship would indicate that fire frequency and nutrient competition from herbaceous species are probably more important than elephant distributions in maintaining the differences in woodland structure between the Maasai and the reserve areas. The separate impacts of elephants and fire cannot be 'teased apart' from the available data.

c) Giraffe: Pellew (1981) has shown that in selected areas of the Serengeti giraffe have been responsible for maintaining trees at a fire-susceptible height. However, inside the Mara reserve virtually no bushland has remained for the giraffe. The mean densities of giraffe for each 10 km block in the study area have been calculated from 12 1979-80 KREMU SRFs. These data are presented in Fig. 8:10b). It is clear that the giraffe have responded to the increased availability of browse in the Maasai areas by moving out of the reserve.

The mean density of giraffe in the Maasai areas is 1.08 ± .122 giraffe.km^{-2} (± S.E: n = 20) and in the reserve .35 ± .069 giraffe.km^{-2} (± S.E: n = 9). In a comparative blockwise analysis this difference is highly significant (Mann-Whitney U-test: $p < 0.001$). The giraffe are weakly but significantly associated with the areas of bushland outside the reserve ($X^2 = 7.63$: d.f. = 1: $p < 0.01$: Cole's Coefficient of Association = .13 ± .048: ± S.E.). Giraffe densities are highest in the areas of high Maasai concentration; in the Lemek valley the mean density is 2.23 giraffe.km^{-2}. However, inside the reserve the density is lower than in any area of the Serengeti sampled by Pellew (1981).

From the analysis presented in this section it can be seen that the two major browsing herbivores, elephants and giraffe, respond completely differently to the presence of high cattle densities. Elephants avoid the Maasai areas with their remaining high cover of woody vegetation; giraffe are attracted to them. Plant-herbivore dynamics in pastoral areas such as the Mara involve a web of complex individual responses that cannot be meaningfully examined in isolation from one another. Norton-Griffiths (1979) and Pellew (1981) argue that a woody vegetation 'stable state' can never be achieved in savanna ecosystems without rigorous herbivore and fire management.

8:8 Discussion

The results of Chapter 7 indicated that declines had taken place throughout the Acacia-Commiphora community. In this chapter the potential for the recovery of these communities has been studied by examining tree age distributions. The declines of woodland into grassland inside the reserve are reflected by very low tree recruitment rates. Outside the reserve, tree recruitment increases in proportion to livestock grazing intensity. Although the recovery of the Acacia-Commiphora type is a slow process, it can be tentatively suggested that in the Maasai areas of Enkikwe, Talek and Olare Sambu the cover of this community will increase to 20-25% over the next ten years. In areas where Acacia gerrardii has become established, recovery rates have been much more rapid (see Chapter 7), bringing an increase in the density of tsetse flies. As a result of the high Maasai immigration rates (see Chapter 4), the Maasai now have to graze their cattle in these tsetse areas and the incidence of trypanosomiasis is increasing.

It is unlikely that woodlands will recover inside the Maasai Mara National Reserve for many years. Without the implementation of an effective fire control programme by the reserve management, fierce fires will continue to sweep through the Mara, burning seedlings back to ground level. The compression of elephants into the reserve at high densities will contribute further to seedling mortality, as will the dry season use of the area by very high densities of wildebeest. However, the continued suppression of woodland in the Mara can only be considered a localized phenomenon. In the north-central Serengeti woody vegetation is rapidly recovering (Norton-Griffiths pers. comm.), frequently characterized by the emergence of single-species stands of <u>Acacia clavigera</u> (Lamprey pers. comm.). These areas face ecological pressures that are markedly different from those of the Mara. They are used by the wildebeest earlier in the year (May-July) and it is therefore conceivable that the frequency of fires in the dry season is reduced by the removal of grass standing crop in the preceding wet season. There is also evidence that increased poaching has greatly reduced the Serengeti elephant population.

Vegetation changes in 'natural' savanna ecosystems almost always represent a response to the direct or indirect interference of man, either through burning, hunting or agricultural expansion. The ability to predict these responses is central to the formulation of management plans for these areas.

Fig. 8:1. The line-intercept transect ground plan.

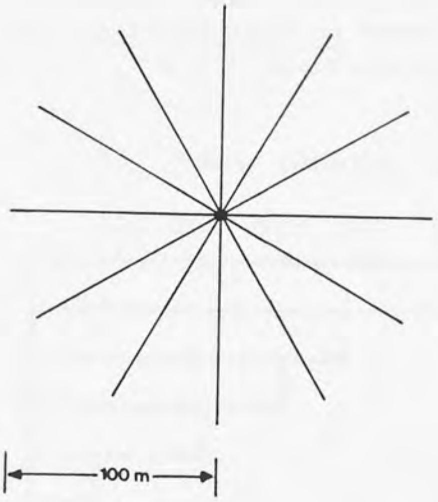


Fig. 8:2. The 5 km blocks (stipled areas) selected for ground sampling by the line-intercept method. All blocks contain areas of Acacia-Commiphora bushed grassland. Some plots in E9 were extended into E8, and some in E7 into E6.

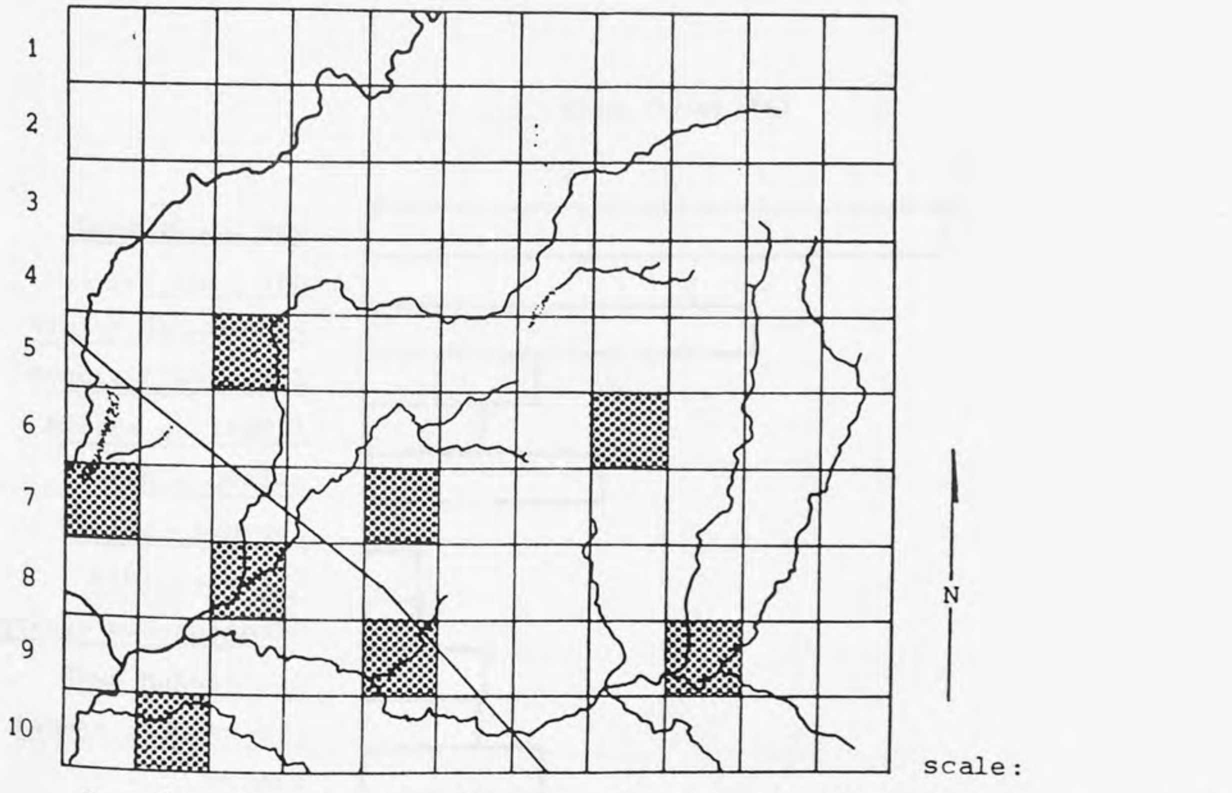


Fig. 8:3a). The species composition by mean density (trees.ha^{-1}) of the *Acacia-Commiphora* community in block I9,calculated from data from 5 line-intercept sample points.

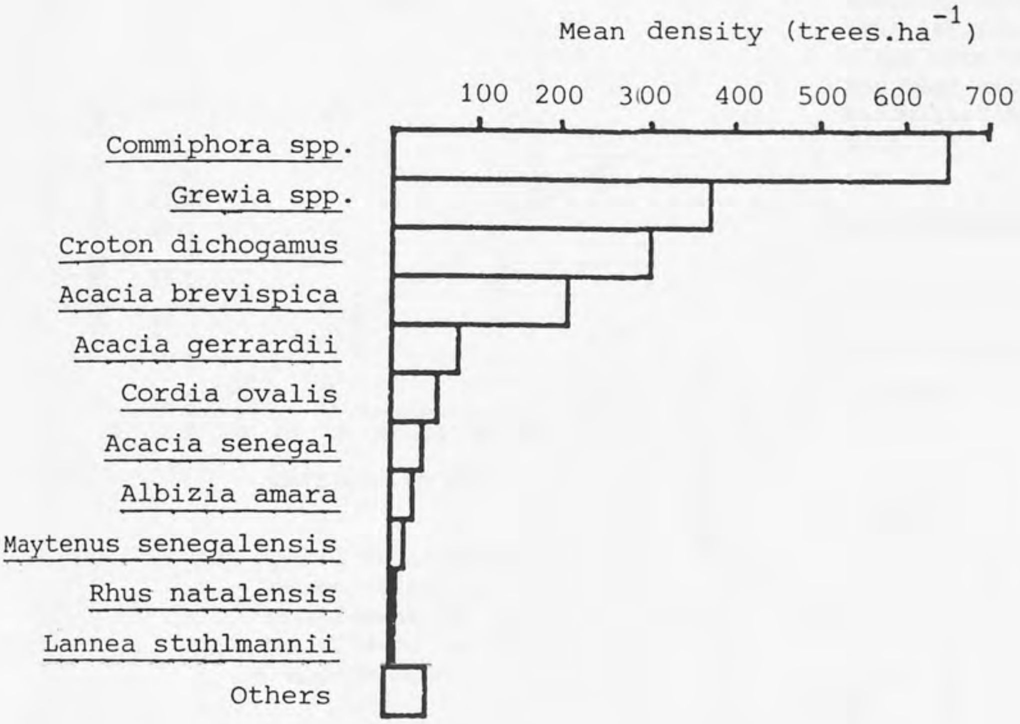


Fig. 8:3b). The species composition by mean cover (%) of the *Acacia-Commiphora* community in block I9.

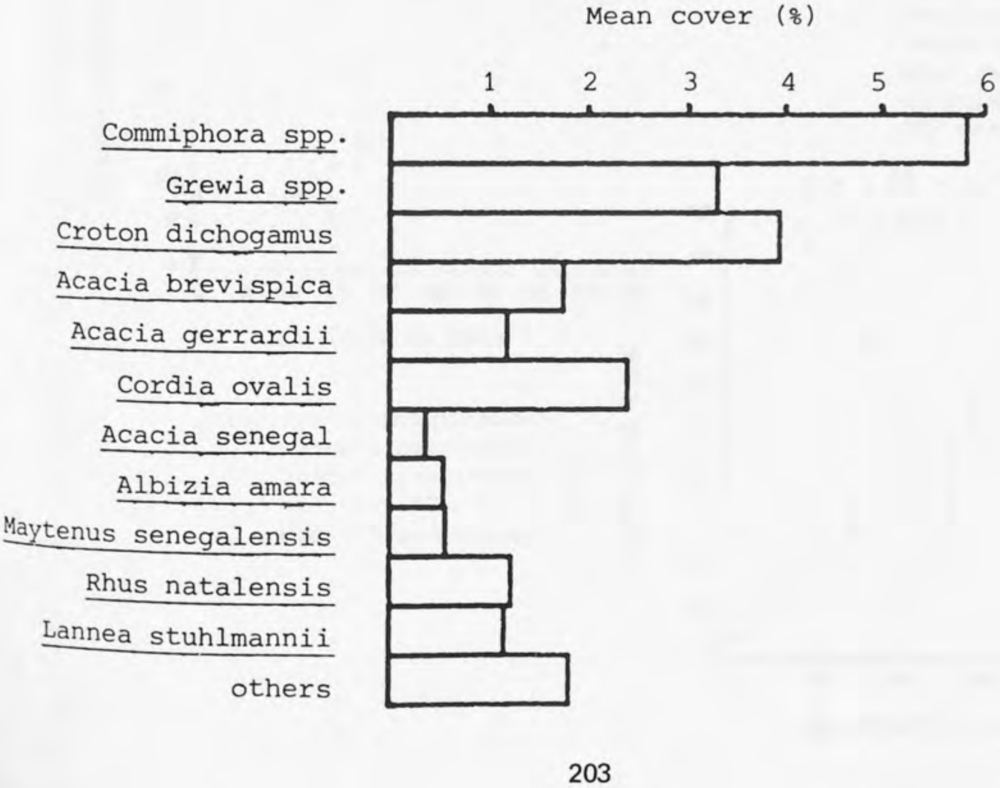


Fig. 8:4. The relationship between seedling recruitment, according to the index (D1/DO) x 100, and grazing intensity as determined from SRF and Model 1 10 km index data.

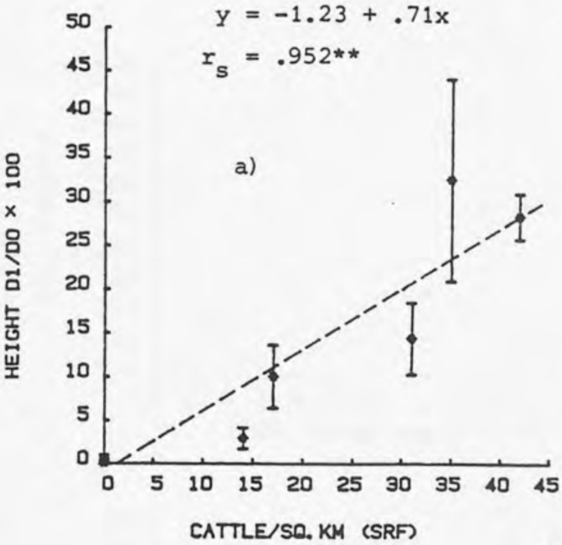


Fig. 8:4a). Relationship between seedling height recruitment (%) from the 0-1m class into the 1-2m class and mean cattle density calculated from all SRF data.

All bars represent ± 1S.E.

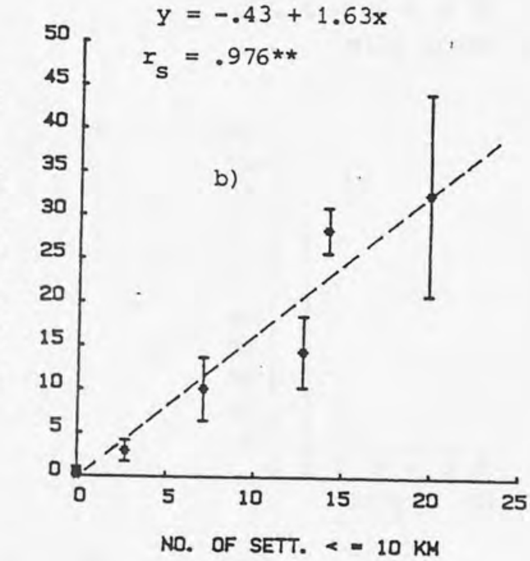


Fig. 8:4b). Relationship between seedling height recruitment (%) and the 1974-83 10 km Model 1 mid-values.

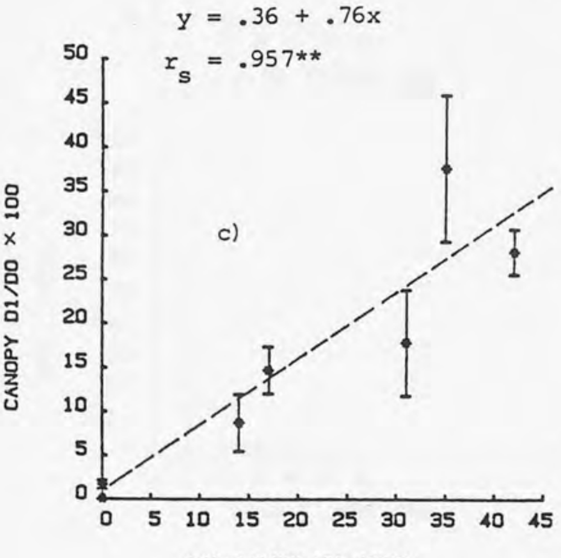


Fig. 8:4c). Relationship between seedling canopy recruitment (%) and mean cattle density calculated from all SRF data.

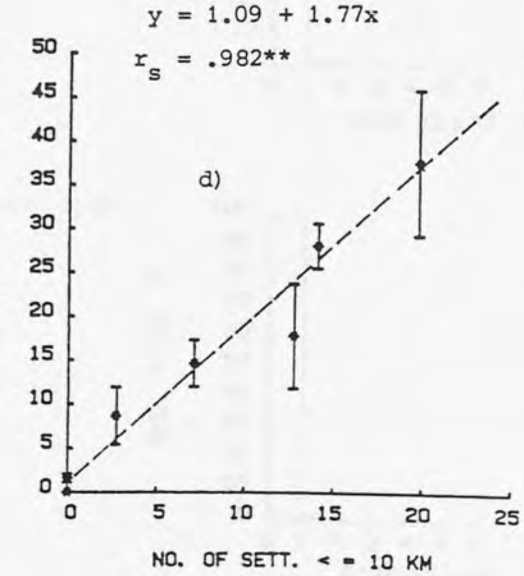
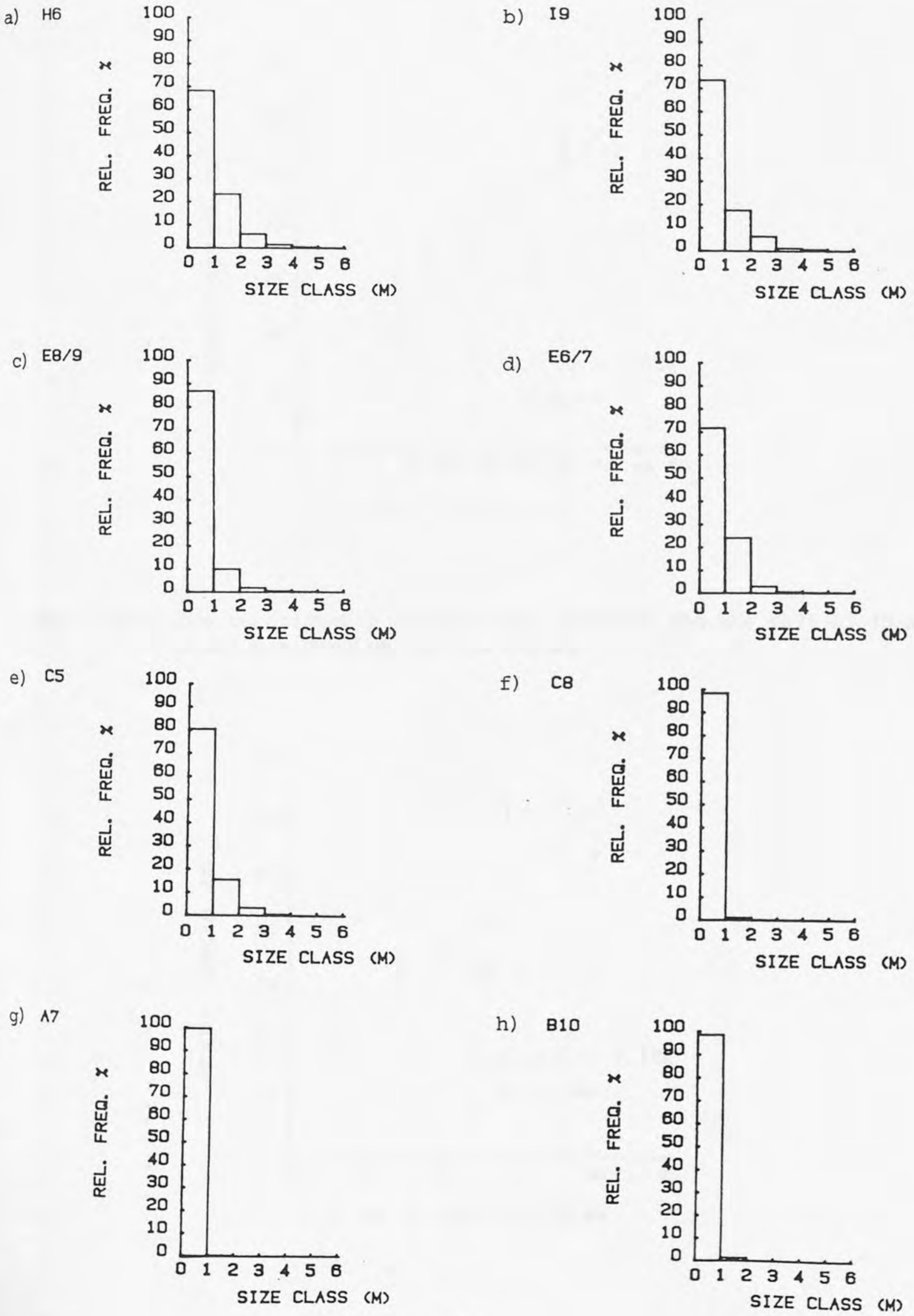


Fig. 8:4d). Relationship between seedling canopy recruitment (%) and the 1974-83 10 km Model 1 mid-values.

Figs. 8:5a)-h). The canopy diameter distribution, expressed as the (%) relative frequency of each size class, for the eight specified 5 km blocks sampled for tree recruitment analysis. The distributions include all tree species.


a) H6

b) I9

c) E8/9

d) E6/7

e) C5

f) C8

g) A7

h) B10

Fig. 8:6a). The relationship between tree survival (e^{-0} x 100) of the Acacia-Commiphora community of a block, and the mean cattle density for the block as calculated from all SRF data.

The bars represent ± 1S.E.

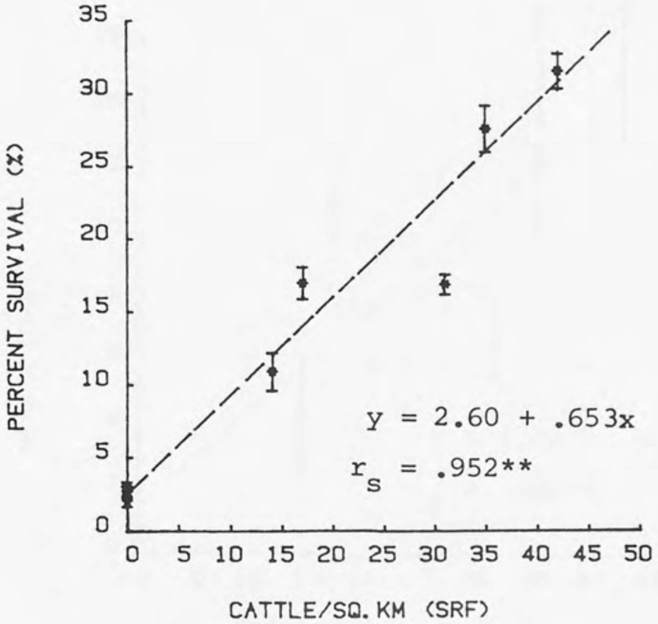


Fig. 8:6b). The relationship between tree survival and the 1974-83 10 km Model 1 mid-value for the block.

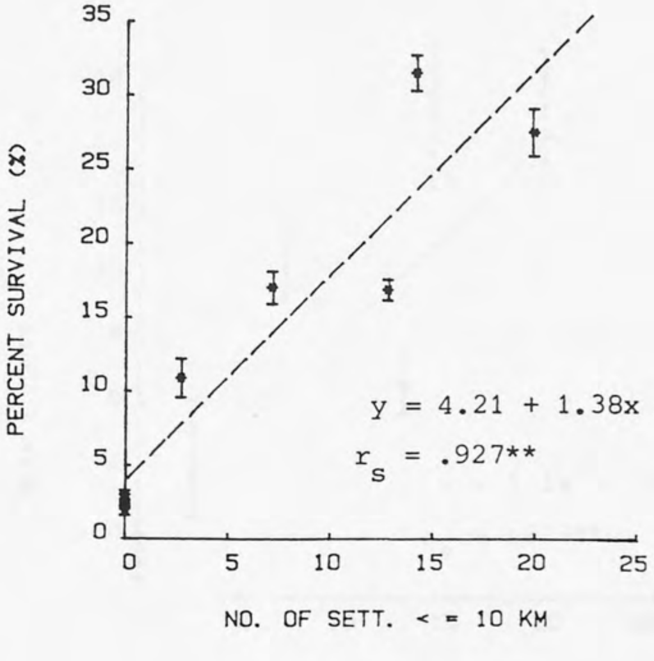


Fig. 8:7a)..The relationship between the mean Acacia-Commiphora cover remaining in a sample block in 1983, and the mean cattle density for the block as calculated from all SRF data.

Bars represent ± 95%c.1

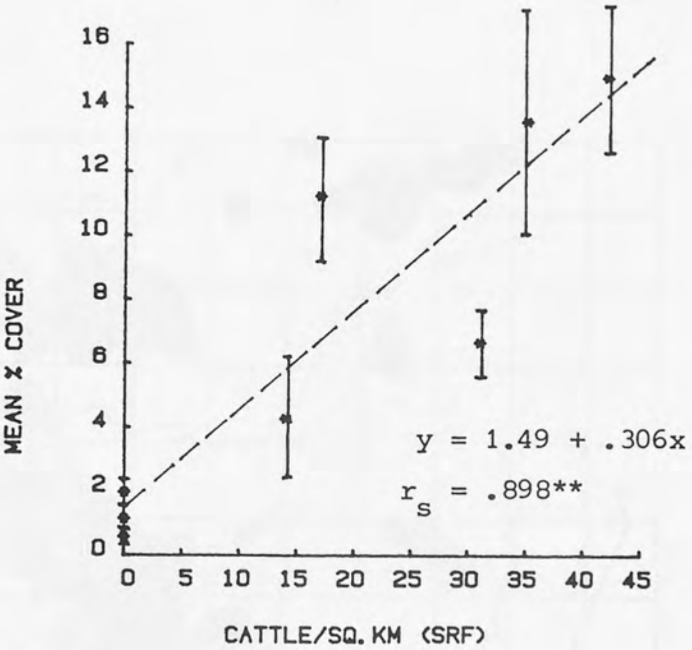


Fig. 8:7b). The relationship between the mean Acacia-Commiphora cover remaining and the 1974-83 10 km Model 1 mid-value.

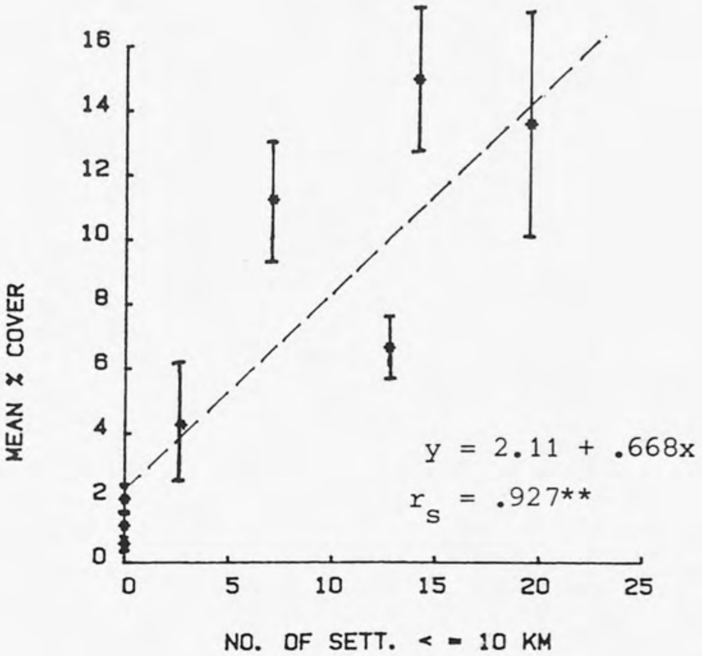
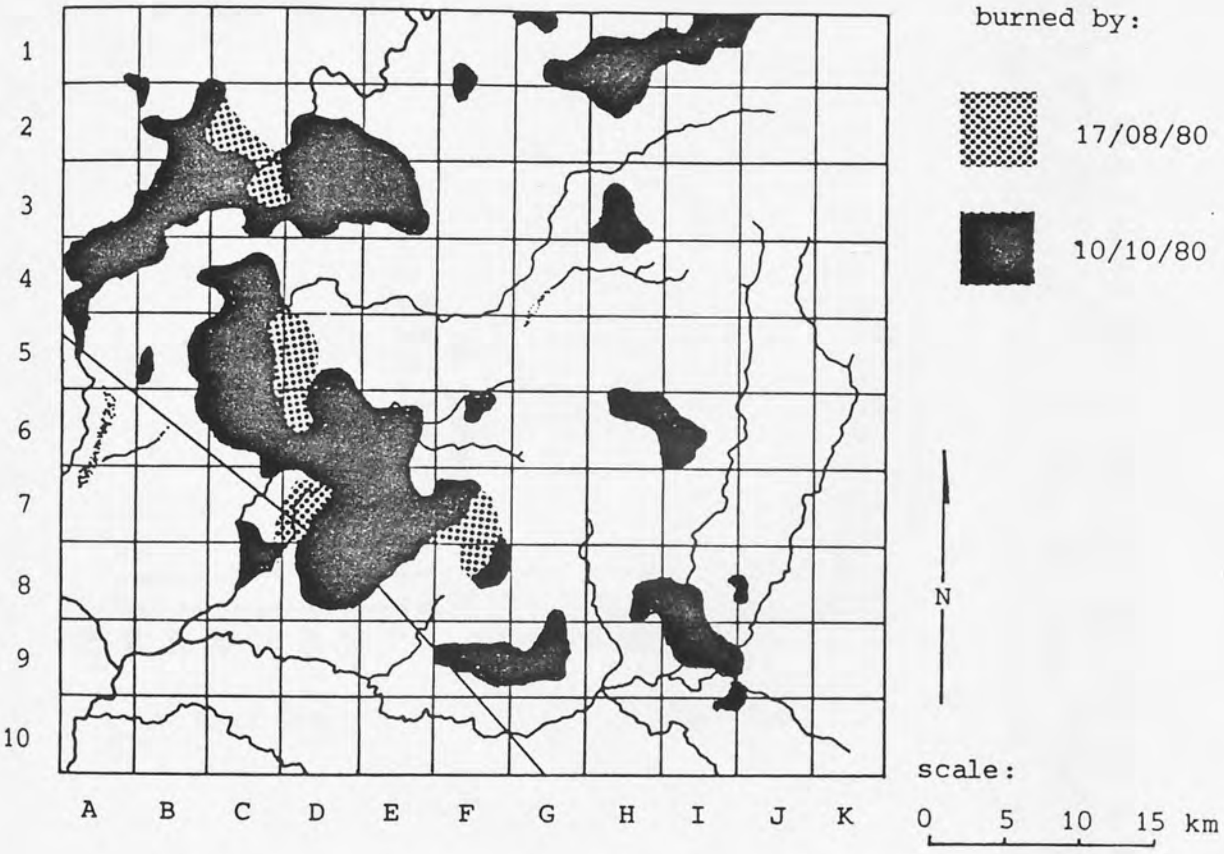
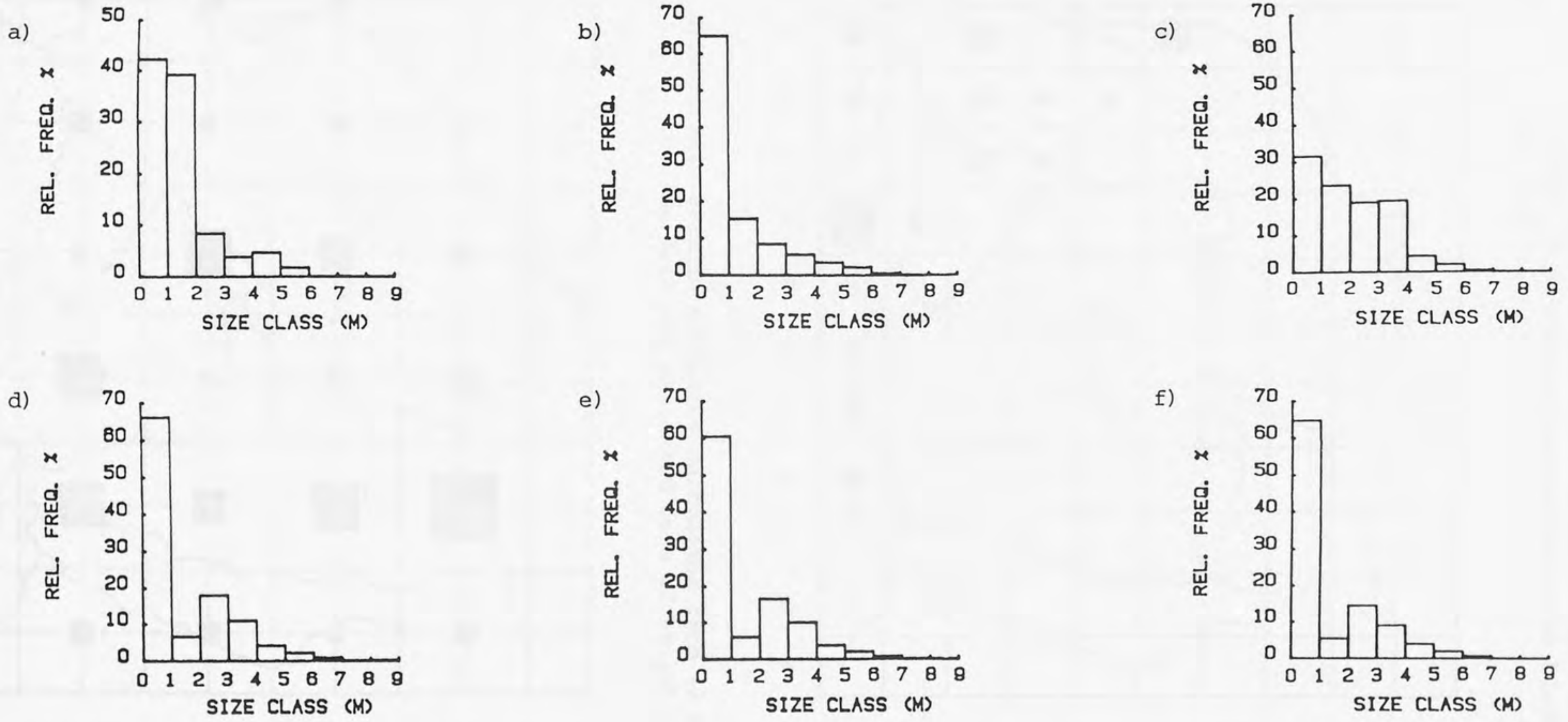


Fig. 8:8. The distribution of burns in 1980, mapped from LANDSAT images (false colour composites) of 17th August 1980 and 10th October 1980. The most extensive fires burned through the Enkikwe and Mara Buffalo areas.





Figs. 8:9a)-f). The canopy diameter distributions, expressed as the (%) relative frequency of each size class, for the Acacia gerrardii community; Figs. a)-c) show the distributions from three plots in the heavily grazed Olare Sambu area that did not burn in 1980, and Figs. d)-f) show the distributions from three plots in the Enkikwe area that burned extensively in 1980.

Fig. 8:10a). Elephant distribution presented as the 'occupance' (or number of sitings of elephants in the block) in 12 SRF's in 1979-80.

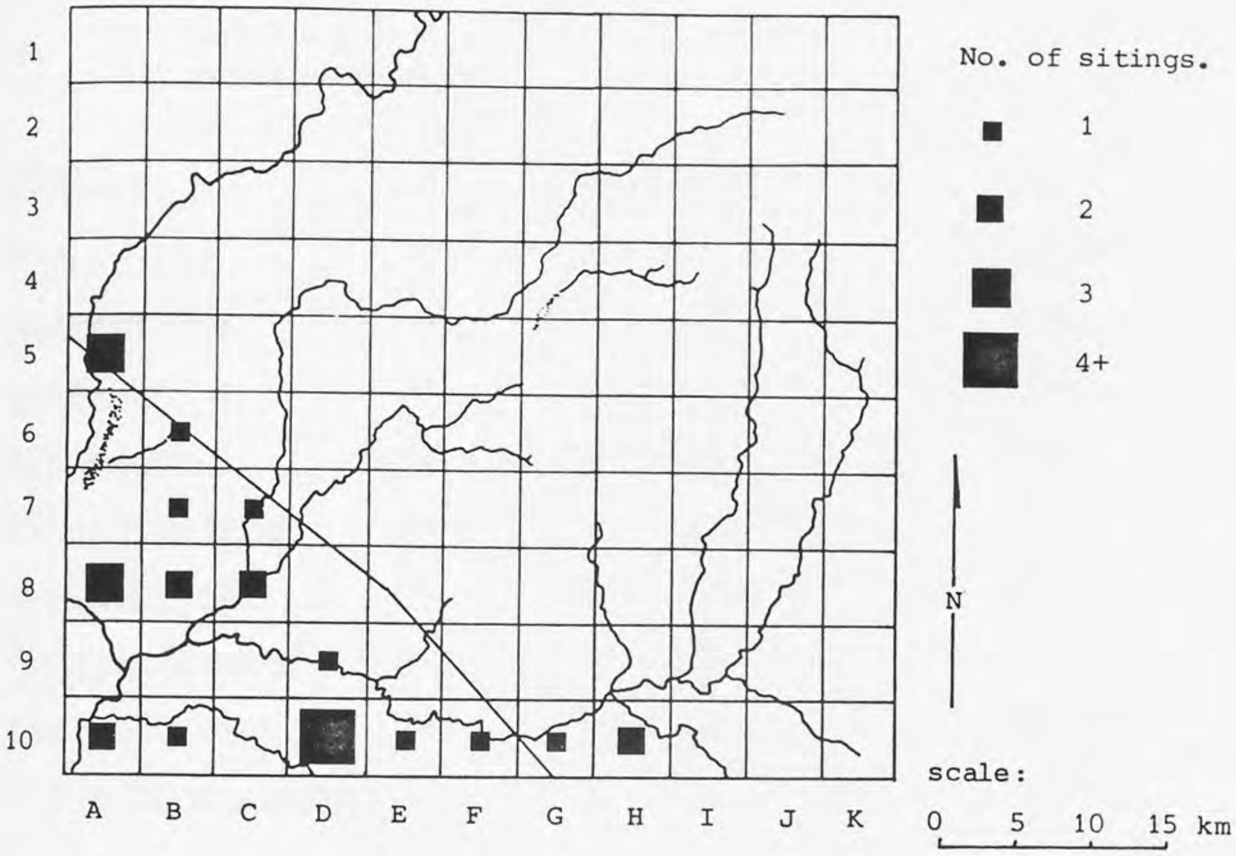


Fig. 8:10b). Mean giraffe densities calculated from 12 SRF's in 1979-80. The data are presented on a 10 km grid.

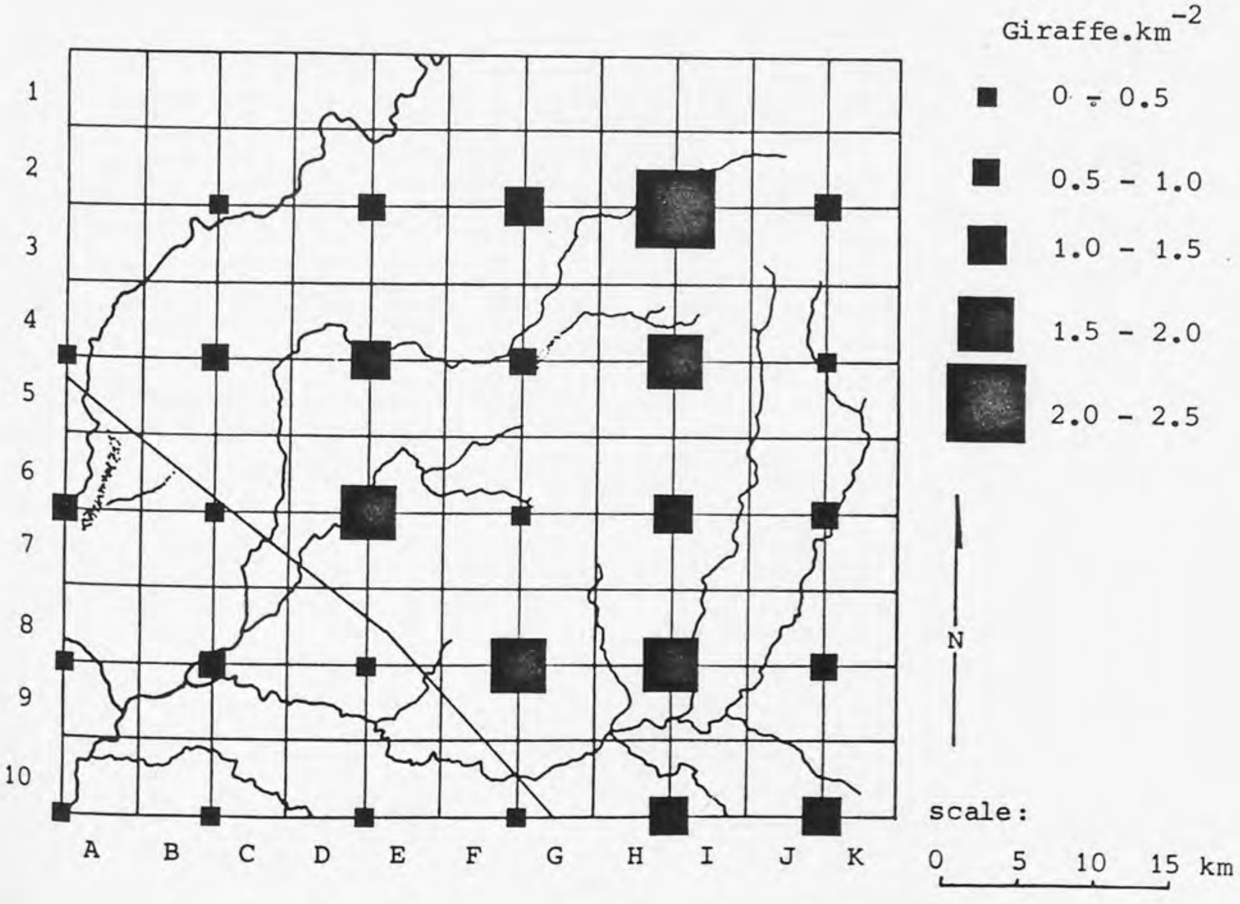


Table 8:1. The relationship of tree height (m) to crown diameter (m) for randomly selected trees of the most abundant species of the *Acacia*-*Commiphora* community. The data were obtained from the 5 km sampling blocks I9, H6 and E9, the blocks where most height classes were represented.

height = h
canopy diameter = c

Species	n	regression equation	r
Cordia ovalis	26	$h = .718c + .463$	.867***
Commiphora spp	123	$h = .826c + .004$	.849***
Grewia spp	77	$h = .824c - .094$	.850***
Acacia senegal	68	$h = .950c + .094$	.753***
Acacia brevispica	41	$h = .858c + .358$	.810***
Acacia gerrardii	55	$h = .968c - .116$	.875***
Croton dichogamus	40	$h = .702c + .612$	.773***
Rhus natalensis	25	$h = .765c + .019$	.965***
Dichrostachys cinerea	27	$h = .791c + .208$	.545**

Table 8:2. The height and canopy recruitment (%) of seedlings from the 0-1 m class into the 1-2 m class, according to the index (D1/D0) x 100 (see text).

5 km sampling block	10 km block	Height recr. index % (+ 95% c.l.)	Canopy recr. index % (+ 95% c.l.)
B10	-*	0	.5 ± .4 %
A7	-*	0	.1 ± .1 %
C8	XI[a]	.2 ± .2 %	1.1 ± .6 %
C5	IV	2.5 ± 1.3 %	8.1 ± 3.0 %
E7	V	10.0 ± 3.7 %	14.9 ± 2.6 %
E9	VIII	14.6 ± 4.0 %	17.6 ± 5.1 %
I9	X	32.3 ± 11.8 %	25.8 ± 2.5 %
H6	VIII	28.1 ± 2.6 %	37.8 ± 8.2 %

*: block lies within reserve: cattle density taken as zero.

[a]: block lies within reserve: designated as X1 (see Fig. 5:3)

Table 8:3. Spearman rank correlation coefficients (r_S) indicating the significance of the relationship between seedling survival (D1/D0 x 100) of the species shown, and livestock densities as calculated from all SRF data and the 1974-1983 10km Model 1 'mid-values' (Tables 5:2 and 5:1 respectively).

Species or genus	Mean SRF cattle densities	10km Model 1 mid-values.
Commiphora spp	.910**	.936**
Acacia senegal	.888*	.808*
Acacia gerrardii	.957**	.908**
Grewia spp	.537	.512

*: $p < .05$

**: $p < .01$

Table 8:4 . The proportion ($e^{-\hat{\theta}}$ x 100) of trees surviving from one canopy class to the next, calculated according to the method described in the text.

5km sampling block	10km block	n^a	mean canopy diameter (m)	$\hat{\theta} \pm$ S.E.	% survival $e^{-\hat{\theta}}$ x 100 $\pm$ S.E.
B10	-*	252	.548	3.65 ± .162	2.6 ± .4 %
A7	-*	154	.513	3.90 ± .222	2.0 ± .4 %
C8	XI	543	.570	3.51 ± .106	3.0 ± .3 %
C5	IV	166	.904	2.21 ± .121	10.9 ± 1.3 %
E7	V	367	1.129	1.77 ± .065	17.0 ± 1.1 %
E9	VIII	1041	1.125	1.78 ± .039	16.9 ± .7 %
I9	X	445	1.737	1.15 ± .039	31.6 ± 1.2 %
H6	VII	260	1.554	1.29 ± .056	27.6 ± 1.6 %

[*] : block lies within game reserve: cattle density zero.

: block lies within game reserve: designated as XI (see Chapter 9)

[a] : n refers to the number of trees encountered by the line-intercept method.

Table 8:5. Seedling densities (seedlings.ha^{-1}) of the major species of the Acacia-Commiphora community inside and outside the Maasai Mara National Reserve. Seedlings are defined as trees in the 0-1m canopy diameter size class. All densities ± S.E. Mann-Whitney U-tests have been performed to test the null hypothesis that there is no significant difference in the mean densities of the component species of the community inside and outside the game reserve.

Species	Density inside reserve (n=27).	Density outside reserve (n=31)	p
Acacia gerrardii	65 ± 14	120 ± 25	NS
A. senegal	29 ± 9	46 ± 13	NS
A. brevispica	20 ± 8	44 ± 11	NS
A. seyal	1 ± 1	2 ± 2	NS
Dichrostachys cinerea	120 ± 27	136 ± 52	NS
Commiphora spp	36 ± 8	175 ± 28	$p < .001$
Grewia spp	97 ± 25	127 ± 22	NS
Ormocarpum trichocarpum	64 ± 23	64 ± 21	NS
Cordia ovalis	4 ± 2	4 ± 2	NS
Rhus natalensis	17 ± 6	26 ± 7	NS
Croton dichogamus	2 ± 1	50 ± 16	$p < .05$
Euclea divinorum	1 ± 1	3 ± 2	NS
Lannea stuhlmannii	5 ± 2	7 ± 2	NS
Albizia amara	9 ± 4	12 ± 4	NS
Others	78 ± 16	39 ± 9	$p < .05$
Total density all species	547 ± 64	856 ± 81	$p < .01$

CHAPTER 9: LANDSAT DATA ANALYSIS OF VEGETATION STATUS

9:1 Introduction

In this study the digital processing of LANDSAT satellite imagery has been carried out to test hypothesis 2 of Section 1:1 - that grass biomass or cover is significantly higher in areas of lower cattle density. The image analysis relies on the use of image processing techniques that have been derived and proven in similar studies elsewhere. However, before these studies can be discussed it is necessary to briefly describe how the LANDSAT system works.

9:2 The LANDSAT Remote Sensing System

Five satellites in the LANDSAT series have been launched, three in the 1970s with a repeat interval of 18 days, and two in 1982 and 1984 respectively with a repeat of 16 days. The first of the series (originally termed ERTS-1) was launched in 1972, but because of the necessity to conserve the life of the onboard image recorder, LANDSAT coverage of Kenya has been limited (Gwynne 1977). Only 5 images of the Mara (path 182, row 61), with low cloud cover, have been immediately available as computer compatible tapes from the EROS Data Centre in America. Three of these images, gathered by LANDSAT 2, are conveniently spread over the wet and dry seasons of 1975 and were purchased for this study.These images are dated June 24th (scene no. 8215307120500), August 17th (scene no. 8220707110500) and December 21st (scene no. 8233307094500).

The following discussion of the sensing systems refers to the first three LANDSAT satellites with almost identical design. Major improvements have been made to LANDSATs 4 and 5 that will be described in Section 9:7.

LANDSATs 1, 2 and 3, all now 'shut-down', each followed a near-polar sun-synchronous orbit at an altitude of approximately 920 km. A complete orbit took 103 minutes and the entire earth's surface was, as described above, potentially imaged every 18 days. Each scene of 185 km x 185 km was taken at about 9.30 a.m. local time, with an imaging time of 28.6 seconds. The satellites were equipped with two image acquisition systems; the Return Beam Vidicon (RBV) and the Multispectral Scanner (MSS). The RBV system has not been reliable and only MSS data has been used in this study.

In the MSS system an oscillating mirror relayed reflected light from six 185 km west-east parallel tracks over the terrain into six detectors for each of 4 spectral bands. Band 4 records the reflectance over the 500-600 nm wavelength (green), Band 5 over 600-700 nm (red), Band 6 over 700-800 nm (near infrared) and Band 7 over 800-1100 nm (near infrared). Each 185 km track, orientated at right angles to the direction of motion of the satellite, was subsampled into about 3200 picture elements ('pixels') with an across-track spacing of about 58 m. The orbital motion of the satellite was used to build up the image in the direction of travel by the constant addition of further six parallel line sweeps. 390 such sweeps, giving 2340 scan lines, make up the second dimension of the image. The average in-track spacing of the lines was 79 m, to give a pixel size of about 58 x 79 m, or 4.6 ha.

If the satellite is within range of a receiving station (less than 3000 km) the image is transmitted directly to earth. If not, the image is recorded on tape for later transmission. Following the transmission of the image signal to a receiving station, the radiance value of each pixel for each band is transformed into a data number (DN), ranging from 0-127 (7-bit binary) for Bands 4, 5 and 6, and from 0-63 (6-bit binary) for Band 7. The digital processing of LANDSAT imagery involves a statistical and mathematical manipulation of the DN numbers for each pixel, usually followed by a colour coding of the resulting transformed pixel variable. For further details of the MSS system, Norwood _et al_ (1972), NASA (1977) and Slater (1979) should be consulted.

9:3 _The Measurement of Vegetation from LANDSAT Data_

All techniques that have been derived to assess vegetation amount from remotely sensed spectral data rely on the fact that healthy green vegetation does not absorb radiation equally from all parts of the spectrum (Whittingham 1974). Chlorophylls a and b absorb blue (400-600 nm) and red wavelengths (600-700 nm) more strongly than green wavelengths (500-600 nm); this is why vegetation appears green. Infrared wavelengths (700-1100 nm) are strongly reflected (Fig. 9:1). As the amount of green biomass decreases red wavelengths are more strongly reflected as shown in Fig. 9:1 (Tucker and Maxwell 1976; Tucker 1977; Siegal and Goetz 1977; Pearson _et al_ 1976; Tucker 1979).

Although the increase in red wavelength reflectance appears to be an almost universal characteristic of decreasing green biomass or cover, the infrared response is more varied. Some authors (e.g. Siegal and Goetz 1977; Tucker 1979) have shown that the infrared response decreases with decreasing vegetation cover. On the other hand Deering (1978) and Satterwhite (1981) report that in certain circumstances the infrared reflectance remains unchanged with decreasing plant biomass or cover. As I shall show later this appears to be the case for the Mara grasslands.

The first spectral index that takes advantage of this differential change in red (R) and infrared (IR) reflectance was the IR/R ratio, initially reported by Jordan (1969) and later investigated in depth, and tested successfully by a number of authors (Pearson and Miller 1972; Colwell 1974; Carneggie _et al_ 1974; Rouse _et al_ 1973; Maxwell 1976; Tucker 1979; Deering 1978; Curran 1980; Curran and Milton 1983). This ratio has also been applied to the monitoring of large scale green biomass changes in the Serengeti (McNaughton 1979) and in the Amboseli National Park by Western (unpublished data) by aircraft-mounted spectroradiometers. The relationship between the ratio and green biomass appears to be linear or slightly curved up to a green biomass of roughly 1500 kg.ha^{-1}: beyond this point the curve in Fig.9:2 begins to flatten when the further addition of green biomass contributes progressively less to a change in the ratio value (Pearson _et al_; Tucker 1979).

Many of the authors above also report similar successes with the simple subtraction IR - R. In an effort to reduce the variation in the data resulting from location differences, Rouse _et al_ (1973) developed the 'vegetation index', later referred to as the 'simple multiratio index' (Ashley and Rea 1975) or the 'normalized difference index' (Deering 1978). This can be expressed as:

$$\text{Green biomass} \propto \frac{IR - R}{IR + R}$$

which can be transformed to the 'complex multiratio' (Rouse et al 1973):

$$\text{Green biomass} \propto \sqrt{\frac{IR - R}{IR + R} + 0.5}$$

In his comprehensive review of all these 'ratios' Deering (1978) established that there was very little difference between any of them, although marginally better results could be obtained with LANDSAT Band 6 (700-800 nm) than with Band 7 (800-1000 nm) for the infrared ratio parameter.

There are subtle but important differences in the vegetation variables that have been well correlated with band ratio indices. For example Carneggie et al (1974), and Deering et al (1975) report that the LANDSAT Band 7/Band 5 (IR/R) ratio peaked at a period of maximum forage production. Other authors (e.g. Pearson and Miller 1972; Tucker 1979) suggest that the ratio value peaks at maximum green biomass. Green cover and 'leaf-area-index' (LAI) - the vertically projected area of all leaf surfaces - have also been shown to relate well to the ratio (Deering 1978; Colwell 1974; Idso et al 1977). However, a critical study of the literature, and especially of Deering's (1978) evaluation, reveals two important reflectance responses on which the vegetation indices appear to hinge. The first is that red reflectance (Band 5) is more directly related (inversely) to green cover than green biomass. It can be suggested that in the red response to green biomass shown in Fig. 9:2, the curve flattens when biomass exceeds some asymptote where the further addition of biomass no longer contributes to an increase in cover. The second observation is that infrared reflectance (Band 7) does not respond to cover changes so much as biomass changes. As discussed earlier, the increase of IR due to increasing biomass or moisture content may be slight (Deering 1978; Satterwhite 1981) or more pronounced (Tucker 1979).

The observations described above are implicit in the recent modelling of vegetation reflectance responses in arid lands by Graetz et al (1982), Allan and Richards (1983) and Griffiths and Collins (1983). These models, essentially modified from those put forward by Richardson and Wiegand (1977) and Kauth and Thomas (1976), assume that the position of a pixel in a Band 7 against Band 5 plot (usually termed Band 7 vs Band 5 'feature space') is indicative of the cover and greenness (the amount of green) of the pixel. The limits to the plot are usually triangular (Fig. 9:3), with vegetation non-green cover, (usually shrubby), greenness and bare ground at the apices. As vegetation dies but with a constant cover, the reflectance of a pixel at A will drop to position T. As this cover is removed to bare soil the position will move progressively further along the 'soil line' from S to B (Graetz and Gentle 1982). However if green cover is removed directly from a pixel at A, the pixel will move from A to C. During the dry season points will tend to lie within an 'envelope' between S and B that contains most of the variance of the data cluster along its axis. During the wet season, the triangle forms as pixels increase in cover and biomass, moving in a perpendicular direction to SB as red reflectance decreases and infrared increases (Griffiths and Collins 1983).

Principal components analysis (PCA) has been used increasingly as a tool with which to process LANDSAT imagery. Details of this analysis are given by Donker and Mulder (1977), Jenson and Waltz (1979), Hielkema (1981), Pratt W.K. (1978) and in more general terms by Davis J.C. (1973). In brief PCA takes into account the high degree of correlation between bands (termed 'redundancy') to realign the axes of the 3- or 4-dimensional feature space (representing the 3 or 4 bands used in the processing) such that the first principal component lies along the data scatter of greatest variance. The second principal component, orientated at right angles (orthogonally) to the first, 'explains' the second greatest component of variance and so on. The direction of rotation of the axes with respect to each band is specified by 'eigenvectors' - (the principal components) - derived from the variance-covariance matrices of each band against each other. The 'new' variance of the new data scatter is described by 'eigenvalues'. The process is explained in Fig. 9:4. As is shown in Appendix J Band 5 is very highly correlated with Band 4 for each of three Mara images used in this study (r = .984, .964 and .931 for June, August and December 1975 respectively). Therefore in Fig. 9:3 the first principal component lies approximately along the soil-line - the line of decreasing vegetation cover (Allan and Richards 1983). In image processing terms the distance of a pixel along the line SB can specify the colour allocated to that pixel. The distance can be divided into regular categories by 'density slicing' such that each 'slice' can be given a separate colour. For example, the nearer to point S the slice lies, the greener the colour that can be allocated to the slice, signifying the greater the cover.

Although the techniques described above are designed to record vegetation amount, other methods are available for vegetation classification. Those most commonly used are 'supervised' and 'unsupervised' classification. In supervised classification, the operator selects areas of a known vegetation type called 'training areas' from the image. In the feature space the pixels within that type fall into clusters with a mean and standard deviation associated with the dimensions of the cluster. Pixels from another vegetation type may be clustered in a different position in feature space (Fig. 9:5). The usual process by which these two types are distinguished by the processor, termed 'maximum likelihood' classification, involves the use of a 'decision boundary' as specified by the line D in Fig. 9:5. Pixels are allocated to one or other vegetation type according to their probability of lying within either distribution. In a 1- or 2-dimensional feature space, the decision boundary is a line whilst in a space with 3 or more dimensions the decision boundary becomes a surface, often curved. Other decision rules are available but maximum likelihood has proved the most versatile and was attempted in this study.

In unsupervised classification, an option that was not available on the GEMS image processor used in this study, the processor is instructed to select out areas of similar reflectance automatically, according to a number of themes specified by the operator. Training areas are not employed. The operator goes to the area on the ground after the classification to identify the themes. This method has been applied with some success to the classification of vegetation in the Loita plains and lower Mau areas by Odenyo (1978), but the adherence of the classification to commonly used rangeland classification procedures, such as that of Pratt et al (1966) may not be accurate. For example, a number of themes may fall within 'wooded grassland' or the theme for 'wooded grassland' may extend well into a known grassland area because the reflectances ('spectral signatures') are so similar.

Supervised classification has been of little value in this study for identifying woodland communities (see Section 9:5). Bentley et al (1976), McCoy and Witt (1978) and Hielkema (1977) have all shown that a vegetation cover below 20% cannot be discerned using any classification technique, although in very special cases successes have been achieved in arid areas for recording a cover as low as 10% using PCA (Allan and Richards 1983). The *Acacia-Commiphora* community cannot therefore be spectrally separated from the underlying grassland, especially because its cover was at a very low point by 1974 (see Chapter 7). This, on the other hand, has proved to be an advantage; one can now be sure that band ratios and PCA transforms applied to the 1975 imagery will refer only to the status of the grassland underlying the *Acacia-Commiphora* community. In the Mara therefore LANDSAT imagery has proved to be a useful tool for recording the distribution of grass cover and biomass without significant reflectance 'interference' from bushland.

In the absence of any 'ground truth' concerning grassland status for 1975, the quantification of green cover and biomass should only be considered relative within each image. Nevertheless, it will be shown in the next section that the results have been particularly successful when considered in conjunction with cattle density estimates obtained from the grazing models for 1974.

Finally, a very useful image enhancement technique, the contrast stretch, has been employed. If an area of an image is selected and histograms for pixel intensity for each band are displayed, the resulting distribution, usually normal in form, occupies only a very small proportion of the potential number (256) of 'grey scales' of the processor. A contrast stretch 'pulls' the histogram outwards in two directions such that the darkest pixels now lie at the 0 end of the grey scale and the brightest at the 255 end. Different stretches are available and were attempted on the GEMS processor but none proved any more effective than the 'autolinear' stretch, an automatic 'ramp' stretch (Fig. 9:6), that enhanced the image sufficiently for training areas to be well defined and easily located. In almost all stretches, the colour red was assigned to Band 7, green to Band 5 and blue to Band 4, a standardized colour allocation used in the generation of false colour composites. Band 6 was not loaded into the image processor because of the high correlation of this band with Band 7 (Donker and Mulder 1977; Deering 1978; Griffiths and Collins 1983) and because the computer store space was required for other purposes.

For further details on image processing techniques Pratt W.K. (1978) and Lillesand and Kiefer (1979) should be consulted.

9:4 Image Processing Methodologies and Results

9:4:i Reflectance Characteristics of Grazed and Ungrazed Rangelands

It will be recalled from Chapter 1 that LANDSAT path 182, row 61 did not include a small portion of the eastern edge of the study area. This was not felt to be important because only grazing strategies in Koyake Group Ranch have been considered in this study. The Lemek valley, another area of high grazing pressure, is also included in all three 1975 images dated 24th June, 17th August and 21st December. However, because of the limits imposed by the dimensions of the processor screen, an image corresponding to only 512 x 512 pixels (1200 km^2) could be examined at any one time. To study the entire study area of 2750 km^2 it was necessary to subsample the image such that every second pixel in each 'row' and 'column' was removed. The slight loss of detail was more than compensated for by the ease of feature identification with reference to the whole study area.

In order to examine the relationship between livestock grazing intensity and reflectance for each band, each of the ten 10 km blocks that lie within Koyake Group Ranch (Fig. 5:3), were demarcated on the contrast stretched image of the study area. An additional 10 km block (designated block XI in Fig. 5:3), that lies inside the game reserve in the Ongata Olduroroi area, was also incorporated into this analysis. The 'trackball' and 'training area box' of the image processor were used to define the limits of the block. The statistics of the pixel set were then displayed in terms of unstretched and stretched intensity-frequency histograms for each band, with the mean, standard deviation and median of the data. The number of pixels in each 10 km block was approximately 5000. With such a large sample size, the mean DN is taken to be representative of the block and standard errors are so low (0.3-0.6% of the mean) that in all graphs of reflectance intensity presented in this chapter, the bars representing standard errors are effectively hidden behind the point asterisk symbol used.

An analysis of the relationship of reflectances between bands for each of the eleven 10 km blocks indicates that Band 5, the red reflectance, is highly correlated with Band 4, the green reflectance, for the subscenes of June (r = .984), August (r = .964) and December (r = .931) (see Appendix J). This correlation has been widely reported for other areas that include Holland (Donker and Mulder 1977), Texas (Deering 1978) and northern Kenya (Griffiths and Collins 1983). In view of the differential absorption of red and green wavelengths (Fig. 9:1), this somewhat surprising observation can be explained by the fact that green reflectance for the three subscenes (see Table 9:1) is significantly lower ($p < 0.001$) than red reflectance. There is no significant correlation, however, between infrared reflectance and red reflectance (r = .343; r = -.445; r = -.497; n = 11) and infrared and green (r = .424; r = -.259; r = -.288), for the 3 images.

Reflectance data for each band, for each 10 km block and for each image are shown in Table 9:1. The mean DN (data number) values for each block in Band 7 vs Band 5 feature space, for the three images, are shown in Figs. 9:7a)-c). The interesting feature of these plots is that infrared reflectance varies little with respect to red reflectance for all three images. Fig. 9:7d) shows the limits to the Band 7 vs Band 5 scatterplots for the entire subscene of December, confirming that most of the variance of the plot is explained by Band 5, the variable best correlated with green cover (Deering 1978). Thus, with increasing cattle density, pixels 'move' in the directions of the arrows in Figs. 9:7a)-c), signifying an increase in the red reflectance and a decrease in vegetative cover. Red reflectance can be considered directly proportional to the cover of bare ground showing through the vegetation.

If this red reflectance is plotted by itself against 1974 Model 1 index data that assumes a 10 km livestock maximum range, a significant relationship emerges (Figs. 9:8a), c) and e)) that becomes more linear if the model is adjusted to assume a 15 km livestock range (Figs. 9:8b), d) and f)). Again, the greater the livestock density (because the number of settlements within range can be multiplied by a constant factor to give density) the lower the green vegetation cover. However, it cannot be assumed that an area with twice the cattle density has half the green cover or biomass. The function relating remaining green cover or biomass to livestock density is likely to be more complex, involving such factors as grazing selectivity, the accessibility of green material and differential rates of productivity. The June and December data in Fig. 9:8 can also be straightened by a logarithmic transformation on the 10 km Model 1 data (see Appendix K). This transform is more likely to describe real-life grazing events because it can be postulated that green cover/biomass is utilized in proportion to its availability. However, the relationship between green cover and cattle density needs further investigation before this assumption can be justified.

The Band 7/Band 5 ratio is also correlated to Model 1 1974 data since, with the relatively constant Band 7 numerator, the ratio simply portrays the inverse of the 'cover of bare ground' - an increase in green cover or biomass with decreasing livestock density. This relationship is shown in Figs. 9:9a)-f) for the 10 km and 15 km Model 1 data sets, and for a logarithmic tranformation on the June and December data, in Appendix L. Other ratios that have been tested are the Band 7 - Band 5 'ratio', the normalized difference ratio of Deering (1978) and the complex multiratio of Rouse et al (1973), which have been described in the previous section. The product moment correlation coefficients (r) between these bands and ratios and the untransformed 10 and 15 km Model 1 index values are shown in Table 9:2. Also shown in Table 9:2 are the correlations with KREMU SRF cattle density data. The regression equations for some of the more important relationships in Table 9:2 are shown in Appendix M. The Band 7 - Band 5 algorithm gives the best correlations with model data and the results of this analysis are plotted in Figs. 9:10a)-f).

9:4:ii Image Processing Results

Having established that a strong relationship exists between the ratios and the theoretical livestock density, image processing can proceed. However, all of the images obtained from the EROS Data Centre were skewed by approximately 10° as a result of earth rotation effects. One of these images, that of December, was therefore 'geometrically corrected' prior to processing using the correction facility on the I^2S image processing system at the Natural Environment Research Council in Swindon, Wiltshire. The following procedure was employed. 23 pixels were identified on the image, the exact UTM coordinates of which could be identified from the 1:50,000 maps. Each of these pixels was coded with a sample ('column') and line ('row') number within the image. The uncorrected image was then warped to fit a new 'dummy' image in an image store into which the geometrically corrected sample and line numbers for each of the 23 pixels were entered. This has resulted in a very accurate 'map' representation of the image in which the average displacement of a pixel from its true coordinates is 1.34 pixels or about 100 m. All subsequent image processing was carried out on a GEMS processor at the National College of Agricultural Engineering in Bedfordshire.

Another corrective algorithm, that of 'destriping', was applied to all subscenes before processing to remove the striping effect caused by the inexact alignment of the six parallel ground tracks in each sweep, and the non-calibration of the sensors.

Although a number of different band ratios were performed, they all gave very similar results and therefore the simple Band 7/Band 5 processed images are presented. The application of this ratio to each image is shown in Plates 9:1a)-c) and to the geometrically-corrected unsubsampled December extract of Koyake Group Ranch in Plate 9:2. The ratios have been density-sliced into regular categories, from low green biomass (yellow) to high green biomass (dark green). The dimensions of the slice categories remain almost the same within each image, and between all images, a process achieved by careful use of the density slice scale facility on the GEMS processor. Each image has also been smoothed using a 'moving boxcar' 3 x 3 filter, a reclassification procedure that re-colour codes each pixel ratio value according to the average value of its 8 neighbouring pixels. This effectively removes the 'speckled' effect of an unfiltered image so that overall trends are more clearly revealed. Again it must be stressed that despite the standardized slicing procedure, green biomass classes should not be regarded as truly constant between images because of atmospheric effects on reflectance data.

The procedure described above effectively density slices the 'greenness' into distinct categories; this greenness can be best equated with green biomass. In Plates 9:3a)-c) the same three uncorrected images have been density sliced along the first principal component of a 3-band PCA analysis. The statistics for these transforms are presented in Table 9:3, showing the eigenvector 'loading' on to each band in each component. In simple terms, the first principal component (PC1) is the line that runs through the origin of the 3-dimensional feature space and through a point corresponding to the first eigenvector values in the infrared, red and green. This principal component explains the greatest proportion of the variance of the plot. The loading of the first principal component on to the red band (Band 5) is very strong, because red reflectance shows the highest variation (see Fig. 9:7d)). The second principal component (PC2) is heavily loaded onto the green (Band 4), a somewhat surprising result that is probably due to the high correlation of Band 4 with Band 5. The third principal component (PC3) is loaded onto the infrared (Band 7), and explains the variation in the data set along the greenness axis TA in Fig. 9:3. In the Mara scenes, PC1 can be considered almost incidental with the soil line, and a density slice along PC1 effectively slices cover categories. The difference in cover between the reserve and the Maasai areas is evident and in the June image a line can be drawn along the boundary of the green class that specifies the reserve northern border.

The density slice of PC1 of the corrected extract of Koyake Group Ranch is shown in Plate 9:4; only two bands were used in this analysis, Bands 7 and 5. An interesting feature that has been well defined by this procedure is the band of high grassland cover along the northern border of the reserve that corresponds almost exactly to the areas of _Acacia gerrardii_ and _Acacia-Commiphora_ bushed grassland mapped in Fig. 6:3. It should be noted that the covers of these woodland types were at a low level in the 1974 photography (see Chapter 7) and it is therefore unlikely that woody vegetation has contributed significantly to the reflectance. It was shown in Chapter 8 (Fig. 8:8) that burning in 1980 was confined almost entirely to this belt, presumably because by this time the tsetse occupation of this area had begun and the area was relatively ungrazed. The LANDSAT analysis shown in Plate 9:4 suggests that the higher green cover of the herbaceous layer was a feature of this bushland zone in December 1975.

In Fig. 9:7d) it was shown that the triangle of data in Band 7 vs Band 5 feature space was pronounced in the December image. As has been shown PC3 can be considered to represent the perpendicular direction of a pixel from the soil line, that is the direction towards the greenness apex of the triangle (line TA in Fig. 9:3). This direction is also 'sliced' by the Band 7/Band 5 ratio analysis. In the next section the direction of PC3 has been calculated from the eigenvectors in Table 9:3 and is presented diagrammatically for each image in Figs. 9:13a)-c). In effect, a density slice of PC2 (the equivalent of PC3 in a 3-band analysis) shown in Plate 9:5 is almost identical to a slice of the Band 7/Band 5 ratio in Plate 9:2, and shows again that grass greenness is highest inside the game reserve.

A further observation from the digital analysis is that a density slice of PC1 (cover) is very similar to a slice of Band 5. It can be concluded that in rangeland areas, such as those of the Mara, principal components analysis provides little further information to that which can be obtained from a simple Band 5 density slice (representing differences in cover) and a Band 7/Band 5 density slice (representing differences in greenness).

Plates 9:1-9:5 and Figs. 9:8-9:10 should all be examined with reference to Fig. 9:11, a contour map of the 15 km maximum range 1974 Model 1 data prepared using GINO-SURF graphics. The numbers on the contours refer to the Model 1 index, that is, the number of settlements within 15 km. The close relationship between June and December green cover and the model data (proportional to cattle numbers) is clear.

At the end of June 1975 the wildebeest migration would have arrived in the Mara (Pennycuick 1975; Stelfox et al 1980), and as I shall show in Chapter 10 they generally occupy the Enkikwe area in particularly heavy densities. As a result the relationship between green cover and livestock densities becomes much less pronounced, as can be seen from the August reflectance vs livestock density data (Figs. 9:8, 9:10, Plate 9:1b) and Plate 9:3b). The wildebeest migrate back to the Serengeti in October and the green cover vs livestock density relationship is reestablished very significantly in the December image.

An unexpected feature of the August reflectance vs livestock density analysis is that green cover/biomass appears to increase slightly in high livestock density areas whilst continuing to decrease in the low density areas (presumably because of green forage removal by wildebeest). The first possible reason is suggested by an examination of the rainfall records plotted in Figs. 9:12a) and b). There was heavy and unseasonal rain in July and August that in some areas - Lemek, Keekorok, Emarti and Governor's Camp - continued through the 'dry' season of 1975. This might have resulted in a sudden 'green flush' such that green cover is raised throughout the area more than should be expected for the time of year. With virtually no rain in November, a uniform rainfall of 50-100 mm in December (indicated by almost all stations) would lead to the particularly well emphasized relationship between reflectance and livestock density in the 21st December image. Daily rainfall records kept at Keekorok indicate that at this station almost all of the December rainfall fell in the first 15 days of the month, giving the soil a week to dry before the scene was imaged.

A second reason for the increased dry season green cover to be discussed shortly might be that atmospheric conditions have differentially influenced the reflectance of the red and infrared.

The east-west rainfall gradient that extends across the study area (see Section 1:3:iii) is so poorly defined that differences in reflectance cannot be connected with lower grassland productivity associated with long-term climatic differences between areas. As Appendix C indicates the mean annual rainfall at Aitong, 978 mm, is close to that of Keekorok, 1031 mm, Governor's Camp, 1170 mm, and Mara Serena, 1369 mm, the last three located inside the game reserve. Similarly the rainfall over 1975 did not differ greatly between rainguages as shown in Figs. 9:12a) and b). The potential grassland production can therefore be considered equal over Koyake Group Ranch, if not the entire study area. In the Serengeti-Mara ecosystem, a rainfall of 1000 mm per annum may result in an annual productivity as high as 7000-8000 $kg.ha^{-1}$ (Braun 1973; Sinclair 1975). In June a typical green and non-green standing crop biomass of ungrazed Themeda triandra, as would exist inside the Mara game reserve would be 3000-5000 $kg.ha^{-1}$ (Cassady 1973; Braun 1973; Onyeanusi 1983; Deshmukh 1984) of which 2000-3000 $kg.ha^{-1}$ would be green (McNaughton 1979). In the grazed areas outside the reserve, such as at Talek, total standing crop biomass does not usually exceed 700 $kg.ha^{-1}$ (Onyeanusi 1983) of which 200-400 $kg.ha^{-1}$ would be green. In Plates 9:1-9:5 the yellow areas would approximate to a green standing crop biomass within the range 0-500 $kg.ha^{-1}$ whilst the light green areas would correspond to a biomass of 1500-2000 $kg.ha^{-1}$. Over the major part of this range red reflectance and the IR/R ratio as recorded by LANDSAT tend to follow an approximately linear function with green biomass (Tucker 1977; Pearson et al 1976; Tucker 1979). The use of four evenly spaced density slice categories (yellow to light green) was therefore intended to divide green biomass into 500 $kg.ha^{-1}$ increments. The fifth slice category (dark green) was employed to 'classify' out, as closely as possible, the forest canopy. The green biomass level represented by this category is unknown but may be as high as 5000 kg.ha^{-1}.

In the year of the fieldwork studies, grass cover varied from about 40% on the Aitong plains (see Section 6:2) to 100% inside the reserve. The density slices referred to above, especially with respect to the first principal component which effectively 'slices' the red reflectance, can be thought of as representing 10-15% increments in green cover. As Deering (1978) has shown, the red reflectance as derived from LANDSAT data does not change further for green biomass levels that exceed an asymptote of about 2500 kg.ha^{-1}. At this level the cover presumably approaches 100%.

The approach followed above illustrates one of the major limitations of using LANDSAT data to estimate green cover and biomass from a period when no 'ground truthing' was available. The image interpretation and processing have to rely on the techniques of other workers who have had the opportunity to gather ground data in synchrony with LANDSAT overpasses. A further complication arises from the fact that atmospheric conditions cannot be regarded as completely constant throughout sequential series of imagery. However, the remarkably similar tables of eigenvectors for all three images used in this study (Table 9:3) suggest that at least for the first principal component, these images can be considered reasonably well standardized for cover assessment. Hielkema (1981) suggests a method whereby LANDSAT data can be normalized by the rotation of the first principal component axis for all sequential imagery onto a 45° slope in Band 7 vs Band 5 feature space, but this technique was considered too elaborate and expensive in terms of computer time for a study of this sort. Similarly, a trigonometric normalising algorithm developed by Griffiths and Collins (1983) shows promise for measuring the perpendicular distance of a pixel away from the 'soil line' into the 'greenness' triangle (Fig. 9:3), but this method remains essentially untested.

A hazy atmosphere may result in the rotation of the triangle in Band 7 vs Band 5 feature space (Hielkema 1981). Another source of reflectance variation between images, that of differing sun elevation, may translate the triangle in feature space (Graetz and Gentle 1982). However, Duggin (1977) has shown that although infrared reflectance of a wheat crop may increase with decreasing solar elevation, red reflectance, which shows the greatest variation with respect to vegetation in the Mara, remains almost unchanged. Furthermore, with a study area located just 1° 15' south of the equator, the sun elevation is virtually identical for the three images; 45° in June, 53° in August and 47° in December.

Differences in underlying soil texture and colour may also contribute to variations in the green vegetation reflectance response (Gates 1965; Condit 1970; Mathews et al 1973; Janza 1975; Siegal and Goetz 1977). However, in the Mara study area, and especially within Koyake Group Ranch, there was very little variation in the texture and colour of the volcanic phonolitic tuffs that predominate over most of the area (Williams 1964). In over 100 scattered soil sample points, soil colour did not depart significantly from the Munsell (1975) colour notation 2.5 Y 4.5/2 ('greyish brown' to 'dark greyish brown'). However the soils of the Loita plains to the east were somewhat lighter (2.5 Y 6/2:

'light brownish grey') and those of the Lemek valley slightly redder (10 YR 5/3: 'brown') than the soils of the central plains. The pale colour of the Loita plains on false colour composites (Plate 1:1) can be attributed to the light soils and the reduced vegetative cover associated with lower rainfall.

9:5 Attempts at Vegetation Classification using LANDSAT Imagery

Before any attempt was made to map the vegetation communities using automated techniques, the Band 7 and Band 5 statistics for the three most spectrally distinct communities were extracted from the imagery and displayed. These vegetation types were the forest communities (Types 1(a) and 1(b)), the *Tarchonanthus camphoratus* community (Type 2(b)) and the grassland communities (Types 4(a) and 4(b)). The results of this extraction procedure are shown in Table 9:4 and are plotted in Figs. 9:13a)-c) for the three images. Also shown in Figs. 9:13a)-c) are the directions of the first and third principal components, calculated from the eigenvectors of the 3 band, 3-dimensional principal component analysis.

The three vegetation types fall into distinct clusters in feature space that could in theory form the basis for an accurate supervised classification. However, the choice of training areas is very critical and in several time consuming and costly classification attempts, involving the redefinition of training areas, no satisfactory results could be obtained that were in any way superior to the classification based on 1974 and 1983 aerial photography. Known areas of grassland were frequently classified as Tarchonanthus because, although the data clusters are spatially distinct, there is some overlap between them. However, an examination of Figs. 9:13a)-c) suggests that with the careful selection of imagery, density slicing at appropriate intervals along the first principal component could yield good results. Although this procedure was used to record relative green cover of grassland communities in the previous section, the mapping of forest and Tarchonanthus communities, especially in the north eastern quarter, has been reasonably accurate in Plates 9:3a)-c). However, time was not available to apply this method simply to the classification of woodland communities.

A particularly important, and rather paradoxical feature revealed by Figs. 9:13a)-c) is that in the vegetation type with the highest green biomass, the forest community, infrared reflectance is relatively low. Nevertheless, by virtue of its very low red reflectance, this community has the highest IR/R ratio. In the principal components analysis it emerges, with reference to PC1, as the community with the highest cover, and with reference to PC3 and the IR/R ratio, as the community with the highest greenness. The impression of high infrared reflectance of forest given by the standard colour rendition of false colour composites (Plate 1:1) - in which the red colour is assigned to Band 7 reflectance - is due to the fact that the red colour becomes dominant when the colours assigned to Band 5 (the colour green) and Band 4 (the colour blue) are of low intensity, (that is, when Band 5 and Band 4 reflectances are low). As has been shown, Bands 4 and 5 decrease with increasing green biomass and thus Gwynne (1977) was able to determine greenness of vegetation in Kajiado district, Kenya, by measuring the red saturation of false colour composite transparencies.

9:6 Discussion

In this chapter digital processing technique, derived and tested elsewhere, have been applied to LANDSAT imagery to provide further evidence that the models that relate livestock grazing to settlement distribution are essentially valid. Green grass biomass and cover levels follow a predictable relationship with livestock density over the wet season of the year (November-May). This relationship disappears after the arrival of the annual wildebeest migration. These changes were, in fact, self evident during the year of fieldwork, when Themeda heights inside the game reserve exceeded 1 m over large areas during the wet season. At the end of the dry season, following the passage of the wildebeest, grass heights inside the reserve were evenly reduced to about 10 cm. In the Maasai areas outside the reserve, grass heights remained at 10 cm or less throughout the year. Onyeanusi (1983) has quantified these grass biomass changes and his results are entirely consistent with those of the LANDSAT image interpretation.

However, whilst the reflectance-livestock density relationship has been seen to hold particularly well for the study area, the processed sub-sampled image of December also included a large part of the northern Serengeti which also appeared to have very little green vegetation. These image extensions have not been included in Plates 9:1-9:5. McNaughton (1979) recorded that, over the year, green forage has a stochastic distribution in the Serengeti-Mara ecosystem, brought about by localized differences in rainfall and forage utilization. This short-term patchiness of cover can be considered quite separate from the effect of long-term heavy grazing by cattle.

In this study the cost of the digital analysis to monitor vegetation over what is a relatively small rangeland area has been its chief disadvantage. With three computer compatible tapes at £500 each, and with the 40 hours of image processing, at a cost of £1000, that were required to obtain the results for this chapter, it can be calculated that the analysis of green cover and biomass over three dates in 1975 has cost £1.0.km^{-2}. Clearly, the digital processing of LANDSAT imagery becomes more cost effective if large areas are to be monitored, and if the needs of different users can be met.

At current aircraft operating expenses in East Africa the cost of using aircraft-mounted spectroradiometers - referred to by ecologists as 'green machines' - to record green biomass over three dates with a strip interval of 5 km, would be approximately £0.8 for each (sampled) square kilometre of rangeland. Although this would not provide the mapping capability provided by the use of LANDSAT imagery, computer-plotted contours could be fitted to the systematically gathered data. The cost of the operation could, however, be dramatically reduced, if not removed altogether, by incorporating the green biomass surveys into currently existing SRF programmes. The duty of data recording would fall to the front seat observer, or, if a larger aircraft were used, an additional observer seated in the rear of the aircraft.

A second disadvantage of the digital analysis of LANDSAT imagery, is that centres that are equipped with image processors and the necessary additional facilities are few and far between.

Satellite remote sensing data can only be considered a viable rangeland monitoring tool if the results can be obtained within a short space of time and the appropriate land-use decisions made quickly. This presupposes that the problems of obtaining sequential imagery, and disseminating information about that imagery, can be overcome. According to NAS (1977); "a few advanced developing countries are already engaged in quantitative analysis of LANDSAT multispectral data and others are moving in this direction. But for most countries a domestic operation using these techniques will be delayed if not prevented by the requirements for highly trained personnel and the cost of the specialized hardware and software".

Ecologists generally believe that the chief value of LANDSAT imagery lies, through visual interpretation, in the construction of reconnaissance scale maps and the manual demarcation of sampling zones in a 'cascade' system - the tiered approach of Gwynne and Croze (1975) - involving aerial photography, aerial livestock surveys and groundwork (Zonneveld 1978; Thalen 1981).

In this chapter the variability of different LANDSAT bands with respect to vegetation status were described, and it was shown that the first principal component, explaining 70-80% of the total variance, was heavily loaded on to Band 5. A simple and economic way to investigate range conditions using LANDSAT imagery would therefore be to carry out a visual interpretation of Band 5 large scale prints, or a densitometer analysis of either 70 mm Band 5 black and white 'chips' or false colour composites using a standardized method such as that described by Gwynne (1977). This procedure may become more viable once the new LANDSATs 4 and 5, and their relay satellites, are fully operational (see Section 9:7).

One of the main priorities in establishing a viable rangeland remote sensing system using satellite data is to regularly monitor vegetation conditions in ground training areas with different soil types. This may not necessarily be expensive because aircraft-mounted spectroradiometers could be calibrated and used in the ground-truthing procedure, and this procedure could be incorporated into existing SRF programmes. Only then will it be possible to avoid inconsistencies in green biomass measurement by satellite which result from different atmospheric conditions, sun elevations and underlying soil types.

9:7 Future Prospects for Rangeland Monitoring by Satellites

In 1982 and 1984 two new LANDSATs were launched with significant improvements over LANDSATs 1, 2 and 3. In addition to the 4 band MSS 80 m resolution system, each is equipped with a 'Thematic Mapper' (TM). The TM is in effect a more advanced multispectral scanner that records reflectance over 7 bands with a 30 m resolution or 'instantaneous field of view' (IFOV). These band dimensions are shown in Table 9:5. Both satellites orbit at 795 km altitude with a repeat interval of 16 days, but neither have an onboard tape recorder. The acquisition of imagery of eastern Africa will therefore be delayed until relay satellites are successfully established in their positions to relay image data to the receiving stations in America or Italy.

Another satellite, the French SPOT, yet to be launched, will scan in three spectral bands with a sampling interval of 20 m and will also be equipped with a panchromatic scanner of IFOV 10 km (Table 9:5). The repeat cycle will be 26 days. With a ground-controlled 'off-nadir' (off-vertical) viewing capability, giving a 950 km swathe, it will be possible to obtain stereo pairs from images obtained on concurrent days.

Further descriptions of the above systems are given by Jackson and Plevin (1983) and Darch (1984).

All of these satellites will increase the potential of satellite imagery as a rangeland monitoring system, but many of the difficulties discussed in the last section remain to be overcome. With an improved resolution and increased number of data points, processing costs may actually escalate and digital analysis might become a completely unaffordable luxury to developing countries. In recognition of these problems, more emphasis has recently been placed on the use of the NOAA 6 and 7 (National Oceanic and Atmospheric Administration) satellites (see Hielkema 1981). These are equipped with AVHRR (Advanced Very High Resolution Radiometer) sensors, a low (1.1 km) resolution multispectral scanner with 4 bands, 2 of which correspond to LANDSAT Bands 7 and 5. Both satellites occupy a near-polar sun-synchronous orbit at 850 km and in tandem provide coverage four times a day that can be transmitted to receiving stations less complex than those designed to receive LANDSAT data. Although these satellites do not provide the detailed imagery of LANDSAT, they have been used successfully by the FAO to monitor conditions in the Sahel and, with a smaller data set, processing costs are lower.

Fig. 9:1. The spectral response of 1) healthy green vegetation, and 2) dry or senescent vegetation (Siegal and Goetz 1977; Curran 1980; Satterwhite 1981).

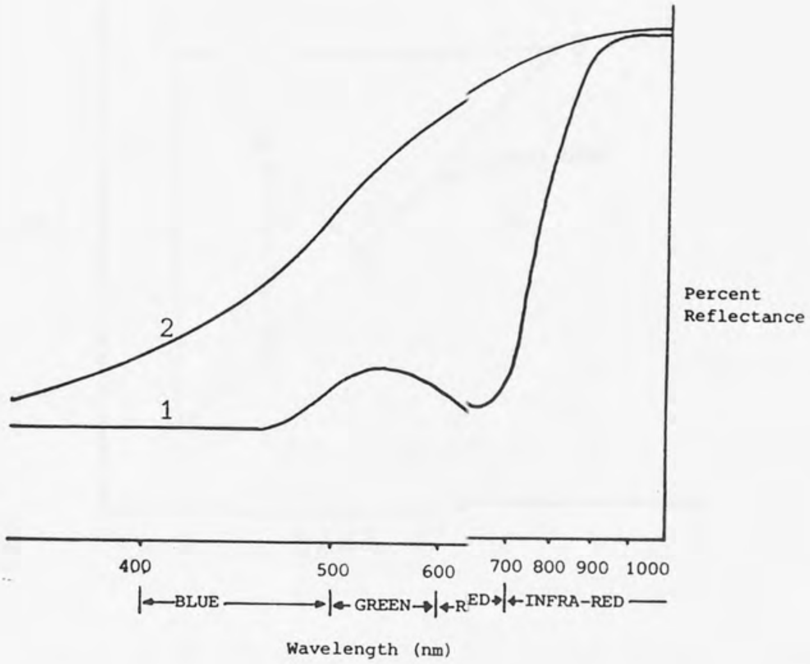


Fig. 9:2. 1) The relationship between red reflectance and green vegetation cover (Deering 1978).

2) The relationship between red reflectance and green biomass (Tucker 1977; Deering 1978).

3) The relationship between the infrared/red ratio and green biomass (Pearson et al 1976; Tucker 1977; McNaughton 1979).

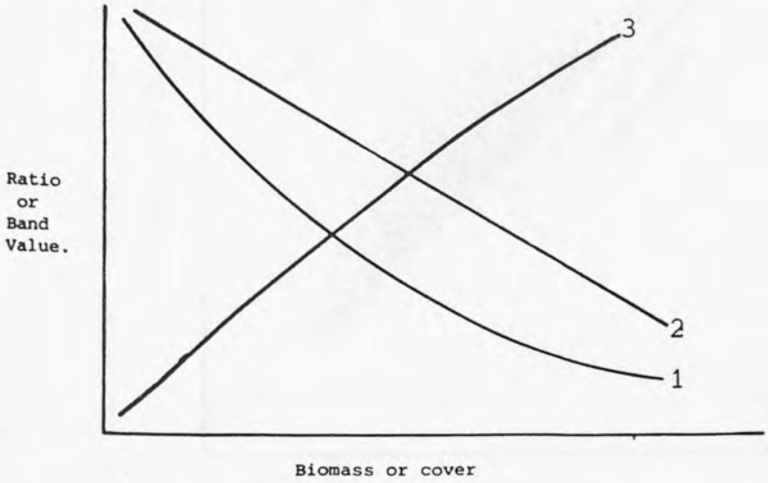


Fig. 9:3. The 'greeness' (G), 'bare ground (B) and 'cover' (S) apices of the triangle of vegetation responses discussed in the text.

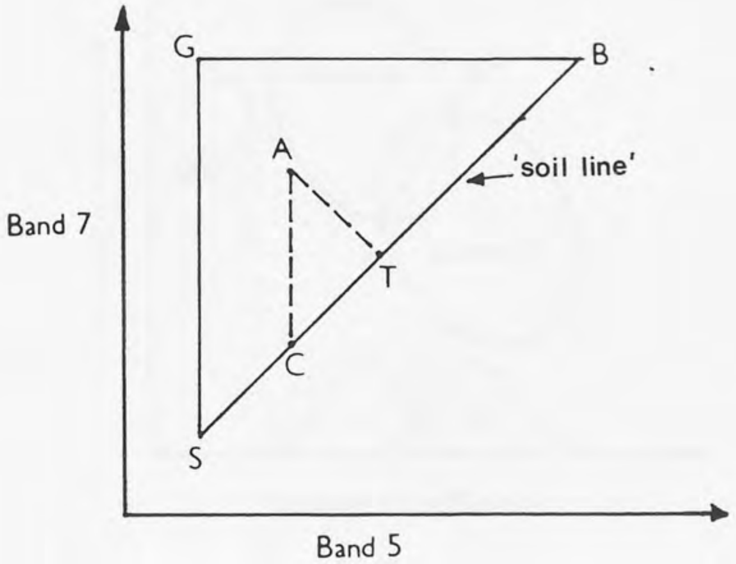


Fig. 9:4. The rotation of axes by principal components analysis (PCA). The eigenvector specifying the first principal component (PC1) describes a rotation of the x and y axes such that the corresponding eigenvalue explains the greatest variance of the data set. The eigenvalue corresponding to the second principal component (PC2) explains the remaining variance of the data. Eigenvector 2 is orthogonal to eigenvector 1. (Jenson and Waltz 1979)

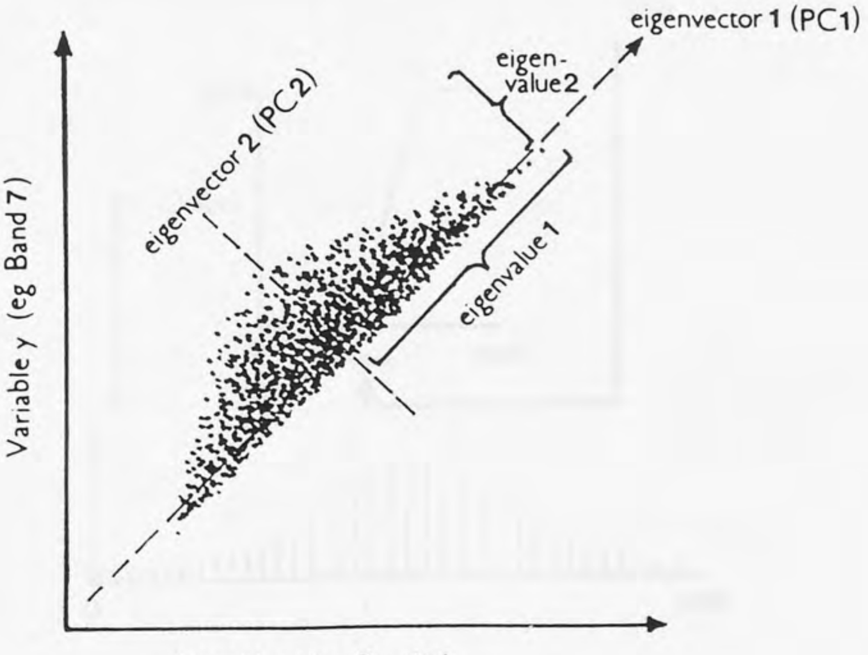


Fig. 9:5. The separation of spectrally distinct classes using 'Maximum Likelihood Classification', the decision rule most commonly used in supervised classification. The line D specifies the 'decision boundary'.

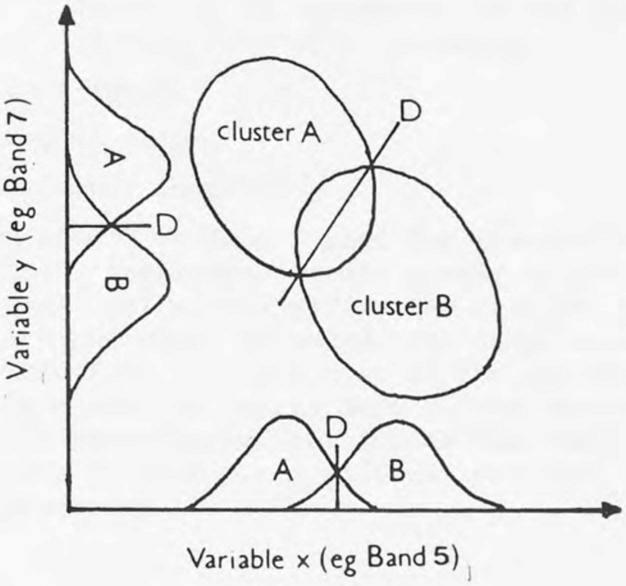
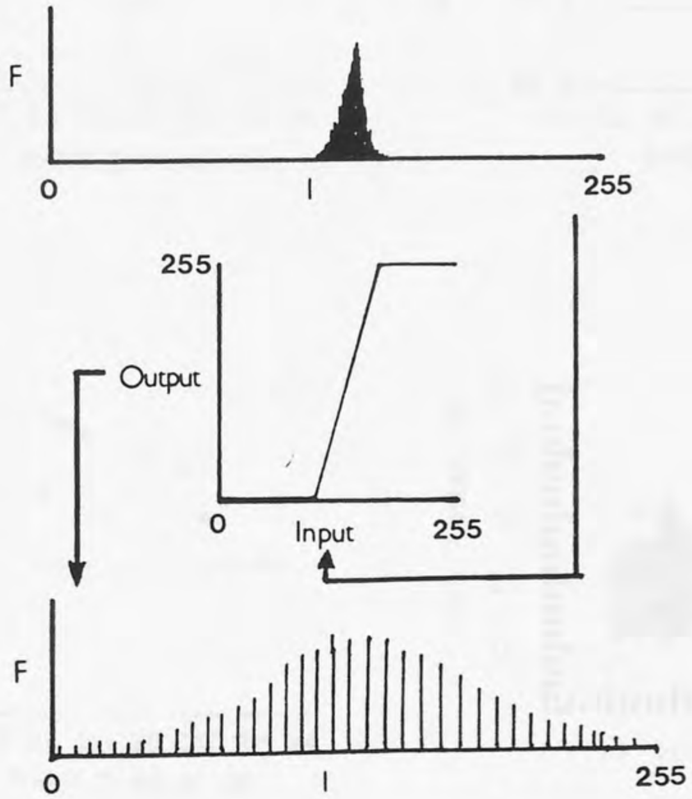


Fig. 9:6. The principal behind the 'autolinear ramp stretch' facility available on the GEMS image processor. The frequency (F) - intensity (I) histogram is stretched to make full use of the 256 available grey-scales. Other stretch options were available but none proved any better than the autolinear stretch.



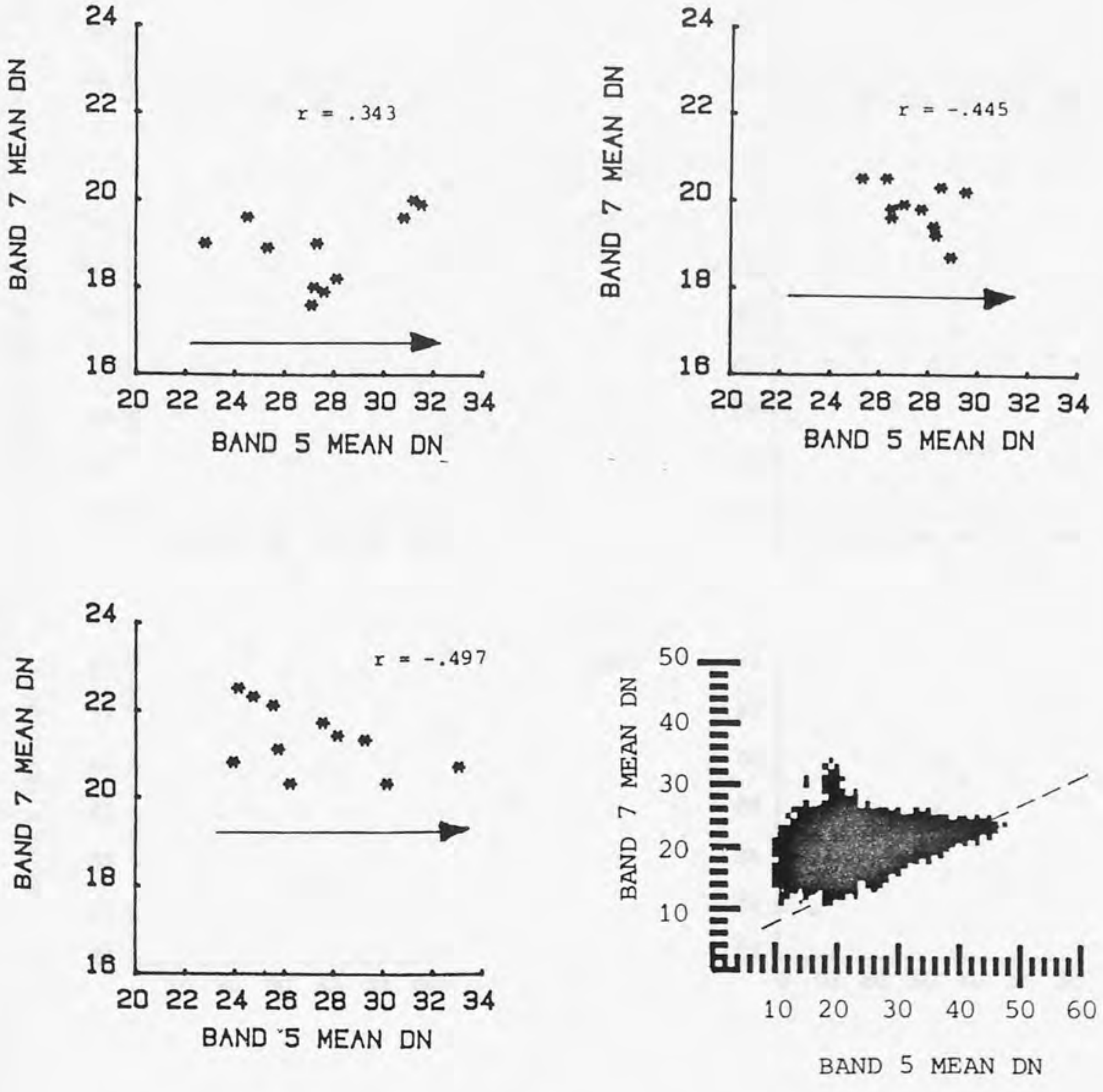
Figs. 9:7a)-d). Band 7 vs Band 5 'feature-space' plots for the three LANDSAT images, in which the Band 7 mean DN value for each 10 km block on Koyake Group Ranch (also including block IX inside the reserve) has been plotted against its corresponding Band 5 value. The arrows show the direction of 'movement' of the pixels as the livestock grazing intensity increases.

Fig. 9:7a). June image.

Fig. 9:7b). August image.

Fig. 9:7c). December image.

Fig. 9:7d). A band 5 vs Band 7 plot for the entire subscene of December 1975, incorporating all pixels in the Mara and trans-Mara area. All pixels giving the mean DN values in Fig. 9:7c) are therefore included. The shape is approximately triangular (see Fig. 9:3) but most of the variance of the data scatter is accounted for by Band 5. The dashed line (— — -) shows the approximate position of the 'soil-line' (see Section 9:3). This feature space plot was produced by the GEMS image processor.

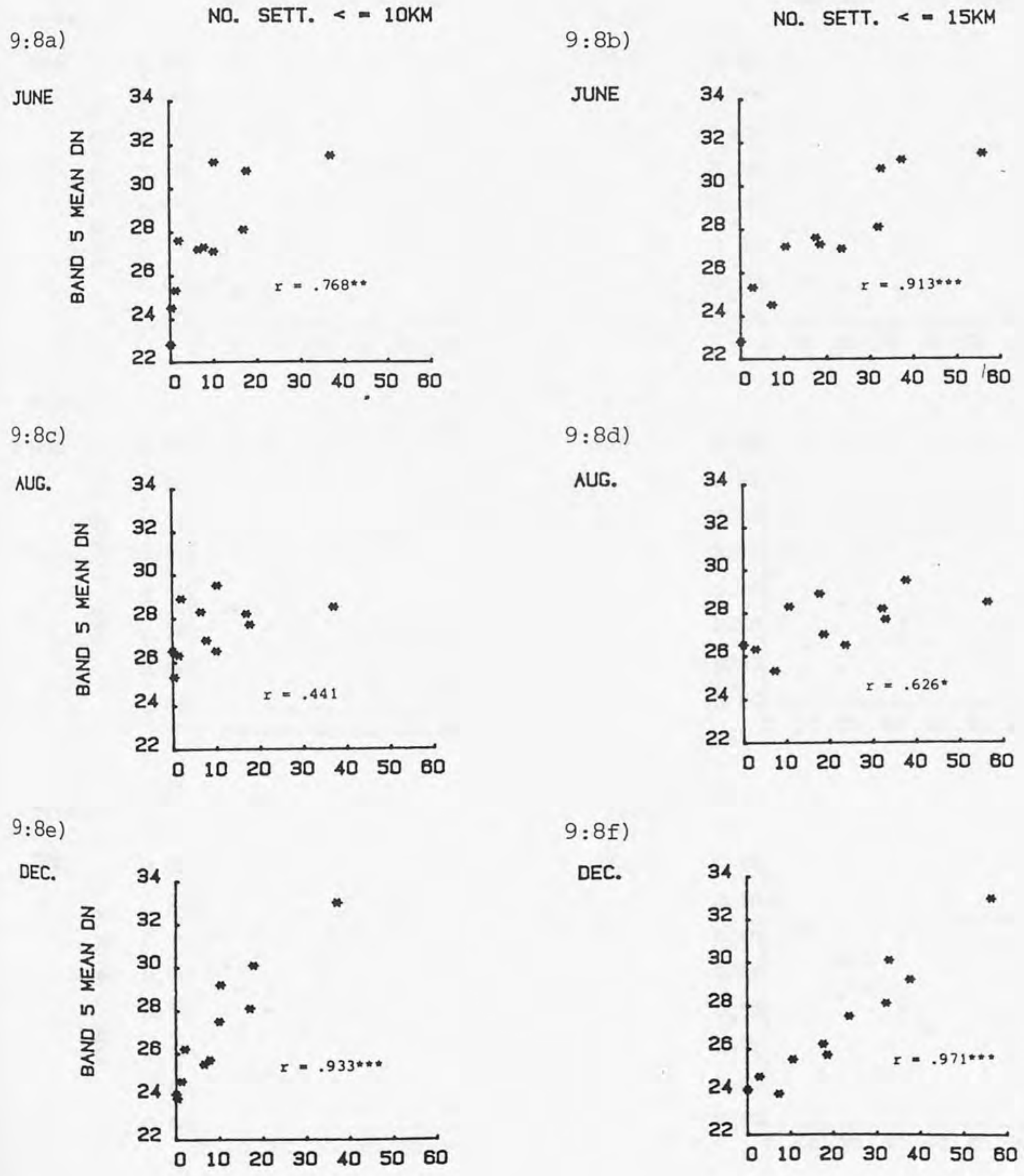


Figs. 9:8a)-f). The relationship between the Band 5 reflectance for each 10 km block in Koyake Group Ranch (also including block IX in the reserve) and the 1974 10 km and 15 km Model 1 index value for the block (i.e. the number of settlements within 10 km or 15 km range respectively. The Band 5 reflectance is expressed as the mean DN (data number) (see text).

Fig. 9:8a). June reflectance data against the 10 km model.
9:8b). June reflectance data against the 15 km model.

9:8c). August reflectance data against the 10 km model.
9:8d). August reflectance data against the 15 km model.

9:8e). December reflectance data against the 10 km model.
9:8f). December reflectance data against the 15 km model.



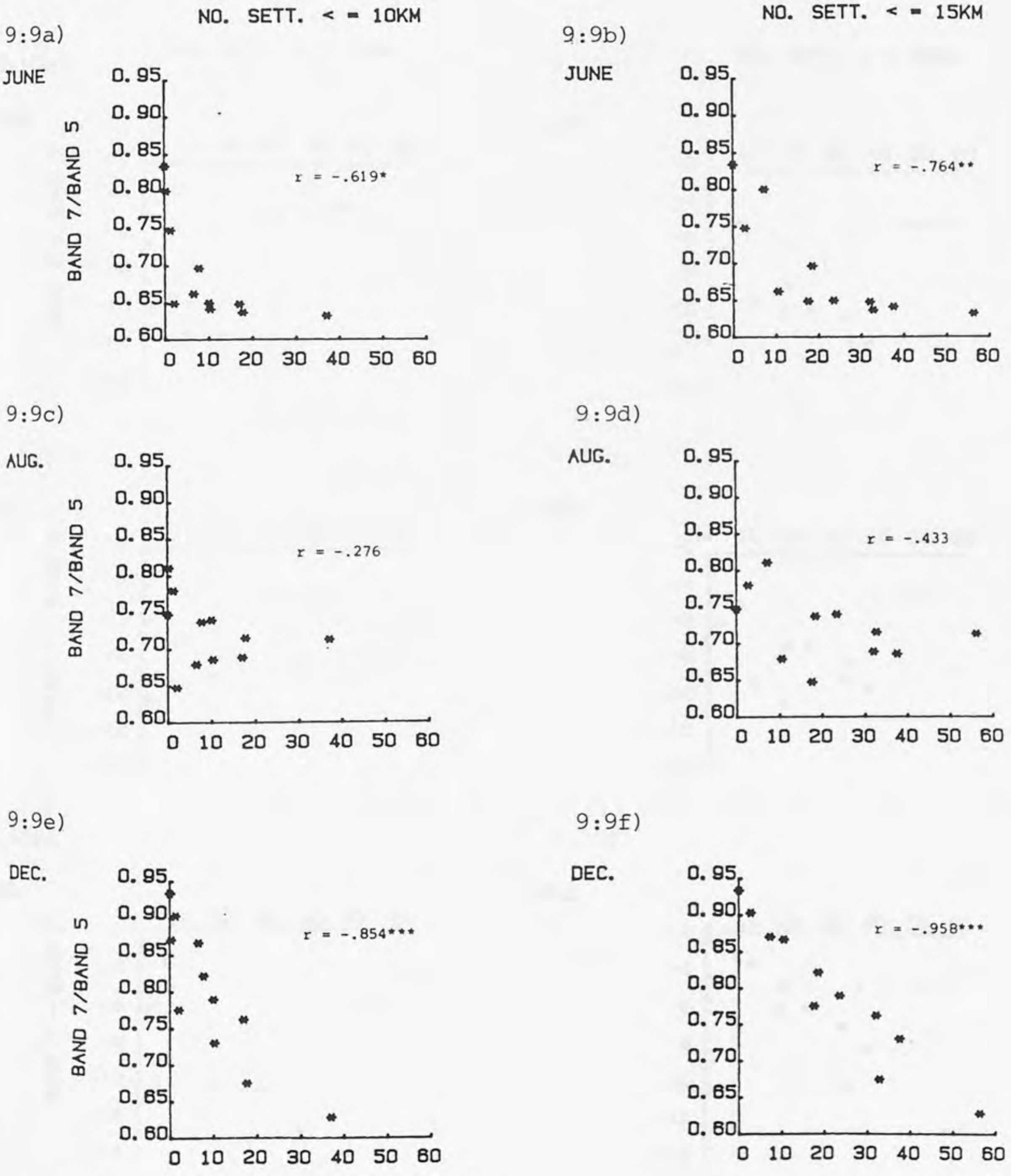
9:8a) 9:8b) 9:8c) 9:8d) 9:8e) 9:8f)

Figs. 9.9a)-f). The relationship between the Band 7/Band 5 ratio for each 10 km block in Koyake Group Ranch (also including block IX in the reserve) and the 1974 10 km and 15 km Model 1 index value for the block.

Fig. 9:9a). June reflectance data against the 10 km model.
9:9b). June reflectance data against the 15 km model.

9:9c). August reflectance data against the 10 km model.
9:9d). August reflectance data against the 15 km model.

9:9e). December reflectance data against the 10 km model.
9:9f). December reflectance data against the 15 km model.



9:9a) 9:9b) 9:9c) 9:9d) 9:9e) 9:9f)

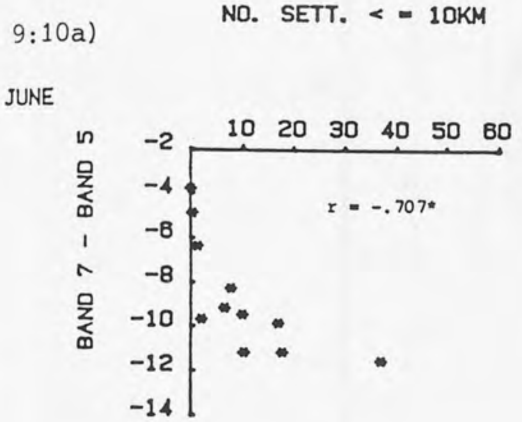
Fig . 9:10a)-f). The relationship between the Band 7 - Band 5 parameter for each 10 km block in Koyake Group Ranch (also including block XI in the reserve) and the 1974 10 km and 15 km Model 1 index value for the block.

Fig. 9:10a). June reflectance data against the 10 km model.
9:10b). June reflectance data against the 15 km model.

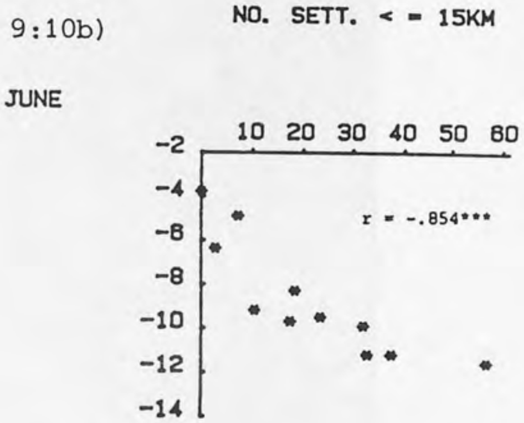
9:10c). August reflectance data against the 10 km model.
9:10d). August reflectance data against the 15 km model.

9:10e). December reflectance data against the 10 km model.
9:10f). December reflectance data against the 15 km model.

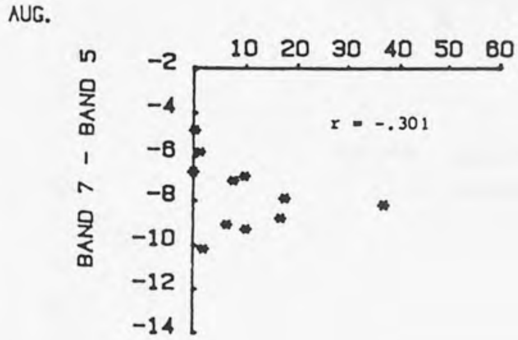
9:10a)



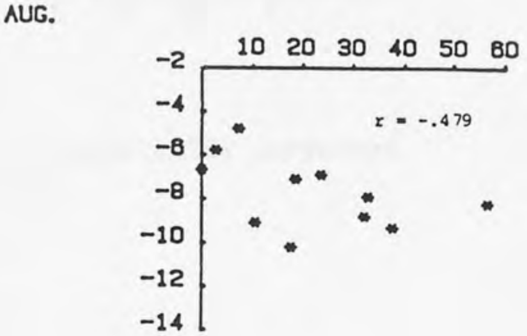
9:10b)



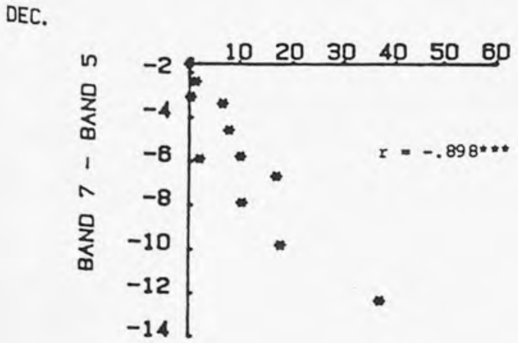
9:10c)



9:10d)



9:10e)



9:10f)

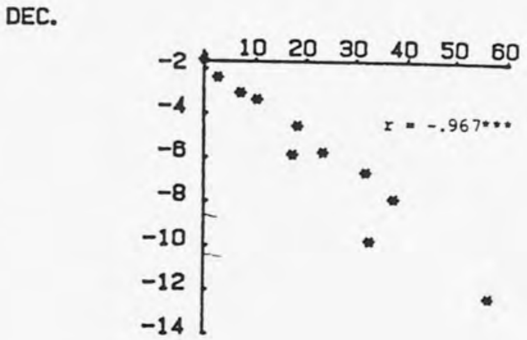
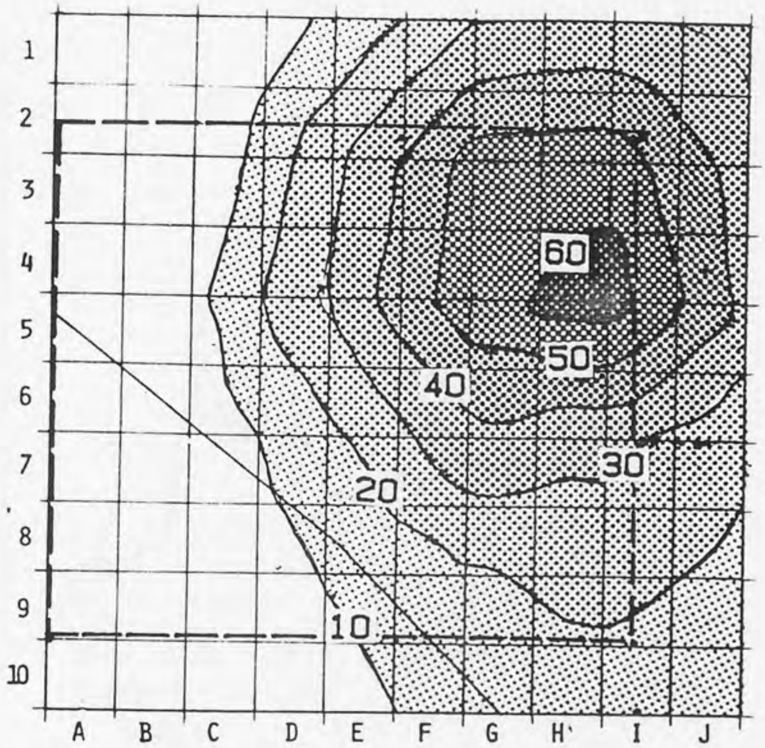


Fig. 9:11. A contour plot showing the number of settlements in 1974 within 15 km range of the isohyets. The contours have been fitted to a 36 point systematic 10 km grid using GINO SURF contouring graphics.



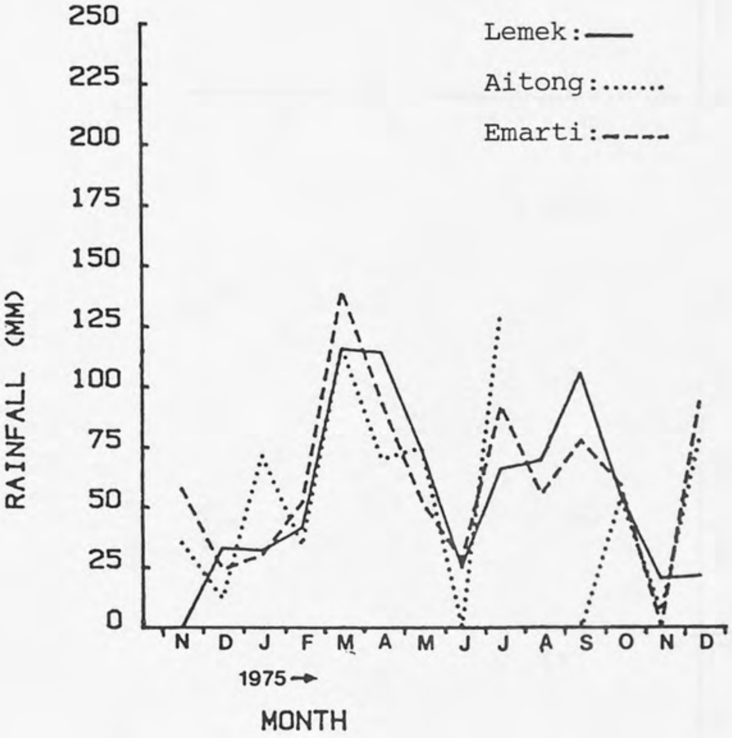
—— —— Limits of the geometrically corrected December subscene.

Figs. 9:12a) and b). The monthly rainfall for 1975 recorded at six rainguage stations in the Mara area.

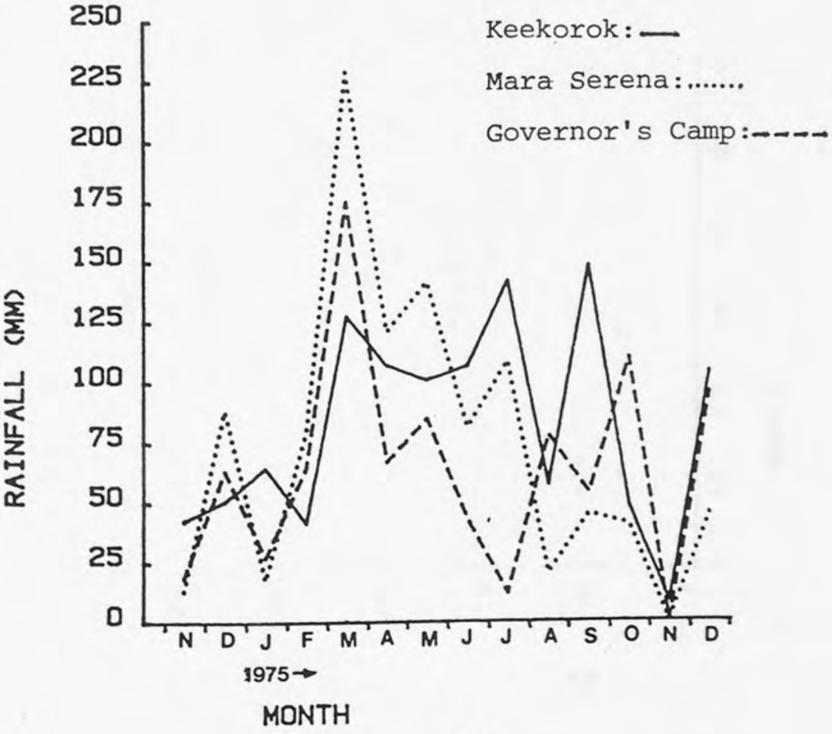
Fig. 9:12a). Lemek, Aitong, Emarti.

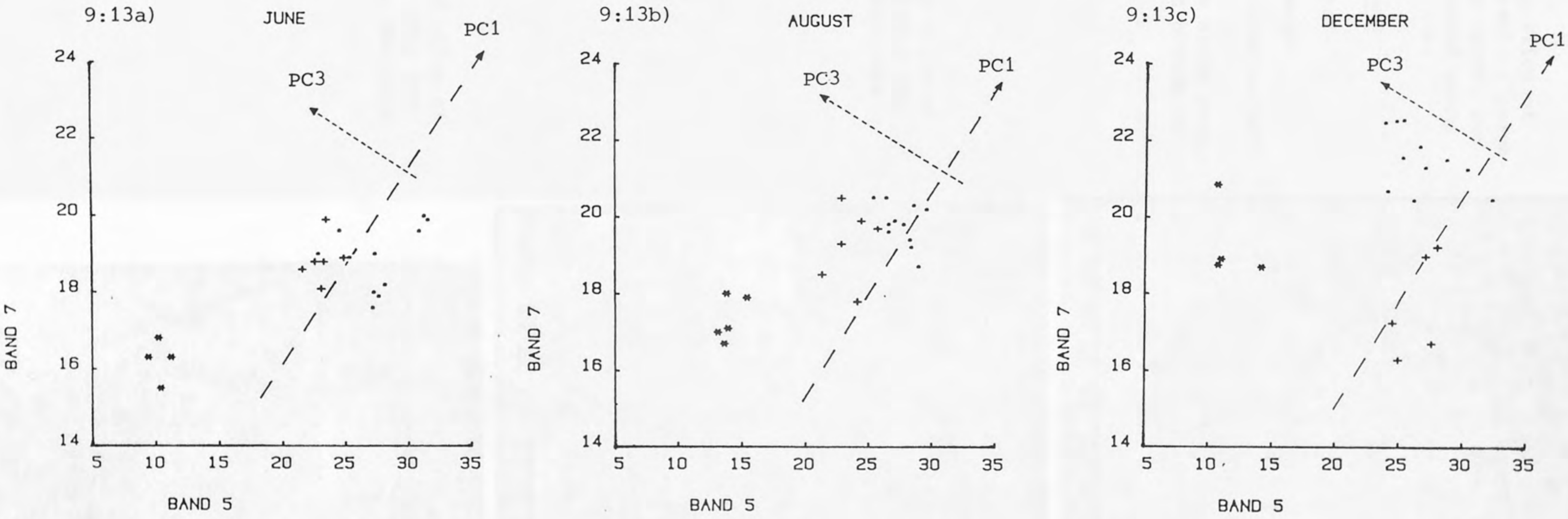
Fig. 9:12b). Keekorok, Mara Serena, Governor's Camp.

9:12a)



9:12b)





Figs. 9:13a)-c). Band 7 vs Band 5 'feature-space' plots for the three images, incorporating 'samples' from grassland (dots: .), Forest Types 1 a) and b) (asterisks: *) and Tarchonanthus bushland (crosses: +). The directions of the first (PC1) and third (PC3) principal components are shown, calculated from the eigenvectors in Table 9:3.

Plate 9:1a). Density slice of the Band 7/Band 5 ratio ('greenness') for the June image. The image has been smoothed using a 3 x 3 'boxcar' filter.

Approx. green biomass

yellow ≏ 0-500 kg.ha^{-1}

500 kg.ha^{-1} increments

light green ≏ 1500-2000 kg.ha^{-1}

Black line delimits study area. Slice dimensions at bottom of image.

Plate 9:1b). Density slice of the Band 7/Band 5 ratio for the August image. Analysis as for Plate 9:1a).

Plate 9:1c). Density slice of the Band 7/Band 5 ratio for the December image. Analysis as for Plate 9:1a).

Plate 9:2. A density slice of the Band 7/Band 5 ratio ('greenness') for the geometrically corrected, unsubsampled December image. The slice dimensions are shown at the bottom and as for Plate 9:1a) the colour categories are designed to slice 500 kg.ha^{-1} green biomass increments.

A = Aitong
T = Talek river
M = Mara river
S = Siria escarpment.
MMNR = Maasai Mara National Reserve.

Plate 9:3a). Density slice of the first principal component ('cover') for the June image. The image has been smoothed using a 3 x 3 'boxcar' filter.

Approx. cover categories

yellow ≏ 40-50%

10-15% increments to

light green ≃ 100%

Black line delimits study area. Slice dimensions at bottom of image.

Plate 9:3b). Density slice of the first principal component for the August image. Analysis as for Plate 9:3a).

Plate 9:3c). Density slice of the first principal component for the December image. Analysis as for Plate 9:3a).

Plate 9:4. A density slice of the first principal component ('cover') of the geometrically corrected, unsubsampled December image. As for Fig. 9:3a) the colour categories are designed to slice vegetation cover from 40-100% in 10-15% increments.

A = Aitong: T = Talek: M = Mara river: S = Siria escarpment: K = Koyage: E = Enkikwe: L = Lemek.

Plate 9:5. A density slice of the second principal component (PC2) in a 2-band analysis (Bands 7 and 5). In this image PC2 is equivalent to PC3 in a 3-band analysis, and represents green biomass increments. It is almost identical to a slice of the Band 7/Band 5 ratio (Plate 9:2) with the same approximate biomass increments associated with each slice. December image.

Table 9:1. The mean DN and standard deviation (SD) of LANDSAT bands 7, 5 and 4 reflectance for the ten 10km blocks in Koyake Group Ranch and the one 10km block (XI) inside the game reserve (see Fig.5:3). Data for the three images are shown. n ≙ 5000 pixels for each block.

		Band 7 DN		Band 5 DN		Band 4 DN	
Date	Block	mean	SD	mean	SD	mean	SD
24/06/75							
	I	19.6	2.7	24.5	4.7	17.9	3.3
	II	18.2	1.5	28.1	4.2	19.8	2.4
	III	19.9	2.0	31.5	4.0	21.3	2.3
	IV	18.9	1.7	25.3	3.3	18.0	1.6
	V	17.9	1.6	27.6	2.7	18.9	1.5
	VI	20.0	1.5	31.2	3.4	21.3	2.0
	VII	19.6	1.8	30.8	4.2	21.0	2.4
	VIII	18.0	1.5	27.2	2.5	18.6	1.3
	IX	19.0	1.4	27.3	3.2	18.7	1.7
	X	17.6	1.3	27.1	2.9	18.9	1.6
	XI	19.0	1.6	22.8	4.0	16.9	1.8
17/08/75							
	I	20.5	1.4	25.3	2.2	21.1	1.4
	II	19.4	1.4	28.2	2.8	22.5	1.9
	III	20.3	1.6	28.5	3.0	22.9	1.9
	IV	20.5	1.3	26.3	2.5	22.0	1.6
	V	18.7	1.4	28.9	2.4	23.0	1.6
	VI	20.2	1.4	29.5	2.6	23.7	1.6
	VII	19.8	1.7	27.7	3.4	22.2	2.3
	VIII	19.2	1.3	28.3	2.3	22.5	1.6
	IX	19.9	1.4	27.0	2.2	22.0	1.7
	X	19.6	1.4	26.5	2.3	21.7	1.7
	XI	19.8	1.3	26.5	3.0	21.6	1.9
21/12/75							
	I	20.8	1.7	23.9	2.5	19.8	1.7
	II	21.4	1.8	28.1	4.9	22.1	2.6
	III	20.7	2.1	33.0	4.5	23.9	2.4
	IV	22.3	1.7	24.7	2.8	20.9	1.9
	V	20.3	2.0	26.2	2.7	21.0	1.9
	VI	21.3	2.0	29.2	3.4	21.5	2.1
	VII	20.3	2.5	30.1	4.5	22.2	2.8
	VIII	22.1	1.6	25.5	2.7	21.0	1.8
	IX	21.1	1.6	25.7	2.7	20.9	1.9
	X	21.7	1.8	27.5	3.0	21.8	2.0
	XI	22.5	1.6	24.1	3.6	20.7	2.2

Table 9:2. Product-moment correlation coefficients (r) between LANDSAT band parameters, and 1974 grazing model and 1979-82 KREMU SRF data, for each 10km block in Koyake Group Ranch and block IX inside the game reserve.

Image date.	Livestock data	bands (B) and band ratios[a]					
		B7	B5	B7/B5	B7-B5	$\frac{B7-B5}{B7+B5}$	$\overline{\frac{B7-B5}{B7+B5}+.5}$
24/06/75	Mod.1 10km	.332	.768**	-.630*	-.716**	-.639*	-.647*
	Mod.2 10km	.361	.738**	-.575	-.668*	-.585*	-.593*
	Mod.1 15km	.361	.913***	-.764**	-.854***	-.773**	-.781**
	Mod.2 15km	.384	.838***	-.669*	-.767**	-.679**	-.688*
	1979-80 catt.dens.$	.197	.780**	-.709**	-.765**	-.716**	-.721**
	1979-80 catt.occ.$	.307	.869***	-.749**	-.825***	-.755**	-.761**
	1981-82 catt.dens.	-.134	.392	-.484	-.461	-.484	-.485
	1981-82 catt.occ.	.119	.814**	-.791**	-.827***	-.796**	-.800**
	All SRF catt.dens.	.083	.761**	-.752**	-.783**	-.757**	-.761**
	All SRF catt.occ.	.238	.883***	-.801**	-.862***	-.807**	-.812**
17/08/75	Mod.1 10km	.137	.441	-.276	.301	-.269	-.255
	Mod.2 10km	.148	.420	-.258	-.283	-.244	-.232
	Mod.1 15km	.072	.626	-.433	-.479	-.421	-.411
	Mod.2 15km	.119	.530	-.347	-.381	-.335	-.323
	1979-80 catt.dens.	.106	.409	-.270	-.288	-.253	-.239
	1979-80 catt.occ.	.164	.491	-.301	-.334	-.286	-.237
	1981-82 catt.dens.	-.149	.373	-.335	-.349	-.335	-.334
	1981-82 catt.occ.	-.105	.491	-.415	-.427	-.406	-.397
	All SRF catt.dens.	.008	.481	-.359	-.380	-.347	-.336
	All SRF catt.occ.	.052	.514	-.365	-.391	-.353	-.341
21/12/75	Mod.1 10km	-.399	.933***	-.854***	-.898***	-.873***	-.885***
	Mod.2 10km	-.404	.911***	-.829***	-.881***	-.850***	-.866***
	Mod.1 15km	-.553	.971***	-.958***	-.967***	-.959***	-.959***
	Mod.2 15km	-.489	.965***	-.911***	-.947***	-.925***	-.935***
	1979-80 catt.dens.	-.352	.900***	-.832***	-.859***	-.838***	-.843***
	1979-80 catt.occ.	-.393	.949***	-.885***	-.911***	-.891***	-.895***
	1981-82 catt.dens.	-.150	.420	-.407	-.397	-.396	-.387
	1981-82 catt.occ.	-.537	.854***	-.860***	-.863***	-.861***	-.861***
	All SRF catt.dens.	-.331	.861***	-.805**	-.820**	-.804**	-.803**
	All SRF catt.occ.	-.477	.947***	-.912***	-.928***	-.916***	-.919***

$: catt.dens. = mean cattle density: catt.occ. = mean cattle occupance.

[a] : the origins of these ratios are explained in the text.

Table 9:3. Table of band statistics, eigenvectors (principal components) and eigenvalues (variance explained by principal components) for the three LANDSAT images.

Date	Statistics of input bands		Band 7	Band 5	Band 4	Eigen-values
24/06/75	Mean		16.7	21.1	19.6	
	Variance		12.25	43.56	10.24	
	Eigenvector loading onto bands	PC1	.4510	.8924	-.0123	82.0%
		PC2	.1516	-.0630	.9864	16.3%
		PC3	.8796	-.4467	.1637	1.6%
17/08/75	Mean		22.8	27.6	20.6	
	Variance		81.00	136.89	15.21	
	Eigenvector loading onto bands	PC1	.5950	.7741	.2163	96.9%
		PC2	.0189	-.2826	.9590	2.2%
		PC3	.8035	-.5665	-.1828	.9%
21/12/75	Mean		19.5	24.0	21.2	
	Variance		10.89	33.64	6.76	
	Eigenvector loading onto bands.	PC1	.4788	.8718	.1034	84.1%
		PC2	.1605	-.2028	.9660	13.6%
		PC3	.8631	-.4459	-.2370	2.3%

Table 9:4. The mean DN and standard deviation (SD) of LANDSAT bands 7, 5 and 4 reflectance for selected areas of forest (vegetation Types 1(a) and 1(b)) and Tarchonanthus bushland (vegetation Type 2(b)). Data for all three images are shown. The number of pixels in each sample lies between 20 and 700; sample size is not displayed by the GEMS image processor.

Date	Vegetation type	Band 7 DN		Band 5 DN		Band 4 DN	
		mean	SD	mean	SD	mean	SD
24/06/75	Forest	16.8	.8	10.2	.7	11.0	.7
		15.5	.8	10.4	.7	10.9	.8
		16.3	.9	9.4	.7	10.3	.5
		16.3	2.2	11.2	1.7	11.3	1.2
	Tarchonanthus	18.8	1.1	22.6	2.6	16.8	1.0
		18.6	2.0	21.6	3.2	16.6	1.6
		19.9	1.5	23.5	2.7	17.5	1.2
		18.1	1.7	23.1	2.9	17.3	1.2
		18.9	1.0	24.9	2.4	18.0	1.4
		18.8	1.6	23.3	2.3	17.0	1.0
17/08/75	Forest	17.1	.9	13.9	.4	15.7	.6
		18.0	.9	13.8	.5	15.7	.7
		16.7	.8	13.6	.7	15.6	.7
		17.9	1.8	15.4	1.9	16.3	1.2
		17.0	.9	13.1	.6	14.8	.9
	Tarchonanthus	20.5	1.1	22.8	2.2	19.5	1.8
		19.9	1.3	24.4	2.8	20.0	1.9
		19.7	1.1	25.7	1.8	21.7	1.3
		18.5	1.6	21.3	1.7	18.3	1.3
		17.8	1.1	24.1	1.9	19.9	1.7
		19.3	1.3	22.8	2.3	18.9	1.7
21/12/75	Forest	18.7	2.2	14.2	2.6	13.4	2.1
		20.9	2.4	10.7	.9	11.5	.6
		18.8	.8	10.8	.7	11.5	.5
		18.9	1.1	11.0	.7	11.5	.5
	Tarchonanthus	16.3	1.4	25.0	3.0	17.8	1.6
		16.7	1.4	27.6	3.0	19.0	1.6
		17.3	2.8	24.5	4.7	17.6	2.6
		19.0	1.3	27.2	2.7	19.2	1.5
		19.2	1.5	28.1	3.2	19.7	1.8

Table 9:5. Satellite imaging systems (from Darch 1984).

CHAPTER 10: CARRYING CAPACITY AND STOCKING RATES IN THE STUDY AREA

10:1 Introduction

Carrying capacity, which may be defined as the ability of a given area to support a certain population of animals on a continuing basis (De Vos 1969), is a controversial concept of range management. Some authors (e.g. Ruthenberg 1976) believe that pastoral practices inevitably lead to overstocking and decreased livestock production. Others (e.g. Western 1982) suggest that the close 'tracking' of pastoral livestock populations to their food supply may actually result in an increased livestock production of pastoral systems when compared with commercial ranching systems. According to Western (1982) "the point at which the long term sustained yield of livestock is maximized represents the ideal stocking rate" and he adds, "at this point both standing crop will be lower and erosion substantially higher than on lightly stocked rangelands".

All authors are in agreement, however, that if this level is greatly exceeded, severe land degradation will take place, characterized by a rapidly declining plant cover, the replacement of palatable species by unpalatable species and increased severe erosion (Pratt and Gwynne 1977).

Brown (1971) has clarified the issue of overstocking as being one of overpopulation. Each individual needs a minimum biomass of livestock to support himself over the year. 'Overgrazing' results when the human population density exceeds the level where the rangelands cannot support, on a continuing basis, the required number of livestock. Brown (1971) acknowledges that in certain situations livestock populations may greatly exceed human requirements and cites the 1961-1962 Kajiado 'disaster' as an example. Here severe drought reduced the cattle population of the **Kaputiei** Maasai from some 740,000, three times human requirements, to 210,000 (Prole 1976).

The Maasai attempt to maximize their herd size on the rationale that, in the event of a drought, more cattle will survive. Cattle are 'capital on the hoof' in that they represent, in a very direct way, the means for the survival of the pastoralist. They are not only his main food source but his currency to purchase wives and, through cattle loans to friends and relatives, extend his influence through the Maasai community. In a system where land is communely owned, maximising one's herd size is a logical goal because the gains to the individual pastoralist are high whilst the costs, in terms of the depletion of grazing resources, are spread over the entire community (Helland 1978; Hardin 1968). This maximization system has evolved over a period when space was not limiting. With their characteristic mobility the Maasai could, in drought years, simply move to new pastures. Today they are hemmed in by agricultural tribes, commercial cultivation schemes and conservation areas, and occasional heavy losses such as those in Kajiado in the early 1960s are inevitable.

In their respective Maasailand development plans, Lewis R.W. (1965) and Strickland (1973) both made reference to a massive influx of Kipsigis and Kikuyu agriculturalists into Narok District (see Chapter 2). This immigration continued throughout the 1970s such that, between 1969 and 1979, the population of the District increased from 125,000 to 210,000 (data from Central

Bureau of Statistics, Nairobi). The leasing of group ranch grazing land in the Mau Narok, trans-Mara and Ololunga areas to farmers (see Section 10:4) has forced many Maasai to move south into the Mara area. It was shown in Chapter 4 that the population of Maasai in the study area is increasing at approximately 7.5% per annum. Using the information presented in Chapters 4 and 5, and estimates of carrying capacity derived by a number of authors, the aim of this chapter is to determine whether or not the study area can support the further influx of Maasai and their stock.

This investigation is important to the formulation of new wildlife conservation plans in Narok District. It will be recalled from Chapter 1 that the study area, predominantly occupied by **il-Purko** Maasai, has been selected as a self-contained grazing unit. To the north it is bordered by the agricultural Kipsigis land unit, to the west by the **Siria** Maasai and the physical barrier of the Siria escarpment, and to the east by the waterless Loita plains and recent wheat development schemes. If the group ranches of Koyake, Ol Kinyie and Lemek (Fig. 2:1) become 'saturated' with immigrating Maasai the only remaining expansion zone will be south into the Maasai Mara National Reserve.

These group ranches of the Mara area are also subjected to a greatly increased dry season grazing pressure from the annual wildebeest migration. In their analysis of livestock and wildlife stocking rates from KREMU systematic reconnaissance flight data, Stelfox et al (1980) divided the rangelands of Narok into 3 ecological units: the Mara unit of 2350 km^2, the Loita unit of 2200 km^2 and the Siana unit of 1850 km^2. Their Mara unit corresponds well with the borders of the study area and also includes the major portion of the Maasai Mara National Reserve. The mean annual biomass, in this unit, of the different species of grazing herbivore, is shown in Table 10:1. Two migratory herbivores, the wildebeest (Connochaetes taurinus), and the zebra (Equus burchelli) contribute 40% and 15% respectively to the mean annual grazing herbivore biomass of 21,700 $kg.km^{-2}$. It is not possible to make a meaningful assessment of the stocking rates on the sub-study area of Koyake Group Ranch, the area from which most of the human pressure on the reserve originates, without examining in further detail the movement patterns of the annual wildebeest migration.

10:2 The Annual Wildebeest Migration

It was indicated in Section 1:4 that the eradication of rinderpest from the Serengeti-Mara ecosystem has led to a six-fold increase in the Serengeti wildebeest population (Sinclair 1979c). The population has stabilized, through dry season food resource limitation, at its present level of 1.4 million animals (Sinclair pers. comm.). The migration follows a route from the calving grounds of the southern Serengeti plains occupied from December-April, through the woodlands of the 'western corridor' and north-central Serengeti from May-July and into the northern Serengeti and Mara for the duration of the dry season (August-November).

The first Serengeti migration spread into the Mara in 1969 (Pennycuick 1975). KREMU SRF surveys indicate that in 1979, a year of typical rainfall (see Fig. 5:4), an initial wave of some 650,000 wildebeest crossed the Kenya-Tanzania border in July (Stelfox et al 1980). As animals drifted back into the northern Serengeti in August the number of wildebeest in the Mara ecological unit declined to 350,000 and remained at this level for the remainder of the dry season. Generally in wet season months no more than 10,000 wildebeest occupy the Mara unit.

Gwynne and Bell (1968) and Bell (1971) have described the 'grazing succession' in which the non-ruminant zebra, requiring bulk forage, precede the ruminant wildebeest in the migration and leave the grass sward at a more suitable height for wildebeest grazing. Bell (1971) related this sequence to the catenae of the Serengeti plains but the early arrival of zebra in the Mara in June was an obvious feature of the migration in both the year of, and the year preceeding, the fieldwork studies (Dublin pers. comm.) Thomson's gazelle (Gazella thomsonii) prefer short grass (McNaughton 1976) and are the third grazers in the succession. They remain after the wildebeest have departed from the southern and central Serengeti but their migratory movements are entirely contained within the Serengeti.

The second completely separate population of wildebeest that uses the Mara reserve as a dry season range spends the wet season months on the northern Loita plains (Talbot and Talbot 1963). As described in Section 1:4 this population has increased from 20,000 in the early 1960s to 100,000 in 1979 (Stelfox et al 1980).

The movement patterns of the two wildebeest populations in the context of the entire Serengeti-Mara ecosystem are presented in

Fig. 10:1. The wet and dry season densities and distributions of wildebeest in the Mara and Loita ecological units, recalculated from 1979 KREMU SRF raw data, are shown in Figs. 10:2a) and b).

Since 1980 much of the wet season range of the Loita population has been ploughed under for wheat. In 1984 for the first year, large numbers of the Loita wildebeest remained in the Mara reserve and Koyake Group Ranch throughout the wet season.

10:3:i Livestock and Wildlife Stocking Rates

In general, African herbivore populations are regulated through their food supply (Sinclair 1977). Coe et al (1976) analysed census data from a number of conservation areas throughout Africa to demonstrate a significant relationship between wild herbivore biomass and mean annual rainfall. They also show that herbivore biomass is significantly correlated with the productivity predictions of Rosenzweig (1968) and suggest that the density at which a wild herbivore population is regulated approximates to the true carrying capacity of the ecosystem. Similarly Le Houerou and Hoste (1977) established a clear relationship between rainfall and primary production in the Sahel and Mediterranean areas. They calculated biomass densities that can be supported at different rainfall levels from theoretical livestock food requirements.

Although the authors above recognize that the rainfall-herbivore biomass relationship may break down at rainfall levels above 700 $mm.annum^{-1}$, their regressions have been shown to hold to rainfalls of over 1000 $mm.annum^{-1}$ in Ethiopia by Bourn (1978).

Bourn records a good correspondence between areas of high desertification risk, as mapped by FAO/UNESCO (FAO/UNESCO 1977) and areas in which cattle biomass exceeded the carrying capacity estimates of Coe et al (1976). He acknowledges that stock other than cattle were not taken into account and that his biomass estimates will err on the low side.

Carrying capacity estimates derived by the authors above show some divergence at the low rainfall end of the scale, but at 1000 mm rainfall, the annual rainfall of the study area, they all suggest that a herbivore biomass of 10,000-15,000 $kg.km^{-2}.annum^{-1}$ can be supported.

In the literature stocking rates are frequently assessed with reference to two different livestock units; the Standard Stock Unit (SSU) of 450 kg (Brown 1971; Pratt and Gwynne 1977) and the Tropical Livestock Unit (TLU) of Boudet and Riviere (1968). The latter was initially applied to range assessment in the Sahel but is gaining in popularity elsewhere. According to Pratt and Gwynne (1977) rangelands lying in Ecozone IV (see Section 1:3:iii) have an ideal stocking rate of 4 $ha.SSU^{-1}$ or 11,250 $kg.km^{-2}$, a figure in close agreement with those of Le Houerou and Hoste (1977) and Coe et al (1976). Jewell (1980) suggests a figure of 5 $ha.SSU^{-1}$ or 9000 $kg.km^{-2}$ but this clearly refers to range areas with lower rainfall than that of the Mara.

Watson (1972) proposes a mean Maasai cattle weight of 180 kg and a mean wildebeest weight of 123 kg. These weights have been used to calculate cattle and wildebeest biomass on Koyake Group Ranch. The mean weight of smallstock is taken as 20 kg (Lamprey and

Field 1983).

Smallstock density estimates from KREMU SRF data are rather unreliable (Peden pers. comm.), and to assess the biomass contribution made by the sheep and goats a count was made in 1983 of the total number of smallstock in each of eight manyattas; four at Talek and four at Koyage. There were 80 ± 11.2 (95% c.l) smallstock/hut or 880 for an average settlement with 11 huts (see Table 4:1).

The cattle biomass estimates of Koyake Group Ranch over the 11 1979 KREMU SRFs were shown in Table 5:6 and are presented in Fig. 10:3a). Wildebeest densities and biomass, again calculated using Jolly's Method 1 (Jolly 1969), are shown in Table 10:2 and Fig. 10:3b). The influx of wildebeest in July is particularly clear. The mean cattle biomass in Koyake Group Ranch in 1979 was 7126 $kg.km^{-2}.annum^{-1}$ and the mean biomass of wildebeest 3524 $kg.km^{-2}.annum^{-1}$ †. By a linear extrapolation between the 1974 and 1983 settlement counts there were 70 manyattas in Koyake Group Ranch in 1979. On this basis smallstock contributed a further 1230 $kg.km^{2}.annum^{-1}$. Thus in 1979 the mean annual biomass density of cattle, smallstock and wildebeest was 11,880 $kg.km^{-2}.annum^{-1}$. According to the data of Stelfox et al (1980) the biomass density of zebra in the Mara ecological unit will increase the total

Footnote: † These biomass estimates have been calculated from data presented in Tables 5:6 and 10:2. The wildebeest biomass estimate assumes a 4 month (July-October) occupation of the Mara by the migration (Stelfox et al 1980), and the estimate has therefore been corrected to take into account the seasonal 'inbalance' in SRFs.

biomass density again to about 14,500 kg.km^{-2}.annum^{-1}. Buffalo (Syncerus caffer), which contribute 17% to the total grazing herbivore biomass of the Mara unit have not been included in this total because large herds were rarely encountered outside the reserve.

It therefore appears that by 1979 Koyake Group Ranch was supporting a herbivore population of 14,500 kg.km^{-2}.annum^{-1}, at about the suggested carrying capacities suggested by Coe et al (1976) and Le Houerou and Hoste (1977). In these biomass estimates only cattle, smallstock, wildebeest and zebra have been included. From the figures of Stelfox et al (1980) presented in Table 10:1 the mean annual biomass of these herbivores in the Mara Ecological Unit (over half of which includes the reserve) is 16,150 kg.km^{-2}. This suggests that mean biomass densities are fairly evenly distributed between the reserve and the Maasai areas.

In 1983 there were 92 manyattas in Koyake Group Ranch. If each immigrating manyatta has brought with it 600 cows (Chapter 5) and 880 smallstock, the mean annual biomass of livestock and wildlife on the group ranch will have increased to 18,000 kg.km^{-2}.annum^{-1} in 1983. Livestock will have contributed 11,600 kg.km^{-2}.annum^{-1} to this total. The 1983 mean cattle density can be calculated as 55 cows.km^{-2}. KREMU SRF data from 1981 and 1982 do not, unfortunately, reveal the increasing cattle density over what is a relatively small area of rangeland (Table 5:6). This is presumably due to the very high variances associated with counts of clumped distributions (Norton-Griffiths 1978). In 1981 KREMU SRF aircraft were changed from single-engined Cessna 185s to faster twin-engined Partenavia aircraft and it is likely the counting biases have changed as a result (Peden pers. comm.).

Bell (1982) suggests that the total forage production of African savanna ecosystems is related to water availability, whilst forage quality, in terms of the ratio between metabollic constituents (protein, carbohydrates) and structural constituents (cellulose and lignin), is dependent on nutrient availability. In his re-evaluation of the biomass-rainfall relationships presented by Coe et al (1976) and Bourn (1978), Bell (1982) discovered that greater herbivore biomass densities could be supported on nutrient rich volcanic soils than on granitic or mixed soils. In only three conservation areas of the 30 that Bell examined were biomass densities comparable with those of Koyake Group Ranch. All three, Virunga National Park in Zaire, Ruwenzori National Park in Uganda and Manyara National Park in Tanzania are areas of volcanic soil. It will be recalled from Section 1:3:i that the soils of the study area are also volcanic in origin and this may explain how such high biomass densities can be supported. Maddock (1979) records that the Serengeti plains with volcanic soils support a much higher density of herbivores than the formula of Coe et al (1976) predicts for the relatively low rainfall (500-600 mm) of this area. Cattle densities on Koyake Group Ranch were much higher than in any example presented by Bourn (1978) and Bell (1982).

Carrying capacity is as much related to the distribution and availability of water as it is to overall forage production (Lamprey 1964; Western 1973). In northern Kenya, for example, the abundant grazing of the waterless Hurri hills is not available to Gabra pastoralists except in the wet season. In the surrounding low country desert conditions prevail through overgrazing around permanent water points (Lusigi 1981). This is a common feature of pastoral areas where nomads are encouraged to settle around water points or administrative centres with shops, dispensaries, livestock dips and other facilities. Desert encroachment results from the coalescence of these denuded areas (Lamprey pers. comm.).

In Chapter 5 it was shown that livestock distributions in the study area are related to settlement distributions and simple mathematical models were derived to describe this dependence. Settlement distributions are themselves tied to permanent water sources such as the springs at Lemek, Aitong and Koyage and the river at Talek. Table 10:3a) presents 1979 SRF data to suggest that block III, the Aitong-Koyage block, with a mean cattle biomass density of 21,100 kg.km^{-2}.annum^{-1}, is greatly overstocked. Livestock biomass will be even higher because smallstock will contribute a further 3000 kg to this total.

It can be calculated from the 10 km Model 1 that with a total livestock biomass of 126,000 kg.manyatta^{-1} any area within 10 km range of 30 of more settlements will be overstocked; in this case a maximum carrying capacity of 11,500 kg.km^{-2}.annum^{-1} (60 cows.km^{2}.annum^{-1}) is assumed. A GINO-SURF contour plot of 1983 10 km Model 1 data is presented in Fig. 10:4b) (CADS 1976). In this plot contours are fitted to a 30 point systematic 10 km grid that exceeds the limits of Koyake Group Ranch. Fig. 10:4b) indicates that the carrying capacity (60 cows.km^{2}.annum^{-1}) of the entire north eastern quarter has been exceeded, without taking into account the additional biomass contributed by smallstock or wildebeest. Fig. 10:4b) can be favourably compared with Fig. 10:4a), the plot of mean annual cattle densities for 1979 (derived from SRF data) to illustrate the predictive value of the model. In Section 5:5 it was shown that in the Lemek valley, which has been within range of 30 or more manyattas for the past 15 years, the number of cows.manyatta^{-1} had decreased to 340. This figure is consistent with the minimum subsistence livestock requirement of 2.5-3.5 SSU per head of human population (or 300-400 cows.manyatta^{-1}) suggested by Brown (1971), Pratt and Gwynne (1977) and Jewell (1980).

This figure of 340 cows/manyatta, converts via Model 1 to 60 cows.km^{-2} or about 11,500 kg.km^{-2}.annum^{-1}. The further addition of smallstock biomass will bring this biomass to approximately 14,000 kg.km^{-2}.annum^{-1}. In the Lemek valley therefore the ratio of livestock/head of population appears to be decreasing as human immigration continues and grazing becomes scarce. Most of the manyattas in the Lemek valley have small maize patches associated with them (see Plate 6:3) as the pastoralists attempt to supplement their diet with maize meal. This is a recent practice. According to the aerial photography there was no cultivation in the valley in 1974.

As a result of long-term overgrazing there is very severe gully erosion in the Lemek valley. In places the presence of trees on tall soil pedestals indicate that over 3 m of topsoil have been lost. This erosion is mainly confined to the valley slopes. The gullies feed into existing tributaries of the Lemek river which becomes the Olare Orok river as it enters the reserve. Terrace erosion is a conspicuous feature of the Lemek valley floor and of the Aitong and Loita plains, but according to Glover and Wateridge (1968) soil losses from this form of erosion are minimal; soil is simply redistributed by washing action to the foot of the terrace as the terrace retreats along a gentle gradient.

10:3:ii Livestock and Wildlife Interactions

Casebeer and Koss (1970) have demonstrated a close similarity in the diet, by species composition, of cattle and wildebeest. Similar observations were made by Mugambi (1982) who conducted feeding observations and faecal analyses of domestic and wild herbivores in the Mara. In his study area that extended along the road from Talek to Aitong, Mugambi found that the diet of cattle and wildebeest, in terms of proportions of Themeda triandra, Pennisetum mezianum and other species taken, overlapped by 62%. Croze et al (1977), however, argue that competition may be reduced by the very selective feeding of wildebeest (Bell 1971) when compared to cattle.

The dry season wildebeest densities and biomass for each 10 km block in Koyake Group Ranch, calculated from 1979 SRF data, are presented in Table 10:3b). The dry season wildebeest and cattle densities have been contoured in Figs. 10:.5a) and b) using GINO-SURF contouring graphics (CADS 1976). These figures indicate that wildebeest respond to the differential availability of grazing on the ranch by gravitating towards the west side of Koyake over the July-November period. Figs. 10:6a) and b) reveal that there is a significant negative correlation between cattle and wildebeest densities for both the yearly (r_s = -.879: n = 10

: $p < 0.01$) and the dry season ($r_s = -.721$: $p < 0.05$) blockwise averages. The best linearity has been achieved with a square root transformation on the density data. Livestock densities in the western half of the ranch are low throughout the year. At low densities cattle can be considered as the first grazers in the grazing succession, 'preparing' the grasslands for more selective foraging by wildebeest.

The interaction of wildebeest and cattle can also be examined using X^2 tests and Cole's Coefficient of Association to test the null hypothesis that the two species are distributed randomly with respect to one another. The results of this analysis, performed according to the methods outlined in Section 5:4 are presented in Table 10:4. Table 10:4 also shows the results of association tests between wildebeest and 1974 and 1983 settlement distributions, and with areas of bushland. Presence/absence X^2 analysis is not effective in demonstrating the separation of wildebeest from cattle in either the wet or the dry season, but the tests do reveal a slight but significant ($p < 0.05$) dry season avoidance by wildebeest of 5 km UTM blocks with settlements in them. A surprising result of this analysis is that, during the wet season, wildebeest are significantly ($p < 0.01$) associated with the settlements. These wildebeest would be small herds of resident animals, possibly preferring the short green grass growing within 5 km of settlements, or they might simply represent the westernmost limit of the Loita plains population; the Aitong and Bardamat settlements would be distributed along these limits. Despite assertions that wildebeest avoid areas of bush (Talbot and Talbot 1963), the results of this analysis suggest that wildebeest are distributed randomly with respect to bushland. On the other hand, the analysis does not take into account the fact that Acacia-Commiphora bushland in the eastern areas of Koyake Group Ranch is much more dense than in the western areas (see Fig. 7:5). Bushland in both areas is placed in the bushed grassland category (Fig. 6:3). Wildebeest may still, therefore, be avoiding areas of dense bushland.

The 1975 LANDSAT imagery can be considered a very approximate guide to the availability of green forage in 1979. Using Spearman rank-correlation coefficients, wildebeest in the dry season show a significant preference for areas with the highest Band 7/Band 5 ratio (highest 'greenness') in both the June (r_s = .576: $p < 0.05$) and December (r_s = .648: $p < 0.05$) images but not in August (r_s = .200: NS) when forage has been depleted. Similarly, there is a negative correlation of wildebeest densities with Band 5 red reflectance (which increases with increasing bare ground) in June (r_s = -.576: $p < 0.05$) and December (r_s = -.673: $p < 0.05$) but again not in August (r_s = -.418). In view of the 4 year span between the LANDSAT imagery and the SRF data, these correlations should be treated with caution.

The 1979 SRF data in Tables 10:2 and 5:6 indicate that in the dry season the wildebeest biomass on Koyake Group Ranch increases to a mean of 9800 $kg.km^{-2}$ from its wet season level of 300 $kg.km^{-2}$. The total biomass of both cattle and wildebeest increases to 15,500 $kg.km^{-2}$ from 6900 $kg.km^{-2}$.

A surprising and important result to emerge from the analysis, shown in Table 10:3, Figs. 10:5 and 10:6, is that in the western half of Koyake Group Ranch, wildebeest are present at much higher densities in the dry season than are cattle in the eastern half. In block IV, for example, the mean dry season wildebeest biomass exceeded 30,000 $kg.km^{-2}$, 2-3 times the estimated carrying capacity. A possible reason to explain how such large numbers can be supported is that the wildebeest occupy the western areas after the grasses have flowered and the root reserves are restocked. Under these conditions heavy grazing by wildebeest early in the dry season (whilst soil water is still available) may promote a burst of increased productivity sometimes as high as 26 $kg.ha^{-1}.day^{-1}$ (McNaughton 1976). With heavy yearlong grazing by cattle, however, grassland cover in the eastern half of Koyake is lower even through the wet season. The photosynthetic surface is smaller and root reserves cannot be fully replenished.

Sinclair (1979c) has shown that the Serengeti wildebeest population is limited by its dry season food supply. He provides a regression equation with which to estimate dry season productivity from rainfall data. The mean monthly July-October rainfall at Aitong in 1979 was 22.6 mm and at Keekorok 28.3 mm (Fig. 5:4). According to Sinclair's regression the grassland productivity in 1979 would have been very low, of the order of 0-0.5 $kg.ha^{-1}.day$. Wildebeest require, for maintenance, a daily food intake of 2.4% of their 130 kg body weight (Sinclair 1977). At the mean 1979 dry season biomass density on Koyake Group Ranch of 9800 $kg.km^{-2}$ the food required per unit area will be 2.4 $kg.ha^{-1}.day^{-1}$. At its most extreme density in block IV the population will require 7.9 $kg.ha^{-1}.day^{-1}$. Clearly in 1979 the wildebeest must have relied on body reserves to carry them through the dry season.

There is no reason to believe why cattle populations should not also be limited by their dry season food supply. During the 1979 dry season the mean cattle biomass on Koyake Group Ranch was 7130 $kg.km^{-2}$, not greatly different from the yearly mean of 7500 $kg.km^{-2}.annum^{-1}$. Cattle require a daily food intake of 2.7% of their body weight (Lamprey and Field 1983). A productivity of 1.5 $kg.ha^{-1}.day^{-1}$ is needed over the group ranch over the dry season to support cattle alone. Cattle requirements increase to 4.6 $kg.ha^{-1}.day^{-1}$ in the high livestock density block III (the Aitong-Koyage block). The average dry season rainfall at Aitong is 53 mm, giving a productivity estimate of 7 $kg.ha^{-1}.day^{-1}$. Theoretically, therefore, in the average year cattle dry season food requirements are met by grass production, even if only $^1/3$-$^1/2$ of this production consists of consumable dry matter (Le Houerou and Hoste 1977). This area, however, shows a high degree of range degradation, characterised by a low grassland cover and the replacement of palatable Themeda triandra grass with Pennisetum mezianum (see Section 6:2).

This investigation suggests that grassland productivity may be reduced in areas subjected to year round heavy grazing. The work of Onyeanusi (1983) supports this hypothesis. Over the 1982 wet season the grassland production of a livestock exclosure in the heavily grazed Talek area was less than half that of exclosures located within the game reserve. On the other hand, an area can be left 'fallow' over the wet season, and then very heavily grazed in the dry season. The two halves of Koyake Group Ranch are grazed according to these two respective grazing regimes, the western half (and also the reserve) by wildebeest and the eastern half by cattle. Clearly, the figures presented in this section are approximate but they serve to shed light on grassland-herbivore dynamics in the Mara area. However, further research is needed to examine in greater detail grassland productivity under different degrees of grazing pressure.

With the continuing immigration of Maasai and their stock into the eastern half of Koyake Group Ranch, a new grazing strategy has been employed by the Maasai. Since 1978 they have moved a large proportion of their cattle population out of Koyake and into the neighboring Oloirien Group Ranch for the duration of the dry season. Oloirien is a ranch of the **Siria** section of Maasai located above the Siria escarpment. As described previously these cattle are initially moved into temporary livestock camps in the Enkikwe area, and thence across the upper Mara bridge and up the escarpment. This emmigration of cattle is evident from the 20 KREMU SRFs presented in Table 5:6. There is a significant difference between estimates of the mean wet season cattle population of Koyake Group Ranch (42,250 ± 5128: ± S.E: n = 11) and the mean dry season population (26,935 ± 3833: ± S.E: n = 9) ($t = 2.39$: d.f. = 18: $p < 0.05$). The Maasai therefore appear to remove over 36% of their cattle in the dry season.

It can be postulated that, for each SRF, the total number of cows counted divided by the total number of times a cow or cattle were encountered between the strip markers gives an index of 'group size'. If this procedure is carried out for each of the 20 SRFs in Table 5:2 it can be calculated that the mean index value for the wet season SRFs is 167 ± 19 (± S.E: n = 11) and for the dry season SRFs 117 ± 16 (± S.E: n = 9). This difference falls marginally short of significance at the 5% level (t = 1.98: d.f. = 18: p = 0.064), but it can still be tentatively suggested that group size is reduced by about 30% following the removal of cattle in the dry season. Over the entire year the mean group size index value is 145 ± 14 (± S.E: n = 20), a figure which compares reasonably well with the 'herd size' estimate from dip records of 105 ± 8 (± S.E: n = 144) for adult cattle and 130 ± 10 (± S.E: n = 144) for cattle-with-calves (Chapter 5).

According to the Maasai, over half the cattle population in 1983 was moved away from Koyake Group Ranch, some of these cattle being taken to Oloirien and some to the adjacent **il-Purko** group ranch of Megwarra (see Fig. 2:1). The Maasai gave two reasons for their removal, both linked to the annual influx of wildebeest rather than to grazing shortages related to human immigration:

a) The wildebeest 'finish the grass'; the Maasai refer to the wildebeest migration as their 'yearly famine'.

b) The wildebeest pass on diseases to their cattle, the most notable referred to as 'turning disease'. This is caused by the migration of Oestrid nasal bot fly larvae from the nose cavity where the eggs are laid, into the brain of their host (Sachs and Debbie 1969). A second disease, malignant catarrhal fever, a virus transmitted through the shed placenta during calving (Rossiter 1981) is not prevalent in the dry season; the two wildebeest populations calve in January on the Serengeti and Loita plains respectively, both areas well removed from Koyake Group Ranch.

Although prior agreements are made with Oloirien Group Ranch with regard to the sharing of grazing resources, there was in 1983 considerable opposition from the members of Oloirien to the movement onto their land of some 15,000 head of cattle. Additional studies would be required to assess the land use pressures on this group ranch but it is unlikely that the **Siria** members of Oloirien will continue to tolerate **il-Purko** cattle on their grazing land without some form of reciprocation. In its favour the Oloirien area receives 1400-1500 mm rainfall per annum (Glover 1966; Epp and Agatsiva 1980), less seasonally distributed than in cis-Mara, and it can therefore support cattle at relatively high densities.

Grazing resources are becoming scarce in Narok District. The events which have led up to the rapid influx of Maasai into the Mara rangelands, with the subsequent overstocking that this has entailed, can be traced to agricultural development on the Mau foothills and Loita plains.

10:4 Land Use Pressures from Expanding Agriculture

Agricultural development in Narok District has been characterized by a marked lack of central planning and control. Very little published information exists giving information on areas already under cultivation or details of future development programmes. The expansion of agriculture appears to have accelerated in the late 1970s and early 1980s, but it has not been possible to use LANDSAT imagery to map cultivated areas because a malfunction in the oscillating mirror of the LANDSAT-3 multispectral scanner, termed a 'line-start-anomaly', has effectively blacked out the western one third of each image. The Mau foothills and Loita plains have not been clearly imaged since 1979.

The migration of numerous agricultural Kipsigis and Kikuyu 'acceptees' into Narok District in the 1960s and 1970s (Chapter 2) has no doubt contributed significantly to the loss of grazing land in high potential Mau and Melili areas of Narok District. An examination of false colour composites indicates that an estimated 8000 hectares of these areas were under smallholding agriculture in 1976. However, it has been the development of large scale wheat and barley 'schemes' in the Mau and Ololunga areas that has had the major effect on Maasai distribution in the region. The **il-Purko** Maasai are divided into three groups: the **Mau Purko**, the **Melili Purko** and the **Osopuko Purko.** It is the last group who have traditionally occupied the Mara area. Many of the immigrating Maasai have been **Mau Purko** forced in by agricultural expansion.

Wheat cultivation in the Ololunga and Ngorengore areas began in the early 1970s. Following the publication of a favourable report prepared by a team of Canadian agricultural experts (Willis et al 1968), an area of some 6000 hectares of the Loita plains lying along the northern border of the Ngorengore-Narok road was leased by the Maasai to European wheat farmers on a 3-year extendable basis. This area can be seen in the LANDSAT colour composite image in Plate 1:1. A game fence was constructed along the southern border of the road to prevent the Loita plains wildebeest population from straying onto the wheat fields. According to the 1974 aerial photography and to a 1980 LANDSAT image that fortuitously 'clips' the northern Loita plains, these wheat fields remained constant in size throughout the 1970s. After 1980 however, the game fence was removed and the ploughing up of the Loita rangelands began in earnest. With the encouragement of the Government and the Narok District administration, group ranch officials convinced their members that money could be brought into the ranches by leasing off large areas of the Loita plains to farmers.

In order to measure the rate of expansion of the wheat schemes on the Loita plains, a field trip was undertaken in March 1984 to map the wheat fields on the ground. The southern limits of the fields are straight and it was possible to drive along the field edges and accurately locate the corner positions by taking compass bearings off prominent features such as peaks on the Bardamat and Ol Kinyie hills. Throughout the exercise reference was continously made to a Directorate of Overseas Surveys beacon in the central Loita plains (Beacon No. 146), which now marks the corner of 4 fields. The resulting wheat scheme map is shown in Fig. 10:7. The schemes are expanding at the rate of 5000 ha (50 km^2).annum^{-1}, at which rate most of the Loita plains will be under cultivation by 1990.

The wheat fields coincide almost exactly with the wet season concentration area of the Loita wildebeest population (see Fig. 10:2a)). A field trip was made to the area in October of 1983 and it was noted that, following their early return to the Loita plains the wildebeest had destroyed over 20 km of barbed wire fence.

Many Maasai interviewed at Talek claim to have been displaced from Ololunga Group Ranch (see Fig. 2:1) on which most of the wheat development has taken place. At the same time an increasing number of the 100,000 Loita wildebeest will be forced into the Maasai Mara National Reserve and Koyake Group Ranch for the entire year, placing even greater pressure on grazing resources. It has been particularly difficult in clarifying the relationship between wealthy Maasai group ranch officials, the farmers and the ordinary Maasai of Ololunga Group Ranch. However, from the extreme hostility of the Maasai living along the southern boundaries of the wheat schemes to strangers and to europeans in particular, it was apparent that the wheat expansion programme is not welcomed by many Maasai of the area.

Kenya has the highest population growth rate in the world and food production is of the highest priority. According to a European farmer at Ngorengore the Loita plains now produce one quarter of Kenya's wheat requirements. The conflict between national and local interests needs to be urgently resolved. Pastoralist welfare, agricultural development and conservation are incompatible goals in the same area. Group ranches such as Koyake cannot hope to achieve any form of economic efficiency with a Maasai immigration rate of 7.5% per annum. The future of the Maasai Mara National Reserve, Kenya's finest wildlife sanctuary which attracts 60,000 visitors annually (WPU 1983), is also placed in jeopardy from the pressure now exerted by the Maasai of Koyake Group Ranch and the neighboring Megwarra Group Ranch. In the drought year of 1984 grazing was in such short supply that the Maasai daily moved their cattle 10 km or more into the reserve.

Koyake Group Ranch was not adjudicated until 1970. According to the Canadian agricultural report of Willis _et al_ (1969) the area coincident with Koyake, (which the report refers to as the

"Kiloriti plain and south to the Mara Game Reserve"), is "70-85% suitable for agriculture". In 1984 there were well substantiated rumours that a large area of rangeland extending from Enkikwe north to the Mara river had been leased for agriculture. Clearly, in view of the land use conflicts of the area a reappraisal of agricultural plans is required.

Narok District is under the local administration of Narok County Council, an elected body of Maasai serving Maasai interests. The Council controls the administration of the Maasai Mara National Reserve. Under considerable pressure from Maasai the Council officially degazetted approximately 200 km^2 of the reserve in 1983, an action legitimized by the Kenya Government. One of these areas (see Fig. 2:1) was Talek, which was first occupied by the Maasai in 1967 (see Chapter 4).

10:5 Discussion

In this chapter, calculations based on theoretical estimates of carrying capacity indicate that the study area has become overstocked. The increase in pressure on grazing resources can be traced to:

a) the expansion of wheat schemes outside the study area with the subsequent displacement of Maasai, their livestock and grazing wildlife into the Mara rangelands,

b) the use of the group ranch areas for the duration of each dry season by 60,000-100,000 wildebeest of the Serengeti migration,

c) the reinvasion of tsetse-flies into areas where 'bush encroachment' is taking place,

d) the unwillingness of the Maasai to sell their stock and adapt to a monetary rather than a cattle-based economy. Even if they were ready to sell cattle, a market in Narok District has not been provided for them. The Maasai of Koyake must walk their cattle 200 km to the nearest market outside Nairobi.

The appropriate solutions to these land use problems depend on the desired development goal for the rangelands of the Mara. The three forms of land use that can be promoted are:

a) Agricultural development,

b) Pastoralist welfare with increased livestock production,

c) Tourism and wildlife conservation.

With careful planning and due consideration of Maasai attitudes a sustainable balance could be achieved between the three. Development plans of this type have already been put forward (Lewis R.W. 1965; Strickland 1973), but have not brought the required results. According to Jacobs (1975): "what has characterized most development in Maasailand is that particular innovation plans never made explicit their theory as to why and for what carefully considered reasons the plan was likely to succeed."

Tourism is probably the most economic form of land use in the Mara area but in order for tourism and conservation to continue the Maasai have to be more fully compensated for the use of their rangelands by wildlife. The Maasai of Koyake that were interviewed all believed that the integrity of the game reserve should be preserved because they were already, in theory, receiving the benefits of tourism in the form of rent payed to the ranch by two tourist lodges located on ranch land. The compensation approach has been tried with some success in the Amboseli National Park where remuneration rates were calculated from SRF data on wildlife densities in Maasai areas. As an alternative but very expensive solution to the wildebeest problem, suggested by the Maasai themselves, a game-proof fence could be constructed along the northern border of the reserve to keep the wildebeest away from the group ranches. However, 100,000 hungry wildebeest are a difficult force to stop and damage would also be caused to the fence by elephants and buffalos.

Few of the Maasai understood the concept of overgrazing. They attributed the lack of grass on Koyake to a 'lack of rain', clearly unsubstantiated, and to the wildebeest. Whilst they are prepared to accept the benefits of the reserve, they are unwilling to meet the costs - voluntary destocking and improved grazing management. Some of the more enlightened members of Koyake explained that the Maasai would sell more cattle if an accessible market was provided for them. At the same time the Maasai could be educated in smallholding agriculture which would enable more people to live on a fixed area of rangeland. The rainfall of 1000 mm is adequate and the soils are fertile.

Game cropping cannot be considered a viable alternative for the Mara rangelands. Such a scheme was attempted in the Serengeti in the early 1970s but it was found to be uneconomical to recruit meat inspectors and veterinary officers, and to run refrigerated trucks on poor roads. Furthermore, the Serengeti wildebeest migration is as much a resource to Tanzania as it is of Kenya, and game cropping might lead to disputes between the two countries.

Simon (1963) expressed the attitude of the Maasai to conservation thus: "The Maasai have long been the agency through which so much of East Africa's irreplaceable wildlife has been preserved ..... In recent years [however] Maasai tolerance of game has altered to scarcely veiled and mounting antagonism and, without their cooperation, wildlife cannot hope to survive. Maasai fears and suspicions would be largely overcome, and they would be more amenable to adopting measures designed to conserve their natural resources, if they were to receive firm guarantees regarding the future of their land, and if the tribe obtained an adequate financial inducement to conserve their fauna".

The 1978-1983 National Development Plan for Kenya (Kenya Govt. 1979) makes clear the Government's view of tourism and conservation; "Given the high priority afforded to an optimum land use strategy in national planning, it will be vital to ensure that the return from the tourism use of [natural] resources exceeds those from alternative uses in order to justify their continued existence".

It is not possible to put any price on the aesthetic value of the game reserve. As the finest wildlife area in Kenya its preservation is of national, if not international, importance. In order to relieve the land use pressure on the Mara a thorough reappraisal should be made of development plans for the area.

Fig. 10:1. The seasonal movements of the Serengeti and Loita (L) wildebeest populations in the Serengeti-Mara ecosystem (adapted from Maddock 1979; Stelfox et al 1980).

Fig. 10.2: a) wet season, and b) dry season distributions and densities of wildebeest in the rangelands of Narok District, determined from data gathered by the 11 KREMU SRF's of 1979. The numbers in the 10km grid squares refer to the mean seasonal density (animals.km^{-2}).

Fig. 10:3a). The monthly cattle biomass on Koyake Group Ranch in 1979, calculated from the 11 SRF's of that year. The bars represent ± 1S.E. (n = 40).

Aston University

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Fig. 10:3b). The monthly wildebeest biomass on Koyake Group Ranch in 1979.

Aston University

Illustration removed for copyright restrictions

Fig. 10:4a). A contour plot of cattle density applied to SRF data of 1979-80. The contours have been fitted to a 30 point systematic 10 km grid using GINO SURF contouring graphics.

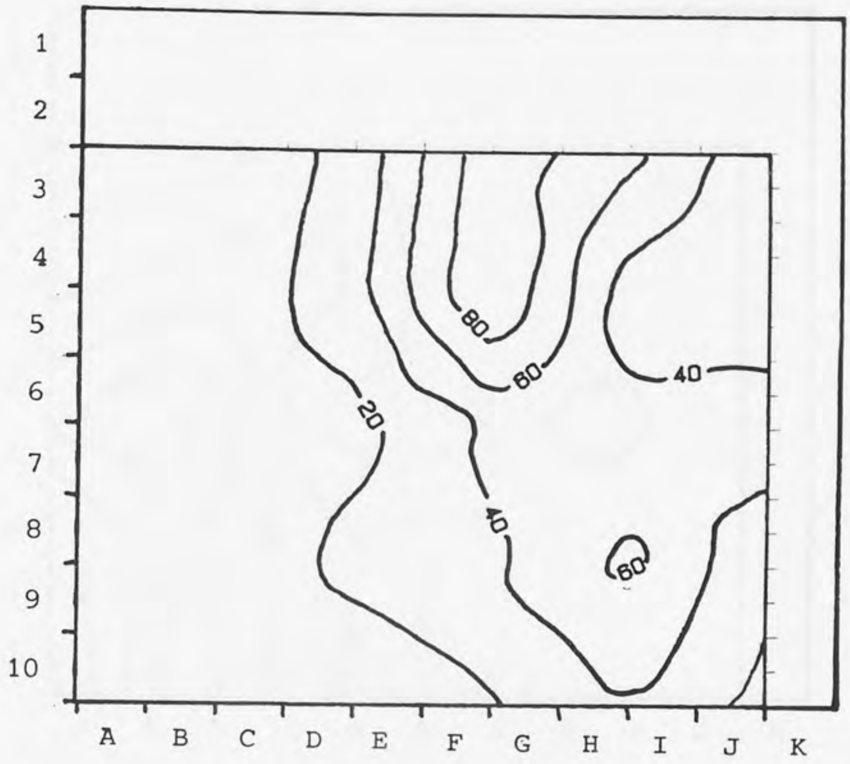

Fig. 10:4b). A contour plot of cattle density as predicted by the 1983 10 km Model 1. The contours have been fitted to a 36 point systematic 10 km grid.

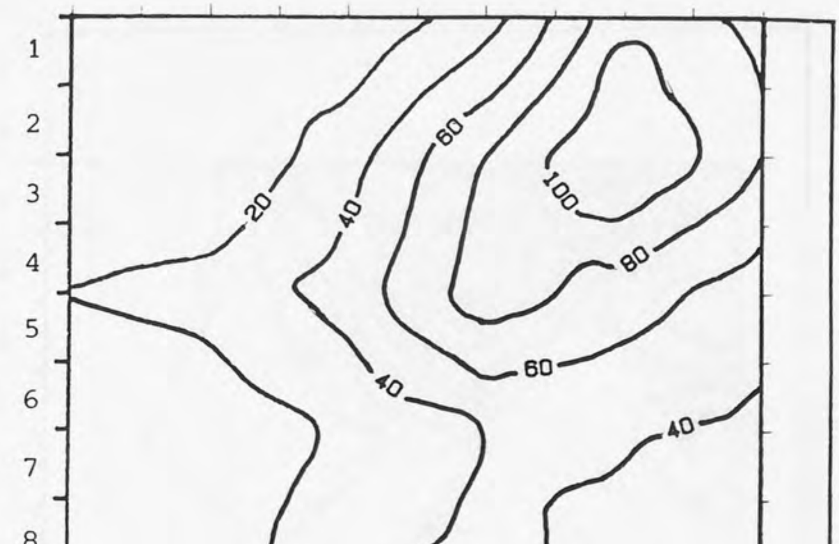

Fig. 10:5a). A contour plot of dry season wildebeest density (No.Km^{-2}) applied to SRF data of 1979-80.

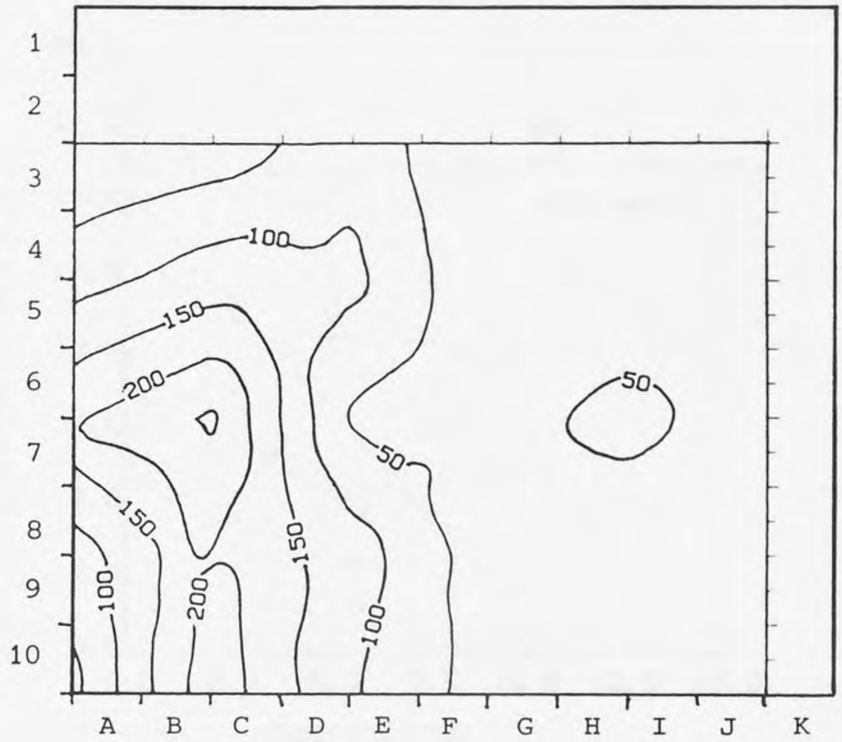

Fig. 10:5b). A contour plot of dry season cattle density (No.km^{-2}) applied to SRF data of 1979-80.

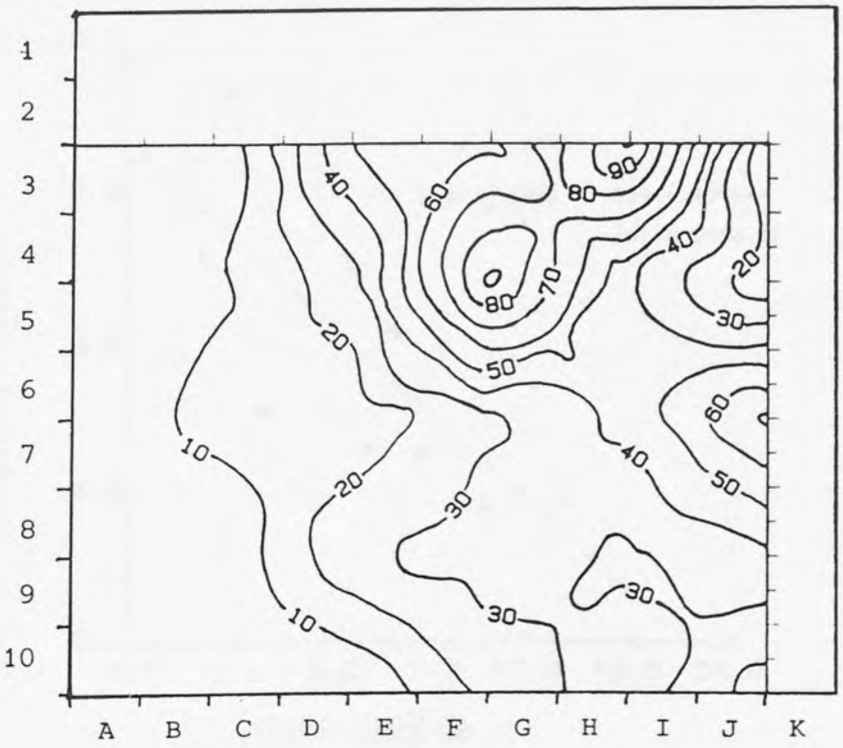

Fig. 10:6a). The relationship between the dry season cattle and wildebeest density for each 10 km block in Koyake Group Ranch. The best linearity has been achieved with a square root transformation on the density data, although satisfactory results were also obtained with a log. transform.

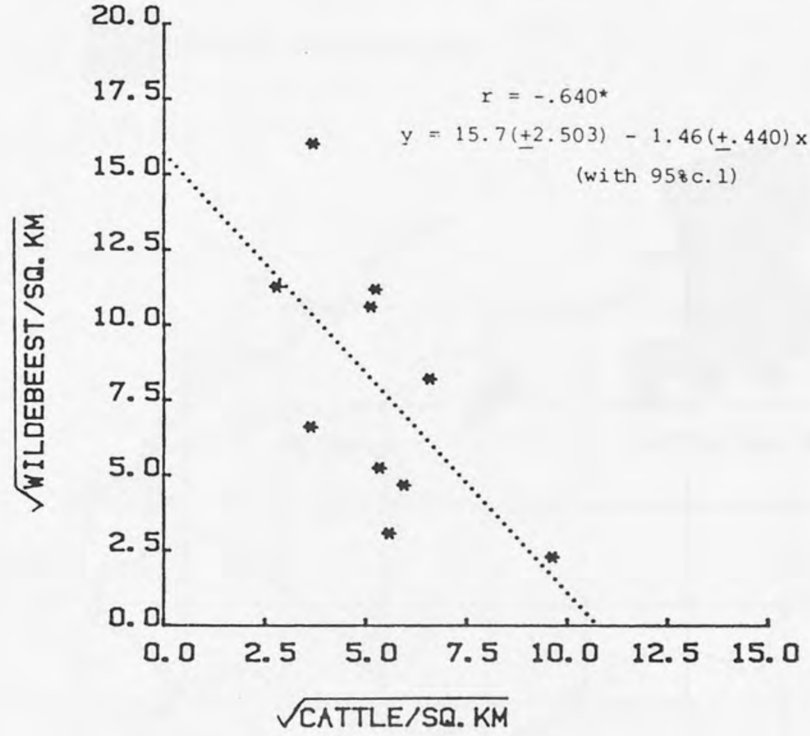

Fig. 10:6b). The relationship between the yearly cattle and wildebeest density for each 10 km block in Koyake Group Ranch.

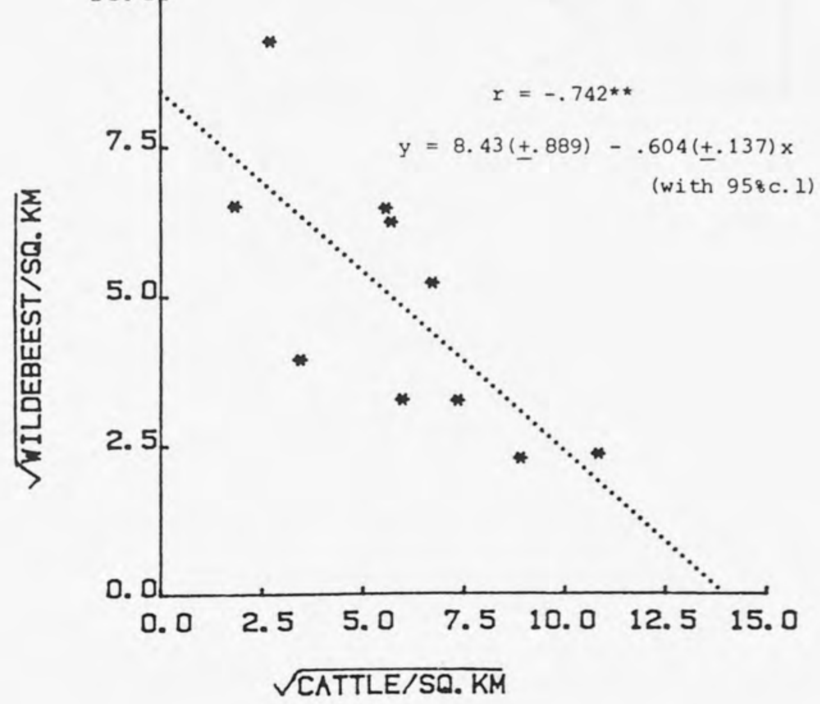

Fig. 10:7. The distribution of large-scale wheat cultivation in the Mara-Loita plains region in March 1984. The cultivation boundaries were mapped on the ground.

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Illustration removed for copyright restrictions

Table 10:1. Grazing and browsing large herbivore densities and biomass for the Mara ecological unit of Stelfox et al (1980). This unit includes most of the game reserve and therefore cattle densities are lower, and wildebeest densities higher than for Koyake Group Ranch. Data from Stelfox et al (1980).

Table 10:2. Estimates of the total wildebeest population and biomass density of Koyake Group Ranch, calculated from the 20 KREMU SRFs of 1979-82 using Jolly's Method 1 (Jolly 1969). Estimates have been corrected upwards by a factor of 1.33 according to the recommendations of Stelfox <u>et al</u> (1980). A mean wildebeest weight of 123 kg. is assumed (Watson 1972).

Table 10:3. a) Cattle densities and biomass, and b) wildebeest densities and biomass for the 10 10 km sampling blocks in Koyake Group Ranch. Data represent block-wise means from 11 1979 systematic reconnaissance flights by KREMU. A 4-month dry season (July-October) is assumed.

a) Cattle

	Yearly		Wet season		Dry season	
Block	No.km^{-2}	kg.km^{-2}	No.km^{-2}	kg.km^{-2}	No.km^{-2}	kg.km^{-2}
I	3.4	603	1.2	212	7.7	1386
II	32.4	5826	35.5	6390	26.1	4698
III	117.4	21132	129.9	23382	92.4	16632
IV	7.3	1305	4.1	743	13.5	2430
V	11.8	2131	11.2	2018	13.1	2358
VI	53.9	9696	66.6	11988	28.4	5112
VII	45.1	8113	46.1	8290	43.1	7758
VIII	30.9	5568	32.7	5886	27.4	4932
IX	35.7	6420	35.9	6462	35.2	6336
X	79.1	14232	103.1	18558	31.0	5580

b) Wildebeest

I	42.3	5302	0	0	126.9	15609
II	38.8	4772	2.0	246	112.4	13825
III	5.5	672	5.6	689	5.2	640
IV	85.7	10537	0	0	257.0	31611
V	15.5	1902	1.4	172	43.6	5363
VI	10.5	1287	2.0	246	27.4	3370
VII	27.1	3337	7.0	861	67.4	8290
VIII	41.7	5133	0.1	12	125.0	15375
IX	10.6	1304	5.0	615	21.8	2681
X	5.1	631	3.0	369	9.4	1156

Table 10:4. The association of wildebeest with cattle, settlements (1974 and 1983) and bushland on Koyake Group Ranch, tested using X^2 and Cole's coefficient of interspecific association (C.c.i.a). Calculated from the 11 SRF's in 1979.

	Wildebeest - wet season	Wildebeest - dry season
Cattle		
x^2	0.666	2.285
C.c.i.a.	-	-
Settlements 1974		
x^2	8.856**	5.248*
C.c.i.a	.203 ± .0678	-.228 ± .1081
Settlements 1983		
x^2	10.273**	6.109*
C.c.i.a.	.317 ± .0990	-.199 ± .0716
Bushland		
x^2	.065	3.63
C.c.i.a.	-	-

Cole's coefficients ± 1 S.E

CHAPTER 11: CONCLUSIONS

In this thesis a variety of monitoring techniques have been applied to the measurement of human and livestock-induced vegetation change in the Mara area. Two specific hypotheses were presented in Section 1.1 which were tested using ground sampling, systematic reconnaissance flight (SRF) and remote sensing methods. Settlement distributions and woodland cover changes were recorded from aerial photographs, livestock distributions from systematic reconnaissance flights, grassland status from LANDSAT imagery and tree age structures from ground sampling.

Both hypotheses in Section 1:1 relied on the accurate quantification of livestock grazing intensity, for which mathematical models were derived to determine grazing intensity from settlement distributions. Two mathematical models were described (see Chapter 5). In the first it was hypothesized that grazing resources were utilized equally in all areas within daily livestock range (10-15 km) of the manyatta. In the second it was suggested that grazing intensity increased towards the manyatta such that cattle density was proportional to the reciprocal of the distance to the manyatta. Both models were successfully tested against cattle densities as calculated from 20 KREMU systematic reconnaissance flights of 1979-1982. The reasons for the similarity of the two models was discussed. The models themselves have been shown to have a useful predictive value in terms of the calculation of stocking densities. For example, it has been calculated that with 600 cows per manyatta any area that is within 10 km range of more than 30 settlements is likely to be overstocked (Chapter 10).

In the following discussion of vegetation trends, reference should be made to the zones of the study area shown in Fig. 11:1.

Hypothesis 1 stated that woody vegetation cover in the Serengeti-Mara ecosystem had not declined as much in areas of high stocking density, and that in these areas tree recruitment was increased in comparison to those areas from which livestock were excluded. This hypothesis was supported by the observations of cover change from aerial photography (Chapter 7) and by the tree recruitment analysis (Chapter 8). However, there were some complex, community and area-specific patterns which emerged. It was shown in Chapter 7 that the cover of all communities, including the _Tarchonanthus_ type that occurs in the high Maasai density areas (Zone 1) declined over the period 1961-1967. Evidence was presented to indicate that this loss coincided with a period of increased rainfall and grass production, which enabled the Maasai to burn their grasslands more frequently, even in the high livestock density areas. After 1967 the _Tarchonanthus_ bushland recovered rapidly, but the _Acacia_-_Commiphora_ community that predominates in Zones 2, 3 and 4 continued to decline. Over the middle part of this century this vegetation type had been infested with tsetse flies and had shielded the southern part of the study area (Zones 2, 3 and 4) from Maasai occupation. With the destruction of the _Acacia_-_Commiphora_ community, tsetse flies disappeared from the Mara area. In the Olare Sambu area (Zone 2), which was soon invaded by Maasai, the cover of the _Acacia_-_Commiphora_ community has stabilized at 10-15% from its previous level of 30-40%.

The Enkikwe area (Zone 3) was completely opened up to grassland, but was then subjected to light-moderate livestock grazing pressure. In this area there has been a rapid increase in the cover of Acacia gerrardii, which forms single species stands. A. gerrardii can be considered as the main bush encroachment species and it was found that this species is regenerating only in those areas which were formally bushland. In the Mara area there has been very little shrub encroachment in edaphic grassland areas.

In the Maasai Mara National Reserve (Zone 4), from which livestock have been officially excluded for over 20 years, the Acacia-Commiphora community has declined completely to grassland. This grassland appears to be maintained by fires in the January-March period, by wildebeest damage to seedlings and by high levels of seedling predation by elephants (Dublin pers. comm.). A recent aerial survey has indicated that the elephant density in the Mara reserve is over twice that of the northern Serengeti area.

Hypothesis 2 in Section 1:1 stated that grass biomass and cover in areas of high livestock density were significantly lower throughout the year than in areas from which livestock were excluded. Using LANDSAT digital processing techniques it was found that the relative green biomass of an area is present in inverse proportion to the cattle density of the area. Stated somewhat differently, the cover of bare ground increases in direct proportion to the number of settlements within daily livestock range.

Over the course of this study it became clear that there was a high degree of intercorrelation between settlement distribution, cattle and wildebeest densities, grass biomass and tree recruitment. The Acacia-Commiphora community was shown to have a stable age structure in areas of moderate-high cattle densities (Zone 2). Grass biomass and cover are lower and it can be assumed that fire frequency and competition between trees and grass for water and nutrients is in turn reduced. The bushland persists or even increases and the wildebeest, which from recent research appear to have a major effect on seedling recruitment, avoid these areas. In the dry season they remain in the plains areas of Zones 3 and 4 where there is more available forage and an unobstructed view of predators (Talbot and Talbot 1963). Elephants are confined to the reserve area (Zone 4) and do not stray into the 'bush encroachment' areas (Zones 1 and 2). In the absence of dry season browse the elephants are selecting seedlings. Giraffe appear to be unaffected by human disturbance and are significantly associated with the Maasai areas where there is greater availability of browse (see Chapter 8).

Against this background it can be predicted that woodlands in the Maasai Mara National Reserve will be suppressed for many years to come. Recovery will only take place if there is a major ecological disturbance, such as the re-emergence of rinderpest. Rigorous fire and herbivore control programmes may prove effective in reducing the pressures inhibiting woodland growth, but on the other hand it may be more realistic to adopt a 'laissez-faire' approach and consider the reserve as a small part of a large ecosystem. It is clear that vegetation diversity cannot be 'forcibly' maintained in such a small area when it is affected by so many external factors.

With reference to the Serengeti, Norton-Griffiths (1979) believes that although conserved savanna areas show a high degree of instability, these areas show a "fine grained mosaic of successional changes, thus maximizing diversity, productivity and resilience of these systems". In this regard it can be argued that the stability of woodlands in areas of high livestock grazing pressure is suggestive of a less productive, more disturbed environment. However little work has been undertaken to compare the vegetation productivity of pastoral areas with corresponding conservation areas with the same climatic and soil conditions. It was suggested in Chapter 10 that grassland productivity was reduced in areas of high cattle density, and evidence was presented from the work of Onyeanusi (1983) to support this proposition. However, Onyeanusi erected only one livestock exclosure in an area of high cattle density, at Talek, and it might by argued that in some circumstances productivity may actually be increased in these areas. Thus Western (1982) suggests that although vegetation cover may be lower and erosion higher in areas of high livestock densities, overall productivity may be increased (if only over the short term), presumably by an accelerated turnover of nutrients. A programme of productivity monitoring is therefore urgently required to examine rates of grass and livestock production in areas of low and high stocking density.

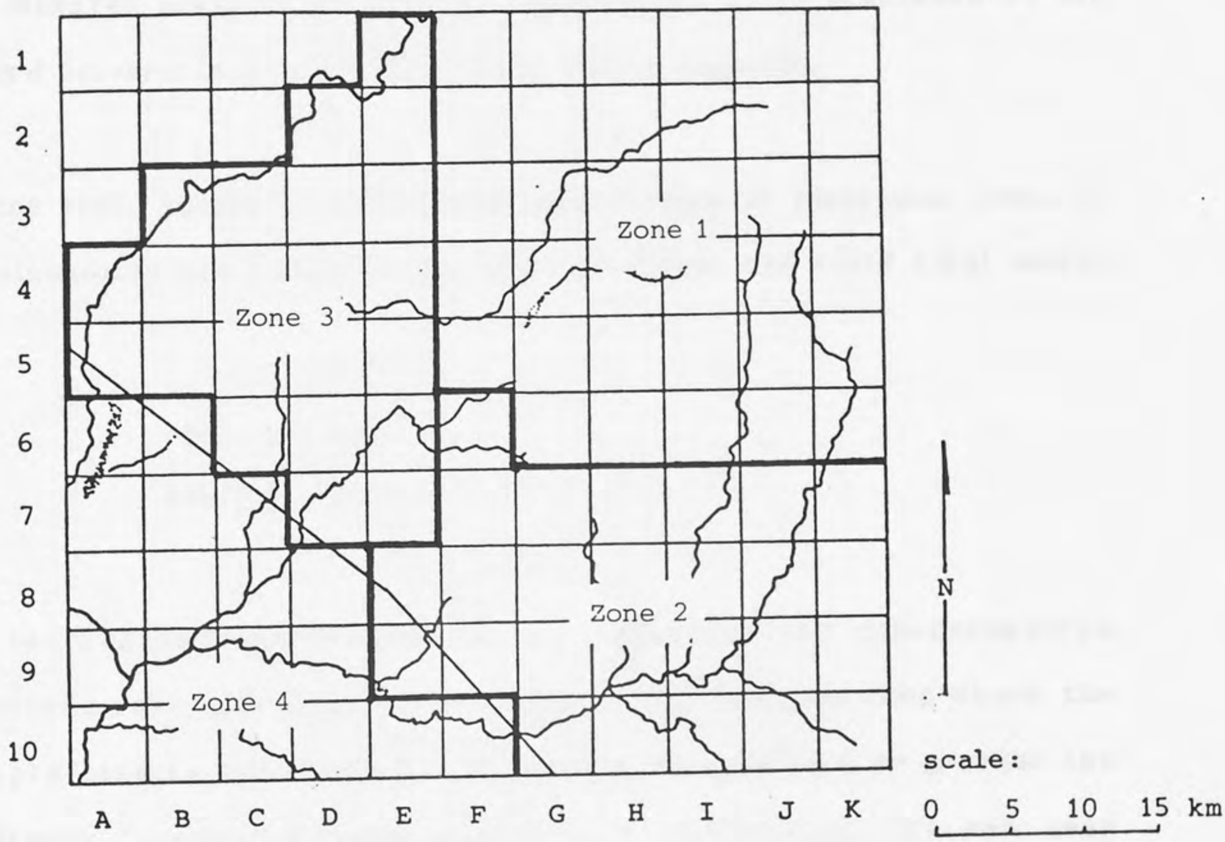
Over the past 15 years Maasai have been rapidly immigrating into the Mara at a rate of 7.5% per annum to make use of the increased area of tsetse-free grassland. In Chapter 10 it was shown that, according to theoretical estimates of carrying capacity, the study area cannot support the further influx of Maasai and their stock. The continuing immigration of Maasai into the area, resulting from the loss of grazing land to commercial, private and smallholdng agriculture will, over the next decade, place great pressure on the Maasai Mara National Reserve. With the regeneration ('bush encroachment') of Acacia gerrardii in the Maasai areas, tsetse flies are increasing. A situation such as this emphasizes the need not only for the long term monitoring of human herbivore and vegetation distributions in African savannas, but for the political will to implement recommendations resulting from the monitoring process.

In this project satellite imagery has proved useful in testing the validity of the grazing models. If in the future satellite remote sensing is to be more fully integrated into rangeland monitoring programmes, a number of improvements are urgently required in the procedure of data acquisition and processing. Imagery must be obtained in synchrony with regular SRF livestock surveys and with aerial photography of settlement and land-use patterns. In the study a major difficulty in mapping grass biomass, which was discussed in detail in Chapter 9, has involved the quantification of biomass classes. Without sufficient 'ground truthing' in 1975, the year of the three images used in this project, the LANDSAT-derived estimates of grass biomass can only be considered relative within each image. Long-term programmes of ground monitoring (which may not necessarily be expensive to implement) are therefore needed to calibrate the remote sensing system to obtain empirical estimates of plant biomass.

Further research is also required into the use of NOAA imagery, which, with a 1.1 km resolution and a one day repetitive coverage, shows great promise as a vegetation monitoring tool

(Townshend and Tucker 1981). The far infrared wavebands of the LANDSATs 4 and 5 thematic mappers may also provide much additional useful information on vegetation distribution and condition. At the 'simple' end of the technological scale spectroradiometers ('green machines') could be incorporated into SRF programmes. These devices offer a less-flexible but low cost alternative to satellite remote sensing. However, only when the potential and cost-effectiveness of satellite and other forms of remote sensing have been explored will it be possible to use remote sensing as a continuous rangeland montoring system, rather than for a series of 'one-off' studies.

Fig. 11:1. Zones of the study area with specific human impact and vegetation response. Figure required for text explanation.



APPENDIX A

Statistical Conventions Used in the Text

Much of the data analysis in this thesis has been carried out using the MINITAB statistical package (Ryan *et al* 1981) available on the Oxford University Zoology Department PDP-11 computer.

In the text, levels of statistical significance of particular tests or relationships are indicated by asterisks (Sokal and Rohlf 1969) where:

* : $p < 0.05$
** : $p < 0.01$
*** : $p < 0.001$

In testing the correlation of two variables the non-parametric Spearman rank correlation coefficient (r_s) has been used where the sample size is less than 9. If the sample size is 9 or greater the ordinary (product-moment) correlation coefficient (r) has been employed, since r_s then approximates to r (Siegal 1956).

APPENDIX B

The Construction of the 3-dimensional Topographic Map

The 3-dimensional topographic map in Fig. 1:3 was prepared using the ISOPRJ routine in the GINO-SURF graphics package (CADS 1976). This construction was undertaken on the University of Oxford VAX mainframe computer and the FORTRAN program was kindly written by Steve Legge of the Oxford University Computing Centre. Initially a data file was set up incorporating spot heights for 550 grid intersections of a 1 km UTM projection of the study area. The south western corner of the study area was specified as the 0,0 coordinate of a cartesian plot. Heights were available from the 1:50,000 topographic maps of the study area, with 20 m contour intervals. In the data file (KENYA3.DAT) a particular spot height was specified, and the number of grid intersections at that spot height was entered. This was followed by the X and Y coordinates of the intersections, e.g. :

```
 2000
    4
50 40
51 40
55 42
45 43
etc.
```

In general, 100 m intervals were selected (e.g. 1800 m, 1900 m), although a number of mid-intervals (e.g. 1820 m, 1840 m) had to be employed to 'suppress' the topography in certain areas. The FORTRAN program is shown overleaf: the emphasis on height (the Z axis) could be altered by changing the HEIRAT parameter, and the direction from which the study area was viewed could be changed by manipulating parameters in the CALL ISOPRJ statement. The representation was initially tested on a Tectronix 1040 graphics terminal and was finally printed on a Calcomp C1051 plotter.

APPENDIX B (cotd.)

```
      PROGRAM KENYA
      DIMENSION SPOTSX(550),SPOTSY(550),SPOTSZ(550),AZ(56,51),W(10000)
      OPEN(7,FILE='KENYA3.DAT',STATUS='OLD')
      IPTR=1
      DO WHILE(.TRUE.)
        READ(7,*,END=100)CONT
        TYPE *,CONT
        READ(7,*)NPOINTS
        DO I=1,NPOINTS
          READ(7,*)SPOTSX(IPTR),SPOTSY(IPTR)
          SPOTSZ(IPTR)=CONT
          IPTR=IPTR+1
        END DO
      END DO
100   CALL CC1051
      TYPE *,'NPOINTS=',IPTR-1
      CALL PICCLE
      CALL RANGRD(549,SPOTSX,SPOTSY,SPOTSZ,56,0.,55.,
     & 51,0.,50.,AZ,10000,W)
      CALL HEIRAT(.220)
      CALL ISOPRJ(56,0.,55.,51,0.,50.,AZ,1,10000,W)
      CALL DEVEND
      STOP
      END
```

APPENDIX C

: The mean monthly rainfall (mm) for seven rainguage stations in the Mara area. The mean monthly potential evaporation (E_o:mm) and airtemperature (°C) are shown for Narok.

Station	Years of records for this analysis	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
Aitong	1971-81	105.8	96.0	119.0	154.0	108.0	47.5	59.0	48.3	61.6	35.3	61.8	81.5	977.8
Keekorok	1966-81	103.5	84.0	115.9	145.7	98.1	78.3	62.5	58.1	68.4	42.9	64.7	109.4	1031.5
Ololunga	1973-81	58.1	81.8	120.2	144.0	63.9	25.3	37.5	30.5	46.1	24.7	53.7	60.3	746.1
Lemek	1968-81	86.8	72.2	80.3	109.4	75.2	46.2	55.9	30.5	49.4	28.0	37.2	45.6	716.7
Governor's Camp	1974-81	100.6	101.7	173.6	187.0	89.7	91.0	67.2	52.2	66.5	39.4	86.4	114.4	1169.7
Mara Serena.	1974-78	178.0	109.3	198.0	166.3	146.1	88.6	83.5	58.8	114.4	51.1	79.0	95.6	1368.7
Narok	1914-1932[a] 1938-1982	76.3	77.4	102.3	146.6	96.2	27.9	16.8	21.3	25.0	26.5	64.8	70.6	751.7
Narok (E_o)[b]		149	148	156	127	122	113	112	122	143	157	142	147	1638
Narok (°C)[b]		17.4	17.3	17.5	17.7	17.0	15.5	14.7	15.2	15.9	16.7	16.6	16.7	

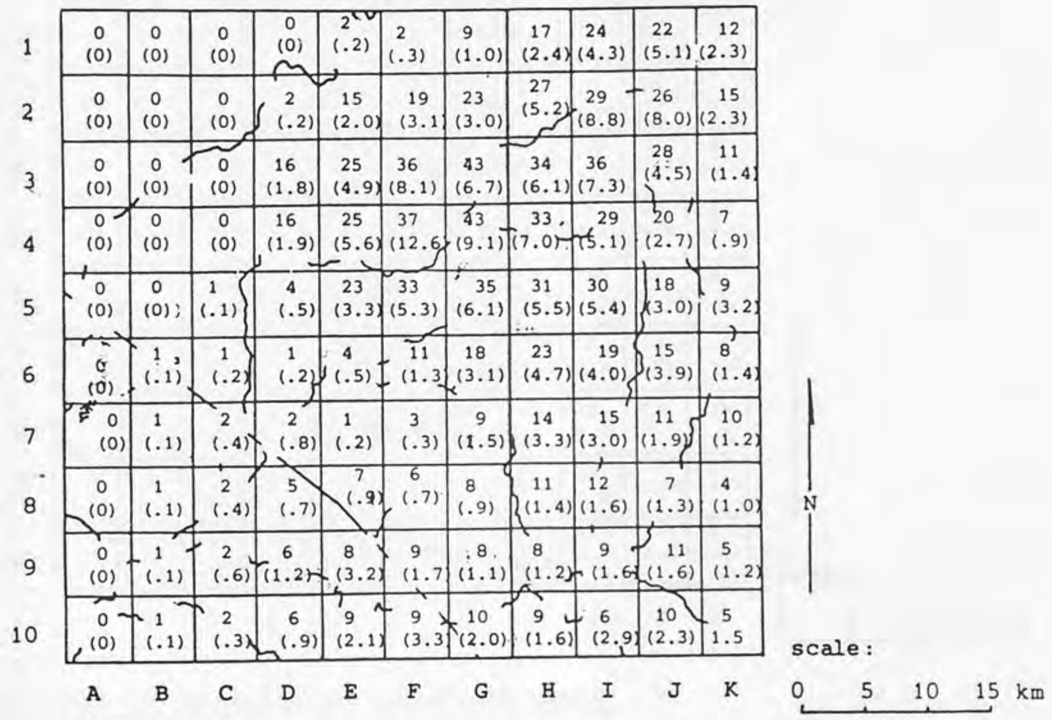
[a] : Monthly rainfall of 1933-37 were missing from the records of the East African Meteorological Dept. in Nairobi. Annual rainfall for these years are given by Glover (1966).

[b] : Data from Woodhead (1968)

APPENDIX D

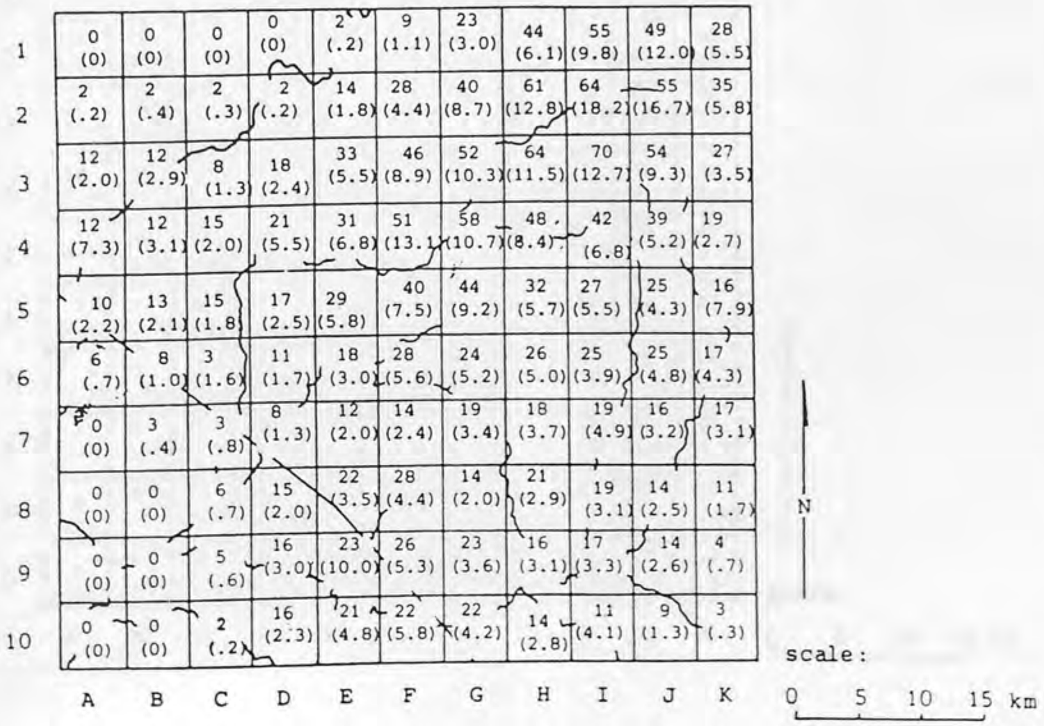
The index values for the 1974 Models 1 and 2 that assume a maximum livestock range of a) 10 km and b) 15 km. The unbracketed numbers are the Model 1 index values, i.e. the number of manyattas within the specified maximum livestock range of the centre of the 5 km grid cell. The bracketed numbers are the Model 2 index values, i.e. the summed reciprocals of the distances of manyattas within the specified maximum livestock range of the centre of the grid cell. The index values around the periphery of the study area may not be accurate because the settlement distribution beyond the borders of the study area is unknown.

a).1974 10 km maximum livestock range



	A	B	C	D	E	F	G	H	I	J	K
1	0 (0)	0 (0)	0 (0)	0 (0)	2 (.2)	2 (.3)	9 (1.0)	17 (2.4)	24 (4.3)	22 (5.1)	12 (2.3)
2	0 (0)	0 (0)	0 (0)	2 (.2)	15 (2.0)	19 (3.1)	23 (3.0)	27 (5.2)	29 (8.8)	26 (8.0)	15 (2.3)
3	0 (0)	0 (0)	0 (0)	16 (1.8)	25 (4.9)	36 (8.1)	43 (6.7)	34 (6.1)	36 (7.3)	28 (4.5)	11 (1.4)
4	0 (0)	0 (0)	0 (0)	16 (1.9)	25 (5.6)	37 (12.6)	43 (9.1)	33 (7.0)	29 (5.1)	20 (2.7)	7 (.9)
5	0 (0)	0 (0)	1 (.1)	4 (.5)	23 (3.3)	33 (5.3)	35 (6.1)	31 (5.5)	30 (5.4)	18 (3.0)	9 (3.2)
6	0 (0)	1 (.1)	1 (.2)	1 (.2)	4 (.5)	11 (1.3)	18 (3.1)	23 (4.7)	19 (4.0)	15 (3.9)	8 (1.4)
7	0 (0)	1 (.1)	2 (.4)	2 (.8)	1 (.2)	3 (.3)	9 (1.5)	14 (3.3)	15 (3.0)	11 (1.9)	10 (1.2)
8	0 (0)	1 (.1)	2 (.4)	5 (.7)	7 (.9)	6 (.7)	8 (.9)	11 (1.4)	12 (1.6)	7 (1.3)	4 (1.0)
9	0 (0)	1 (.1)	2 (.6)	6 (1.2)	8 (3.2)	9 (1.7)	8 (1.1)	8 (1.2)	9 (1.6)	11 (1.6)	5 (1.2)
10	0 (0)	1 (.1)	2 (.3)	6 (.9)	9 (2.1)	9 (3.3)	10 (2.0)	9 (1.6)	6 (2.9)	10 (2.3)	5 1.5

b). 1974 15 km maximum livestock range

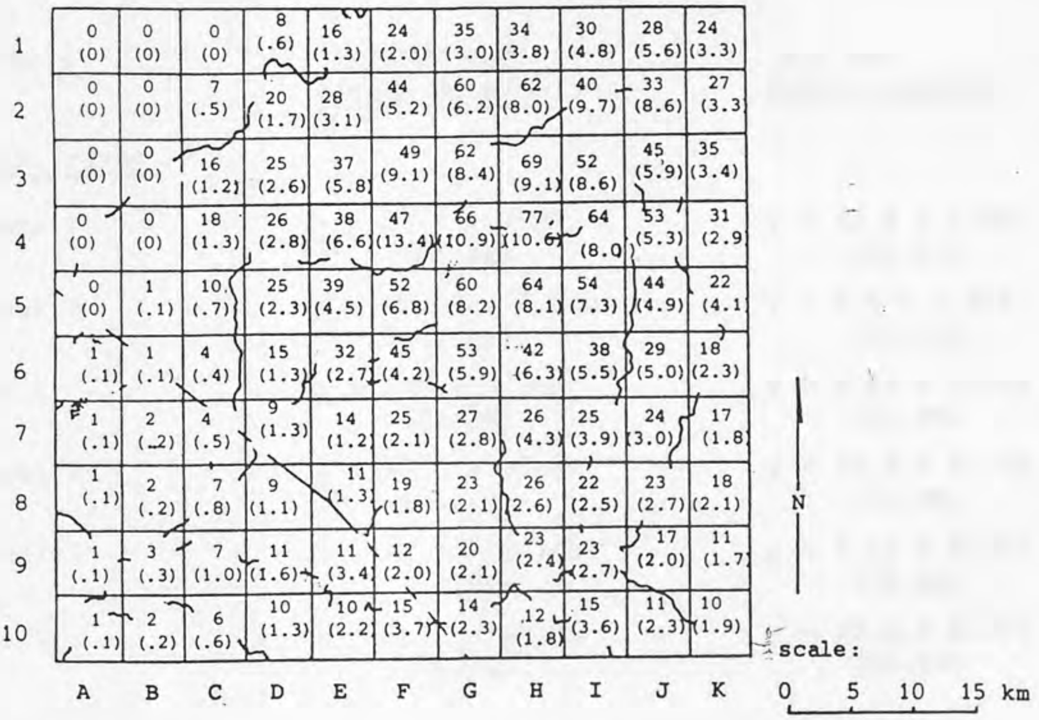


	A	B	C	D	E	F	G	H	I	J	K
1	0 (0)	0 (0)	0 (0)	0 (0)	2 (.2)	9 (1.1)	23 (3.0)	44 (6.1)	55 (9.8)	49 (12.0)	28 (5.5)
2	2 (.2)	2 (.4)	2 (.3)	2 (.2)	14 (1.8)	28 (4.4)	40 (8.7)	61 (12.8)	64 (18.2)	55 (16.7)	35 (5.8)
3	12 (2.0)	12 (2.9)	8 (1.3)	18 (2.4)	33 (5.5)	46 (8.9)	52 (10.3)	64 (11.5)	70 (12.7)	54 (9.3)	27 (3.5)
4	12 (7.3)	12 (3.1)	15 (2.0)	21 (5.5)	31 (6.8)	51 (13.1)	58 (10.7)	48 (8.4)	42 (6.8)	39 (5.2)	19 (2.7)
5	10 (2.2)	13 (2.1)	15 (1.8)	17 (2.5)	29 (5.8)	40 (7.5)	44 (9.2)	32 (5.7)	27 (5.5)	25 (4.3)	16 (7.9)
6	6 (.7)	8 (1.0)	3 (1.6)	11 (1.7)	18 (3.0)	28 (5.6)	24 (5.2)	26 (5.0)	25 (3.9)	25 (4.8)	17 (4.3)
7	0 (0)	3 (.4)	3 (.8)	8 (1.3)	12 (2.0)	14 (2.4)	19 (3.4)	18 (3.7)	19 (4.9)	16 (3.2)	17 (3.1)
8	0 (0)	0 (0)	6 (.7)	15 (2.0)	22 (3.5)	28 (4.4)	14 (2.0)	21 (2.9)	19 (3.1)	14 (2.5)	11 (1.7)
9	0 (0)	0 (0)	5 (.6)	16 (3.0)	23 (10.0)	26 (5.3)	23 (3.6)	16 (3.1)	17 (3.3)	14 (2.6)	4 (.7)
10	0 (0)	0 (0)	2 (.2)	16 (2.3)	21 (4.8)	22 (5.8)	22 (4.2)	14 (2.8)	11 (4.1)	9 (1.3)	3 (.3)

APPENDIX D (cotd.)

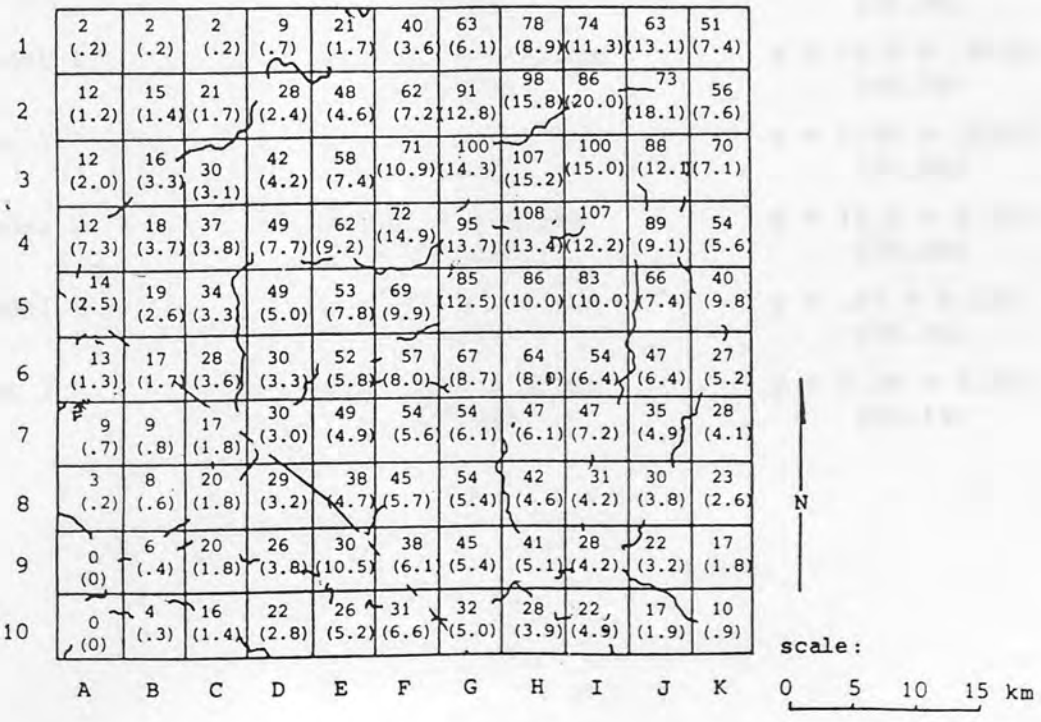
The index values for the 1983 Models 1 and 2 that assume a maximum livestock range of a) 10 km and b) 15 km.

a). 1983 10 km maximum livestock range



	A	B	C	D	E	F	G	H	I	J	K
1	0 (0)	0 (0)	0 (0)	8 (.6)	16 (1.3)	24 (2.0)	35 (3.0)	34 (3.8)	30 (4.8)	28 (5.6)	24 (3.3)
2	0 (0)	0 (0)	7 (.5)	20 (1.7)	28 (3.1)	44 (5.2)	60 (6.2)	62 (8.0)	40 (9.7)	33 (8.6)	27 (3.3)
3	0 (0)	0 (0)	16 (1.2)	25 (2.6)	37 (5.8)	49 (9.1)	62 (8.4)	69 (9.1)	52 (8.6)	45 (5.9)	35 (3.4)
4	0 (0)	0 (0)	18 (1.3)	26 (2.8)	38 (6.6)	47 (13.4)	66 (10.9)	77 (10.6)	64 (8.0)	53 (5.3)	31 (2.9)
5	0 (0)	1 (.1)	10 (.7)	25 (2.3)	39 (4.5)	52 (6.8)	60 (8.2)	64 (8.1)	54 (7.3)	44 (4.9)	22 (4.1)
6	1 (.1)	1 (.1)	4 (.4)	15 (1.3)	32 (2.7)	45 (4.2)	53 (5.9)	42 (6.3)	38 (5.5)	29 (5.0)	18 (2.3)
7	1 (.1)	2 (.2)	4 (.5)	9 (1.3)	14 (1.2)	25 (2.1)	27 (2.8)	26 (4.3)	25 (3.9)	24 (3.0)	17 (1.8)
8	1 (.1)	2 (.2)	7 (.8)	9 (1.1)	11 (1.3)	19 (1.8)	23 (2.1)	26 (2.6)	22 (2.5)	23 (2.7)	18 (2.1)
9	1 (.1)	3 (.3)	7 (1.0)	11 (1.6)	11 (3.4)	12 (2.0)	20 (2.1)	23 (2.4)	23 (2.7)	17 (2.0)	11 (1.7)
10	1 (.1)	2 (.2)	6 (.6)	10 (1.3)	10 (2.2)	15 (3.7)	14 (2.3)	12 (1.8)	15 (3.6)	11 (2.3)	10 (1.9)

b). 1983 15 km maximum livestock range



	A	B	C	D	E	F	G	H	I	J	K
1	2 (.2)	2 (.2)	2 (.2)	9 (.7)	21 (1.7)	40 (3.6)	63 (6.1)	78 (8.9)	74 (11.3)	63 (13.1)	51 (7.4)
2	12 (1.2)	15 (1.4)	21 (1.7)	28 (2.4)	48 (4.6)	62 (7.2)	91 (12.8)	98 (15.8)	86 (20.0)	73 (18.1)	56 (7.6)
3	12 (2.0)	16 (3.3)	30 (3.1)	42 (4.2)	58 (7.4)	71 (10.9)	100 (14.3)	107 (15.2)	100 (15.0)	88 (12.1)	70 (7.1)
4	12 (7.3)	18 (3.7)	37 (3.8)	49 (7.7)	62 (9.2)	72 (14.9)	95 (13.7)	108 (13.4)	107 (12.2)	89 (9.1)	54 (5.6)
5	14 (2.5)	19 (2.6)	34 (3.3)	49 (5.0)	53 (7.8)	69 (9.9)	85 (12.5)	86 (10.0)	83 (10.0)	66 (7.4)	40 (9.8)
6	13 (1.3)	17 (1.7)	28 (3.6)	30 (3.3)	52 (5.8)	57 (8.0)	67 (8.7)	64 (8.0)	54 (6.4)	47 (6.4)	27 (5.2)
7	9 (.7)	9 (.8)	17 (1.8)	30 (3.0)	49 (4.9)	54 (5.6)	54 (6.1)	47 (6.1)	47 (7.2)	35 (4.9)	28 (4.1)
8	3 (.2)	8 (.6)	20 (1.8)	29 (3.2)	38 (4.7)	45 (5.7)	54 (5.4)	42 (4.6)	31 (4.2)	30 (3.8)	23 (2.6)
9	0 (0)	6 (.4)	20 (1.8)	26 (3.8)	30 (10.5)	38 (6.1)	45 (5.4)	41 (5.1)	28 (4.2)	22 (3.2)	17 (1.8)
10	0 (0)	4 (.3)	16 (1.4)	22 (2.8)	26 (5.2)	31 (6.6)	32 (5.0)	28 (3.9)	22 (4.9)	17 (1.9)	10 (.9)

APPENDIX E

Table giving the least-squares linear regressions of grazing model index values (predictor variables) and the SRF cattle density estimates (cattle.km^{-2}). The figures in brackets are the values of R^2 for the relationships.

	parameter x	
parameter y	1979-80 SRF cattle density	All SRF cattle density
10 km max. range		
1974 Model 1	y = 11.7 + 2.37x (81.5%)	y = 16.5 + 1.56x (85.8%)
1983 Model 1	y = -7.93 + 2.22x (77.3%)	y = 4.6 + 1.41x (76.1%)
MV Model 1	y = .45 + 2.36x (81.8%)	y = 9.53 + 1.53x (83.2%)
1974 Model 2	y = 16.0 + 10.3x (76.1%)	y = 19.7 + 6.64x (76.9%)
1983 Model 2	y = -1.8 + 9.79x (72.0%)	y = 7.11 + 6.56x (78.8%)
MV Model 2	y = 5.97 + 10.3x (76.2%)	y = 12.8 + 6.79x (80.1%)
15 km max. range		
1974 Model 1	y = .36 + 1.57x (76.9%)	y = 9.92 + .993x (75.4%)
1983 Model 1	y = -19.8 + 1.30x (66.2%)	y = -3.0 + .829x (65.3%)
MV model 1	y = -11.3 + 1.44x (72.1%)	y = 2.46 + .916x (70.9%)
1974 Model 2	y = 8.54 + 9.28x (80.1%)	y = 15.0 + 5.91x (79.2%)
1983 Model 2	y = -11.7 + 8.32x (72.4%)	y = .67 + 5.54x (78.3%)
MV Model 2	y = -2.84 + 8.92x (77.4%)	y = 7.18 + 5.81x (80.1%)

APPENDIX F

Some results of a computer simulation of the dot-grid technique for estimating woody vegetation cover (see Chapter 7). In this simulation a 'woodland' of randomly located 'trees' (of preset % cover) was superimposed on an artificial grid of 81 sytematically positioned 'dots' within a one hectare plot. The distance between trees and dots was measured by Pythagoras' theorem. 'Cover' is expressed as the percentage of the total number of dots (81) that are touching a tree or trees. The preset cover, the dot size and the tree size could be altered. In Fig.a) the cover is preset at 10% and the trees at 4 m; the dot size is altered to determine how the cover estimate changes with changing dot size. In Fig.b) the cover is preset at 10% and the dot size at 2.5 m; the treesize is altered to determine how the cover estimate changes with changing tree size. In this case the cover estimate follows an inverse relationship with respect to tree size. The bars represent ± 1.S.E. for n = 5 (5 cover estimates were made for each set of input parameters). The computations were performed using an Apple II microcomputer programmed in BASIC.

Fig.a)

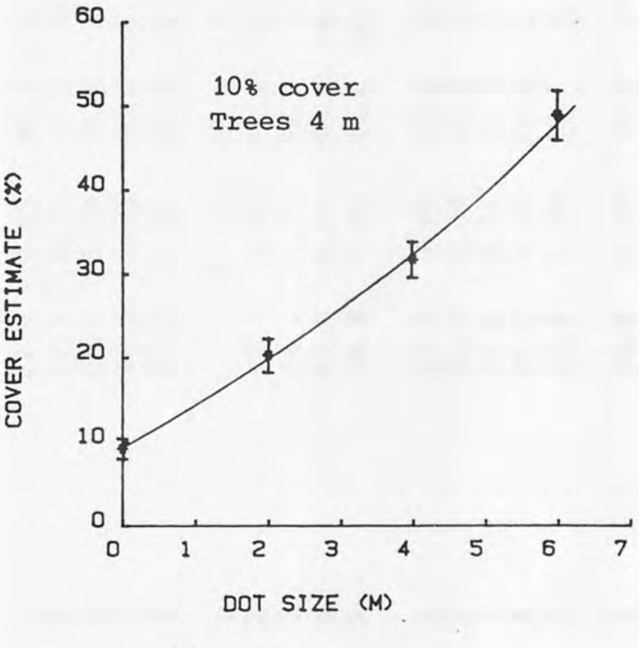
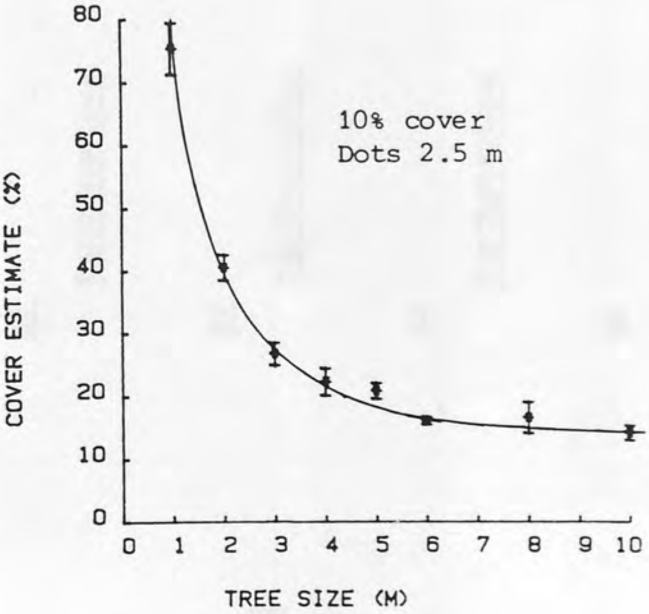


Fig.b)



APPENDIX G

Woodland cover (%) (± 95% confidence limits) from 1950 to 1983, as determined from the dot-grid analysis of the 5 sets of aerial photography.

5km block and vegetation type.	Sample point number	1950		1961		1967		1974		1983	
		%	95%c.l	%	95%c.l	%	95%c.l	%	95%c.l	%	95%c.l
<u>I5</u>	1	62.4	± 3.85	40.8	± 8.42	20.0	± 4.17	29.3	± 4.54	47.3	± 9.04
	2	37.1	3.31	33.5	8.53	25.7	3.85	29.3	5.31	31.0	9.56
<u>Tarchonanthus</u>	3	50.6	5.79	55.1	4.75	29.0	3.31	33.8	9.04	39.2	8.30
	4	44.1	5.26	41.6	6.84	22.9	4.16	28.9	4.37	32.7	7.40
	5	47.8	5.84	51.8	5.84	37.1	7.04	41.8	7.67	38.4	5.79
<u>H3</u>	1	–[a]		80.0	4.88	42.4	6.26	56.4	7.96	68.2	6.37
	2	47.3	4.88	72.2	7.31	35.1	5.50	38.2	7.67	53.5	4.54
<u>Tarchonanthus</u>	3	44.1	7.74	58.0	7.94	40.4	7.70	45.3	9.29	53.5	4.64
	4	55.5	6.57	58.0	6.06	22.0	4.10	31.1	6.48	35.5	7.53
	5	38.4	7.90	41.2	10.67	23.7	6.62	36.4	6.05	33.9	5.26
F2	1	15.5	3.85	12.2	3.59	9.0	2.89	18.2	5.99	33.9	6.62
	2	22.4	4.39	18.4	3.11	14.7	2.78	33.3	3.91	47.8	7.31
<u>Tarchonanthus</u>	3	42.9	4.01	45.3	3.76	29.0	3.76	48.4	9.85	37.1	6.81
	4	35.0	3.42	29.4	5.84	31.8	8.53	29.8	5.39	28.6	4.75
	5	18.4	2.54	15.1	6.86	9.0	5.26	10.2	4.19	9.0	3.85
D2	1	18.0	4.17	18.4	4.01	11.8	2.12	11.1	3.38	11.8	3.31
	2	14.7	5.20	23.7	4.25	14.3	4.01	14.2	5.72	7.3	1.39
<u>Tarchonanthus</u>	3	23.3	2.27	29.4	3.40	18.8	2.12	20.4	5.31	10.6	2.78
	4	29.8	5.84	46.9	7.82	27.3	4.61	24.4	3.38	11.0	3.40
	5	16.7	5.50	35.1	5.49	25.7	5.26	19.6	3.03	15.9	4.88

[a]: vegetation obscured by hill shadow.

APPENDIX G (cotd.)

Woodland cover (%) (± 95% confidence limits) from 1950 to 1983, as determined from the dot-grid analysis of the 5 sets of aerial photography.

5km block and		1950		1961		1967		1974		1983	
vegetation type.	Sample point number	%	95%c.l	%	95%c.l	%	95%c.l	%	95%c.l	%	95%c.l
I9	1	42.9	± 9.49	32.2	± 7.48	17.1	± 2.89	22.2	± 6.77	22.9	± 4.88
	2	46.5	± 9.73	40.4	7.70	15.5	3.11	14.2	4.62	17.6	7.53
Acacia-Commiphora	3	58.4	7.74	55.9	9.08	22.0	4.81	23.1	5.02	20.0	5.50
	4	44.1	9.66	34.7	5.95	14.7	1.53	22.7	3.03	22.0	9.39
	5	16.7	4.88	23.7	4.12	15.5	2.04	18.7	4.19	17.1	3.48
J7	1	*		75.5	8.02	35.9	9.92	25.8	2.47	21.6	1.39
	2	*		74.3	4.61	26.1	2.78	10.7	2.31	8.1	2.54
Acacia-Commiphora	3	*		55.5	3.31	20.4	1.79	9.8	2.47	4.5	3.31
	4	*		42.4	9.56	20.0	3.76	13.8	4.94	8.6	5.20
	5	*		51.8	10.85	23.7	2.27	20.9	4.62	15.1	1.39
E7	1	27.3	4.61	9.0	4.94	2.0	2.54	8.4	2.31	30.2	5.50
	2	22.0	5.20	13.9	5.23	5.0	2.89	10.7	3.60	24.1	6.57
Acacia-Commiphora	3	29.0	5.50	20.0	6.81	9.4	1.39	8.9	4.37	3.3	3.40
	4	35.1	4.54	20.8	2.12	12.2	2.54	7.1	1.24	3.3	1.39
	5	34.3	4.17	42.4	5.79	19.6	3.40	6.7	2.76	0	
B5	1	30.2	8.68	11.0	1.47	5.7	2.12	0		0	
Acacia-Commiphora	2	15.9	7.70	17.6	4.61	5.7	1.14	0		0	
with transition to	3	49.4	4.88	29.0	5.20	12.2	2.54	.9	1.51	19.2	4.25
Acacia gerrardii on	4	31.0	4.88	26.5	4.01	6.1	2.54	.9	1.51	24.9	4.54
points 4 and 5.	5	24.1	4.17	19.6	6.62	7.8	2.12	2.2	1.95	26.9	3.31

*: Dot-grid analysis not undertaken because of poor quality of these 1950 photographs.

APPENDIX G (cotd.)

Woodland cover (%)(± 95% confidence limits) from 1950 to 1983, as determined from the dot-grid analysis of the 5 sets of aerial photography.

5km block and vegetation type.	Sample point number	1950		1961		1967		1974		1983	
		%	95%c.1	%	95%c.1	%	95%c.1	%	95%c.1	%	95%c.1
C5	1	13.5	± 4.25	23.7	± 4.61	7.8	± 2.78	1.3	± 1.51	0	
Acacia-Commiphora	2	13.5	2.27	19.6	3.85	9.4	2.89	3.1	3.15	1.2	1.39
with transition to	3	13.7	4.95	23.7	5.84	9.0	2.89	.9	1.51	0	
Acacia gerrardii on	4	8.6	1.14	15.5	4.25	7.8	1.14	17.3	1.69	31.0	4.88
points 3, 4 and 5.	5	22.4	4.01	26.5	7.40	7.3	2.91	12.0	1.51	24.1	2.78
B3	1	28.2	6.55	18.8	4.17	9.4	2.27	6.2	1.23	38.8	1.79
Acacia-Commiphora	2	27.3	6.86	17.1	3.40	11.0	2.89	8.9	3.91	31.0	4.88
with transition to	3	18.0	3.76	23.3	5.84	13.1	4.25	6.2	2.31	1.2	2.27
Acacia gerrardii on	4	22.0	5.50	20.4	5.95	15.9	6.57	9.3	2.31	.8	1.39
points 1 and 2.	5	15.1	5.84	25.7	8.14	18.0	6.60	11.6	5.31	2.9	2.89
E9	1	24.9	5.77	15.1	4.00	8.2	2.67	6.9	3.27	3.2	2.57
	2	53.5	7.88	19.4	4.51	10.2	1.60	3.6	2.69	1.3	1.40
Acacia-Commiphora	3	41.2	4.16	10.6	5.59	5.1	2.41	2.4	3.06	.7	1.22
	4	29.4	8.78	42.4	7.54	13.0	2.53	7.8	4.39	6.3	2.79
	5	26.5	3.10	47.0	6.05	17.4	4.51	15.6	5.34	20.0	4.22
B10	1	10.6	3.30	21.6	4.27	8.3	2.56	2.9	.95	0	
Acacia-Commiphora	2	18.8	3.30	22.3	3.90	6.9	2.09	.3	.95	0	
now cleared to	3	20.8	7.02	18.0	5.05	7.6	3.36	1.2	2.11	0	
grassland.	4	20.8	4.53	15.5	4.41	4.3	2.81	.7	2.02	0	
	5	27.8	6.84	16.8	4.60	5.0	2.72	0		0	

APPENDIX G (cotd.)

Woodland cover (%) (± 95% confidence limits) from 1950 to 1983, as determined from the dot-grid analysis of the 5 sets of aerial photography.

5km block and vegetation type.	Sample point number	1950		1961		1967		1974		1983	
		%	95%c.l	%	95%c.l	%	95%c.l	%	95%c.l	%	95%c.l
C8	1	30.2	± 7.46	18.6	± 4.55	4.9	± 2.39	.8	± 1.31	.2	± .76
Acacia-Commiphora	2	18.4	3.58	14.0	4.03	4.1	2.38	.2	.80	0	
now cleared to	3	19.6	6.09	24.7	3.03	6.9	2.45	1.6	2.00	0	
grassland.	4	18.4	4.73	6.9	2.98	1.4	2.09	1.2	1.77	.2	.76
	5	14.3	2.26	14.1	3.47	4.1	3.68	2.7	2.07	.8	1.20
A7	1	22.9	7.02	21.6	4.69	5.0	2.94	1.9	1.68	0	
Acacia-Commiphora	2	29.4	3.30	19.8	4.27	1.9	1.87	2.4	1.77	0	
now cleared to	3	16.7	4.93	28.1	7.45	9.3	2.59	1.9	1.68	.8	.97
grassland.	4	38.8	1.79	28.8	6.77	6.2	2.59	1.4	2.56	0	
	5	38.4	9.19	6.0	3.36	1.4	2.07	.2	.84	0	

APPENDIX H

The relative frequency (%) of the canopy diameter size classes of the *Acacia-Commiphora* community in the eight 5km sampling blocks. The total of 5 sample points located in what is now pure *Acacia gerrardii* (having once been *Acacia-Commiphora*) have been omitted from this analysis: tree size distributions of the *A. gerrardii* community are shown in Figs 8. a)-f).

			Size class (m)								
5km sampling block	10km block	n[a]	0-.99	1-1.99	2-2.99	3-3.99	4-4.99	5-5.99	6-6.99	7-7.99	8-8.99
B10	-*	252	98.55	1.37	.08						
A7	-*	154	99.56	.44							
C8	XI	543	98.53	1.19	.19	.09					
C5	IV	166	80.47	15.61	3.30	.62					
E7	V	367	71.71	24.12	2.87	.75	.29	.16	.07	.03	
E9	VIII	1041	86.92	10.09	1.91	.61	.31	.10	.05	.01	
I9	X	445	73.55	17.64	6.35	1.33	.76	.14	.06	.14	.02
H6	VII	260	68.32	23.27	6.04	1.54	.58	.25			

*: block lies within game reserve.

: block lies within game reserve: designated as XI (see Chapter 10).

[a]: n refers to the total number of trees encountered by the line-intercept transects in the block.

APPENDIX H (cotd.)

The mean densities (trees.ha^{-1}) of the canopy diameter size classes of the Acacia-Commiphora community in the eight 5km sampling blocks. The total of 5 sample points located in the Acacia gerrardii community have been omitted from this analysis.

			Size class (m)									
5km sampling block	10km block	n[a]	0-.99	1-1.99	2-2.99	3-3.99	4-4.99	5-5.99	6-6.99	7-7.99	8-8.99	Total
B10	-*	252	500	7	1							508
A7	-*	154	275	1								276
C8	XI	543	828	10	2	1						841
C5	IV	166	523	101	21	4						649
E7	V	367	895	301	36	9	4	2	1			1248
E9	VIII	1041	972	113	21	7	3	1	1			1118
I9	X	445	963	231	83	17	10	2	1	1		1308
H6	VII	260	813	277	72	18	7	3				1190

* : block lies within game reserve.

: block lies within game reserve: designated as XI (see Chapter 10).

: n refers to the number of trees encountered by the line-intercept method.

APPENDIX H (cotd.)

The mean cover (%) of the canopy diameter size classes of the *Acacia-Commiphora* community in the eight 5km sampling blocks. The total of 5 sample points located in the *Acacia gerrardii* community have been omitted from this analysis.

			Size class (m)									
5km sampling block	10km block	n[a]	0-.99	1-1.99	2-2.99	3-3.99	4-4.99	5-5.99	6-6.99	7-7.99	8-8.99	Total
B10	-*	252	.98	.12	.02							1.12%
A7	-*	154	.54	.02								.56%
C8	XI	543	1.63	.18	.08	.07						1.96%
C5	IV	166	1.03	1.79	1.05	.39						4.26%
E7	V	367	1.76	5.32	1.76	.90	.58	.47	.29	.17		11.25%
E9	VIII	1041	1.91	1.99	1.05	.66	.55	.27	.19	.05		6.67%
I9	X	445	1.89	4.08	4.08	1.68	1.58	.44	.26	.81	.15	14.97%
H6	VII	260	1.60	4.90	3.53	1.76	1.10	.71				13.60%

* : block lies within reserve.

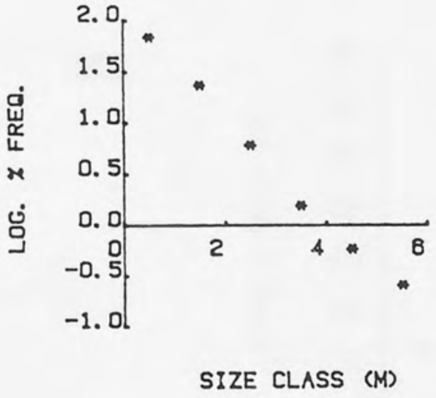
: block lies within game reserve: designated as XI (see Chapter 9)

[a] : n refers to the total number of trees encountered by the line-intercept method.

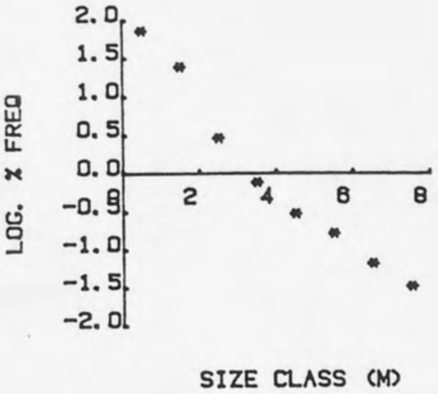
APPENDIX I

The negative exponential tree age distribution for each of the specified 5 km sampling blocks straightened by a log.$_{10}$ transformation on the % frequency (y-) axis.

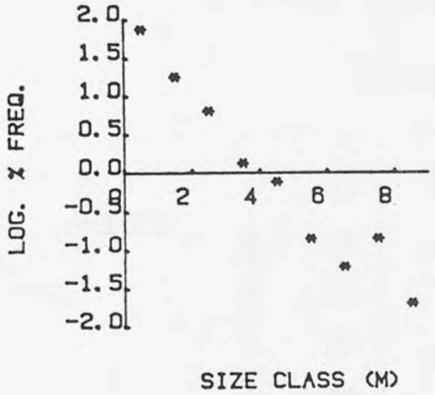
H6



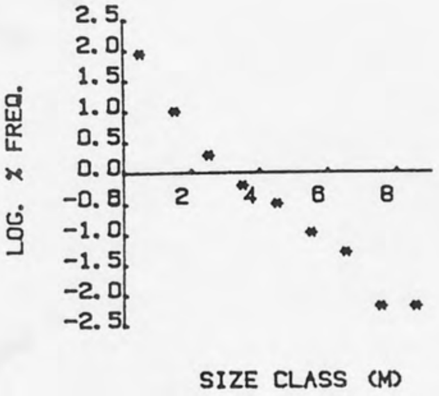
E6/7



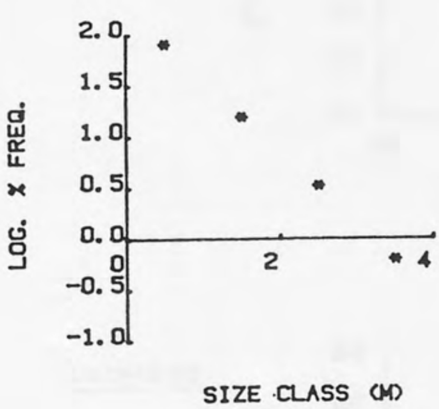
I9



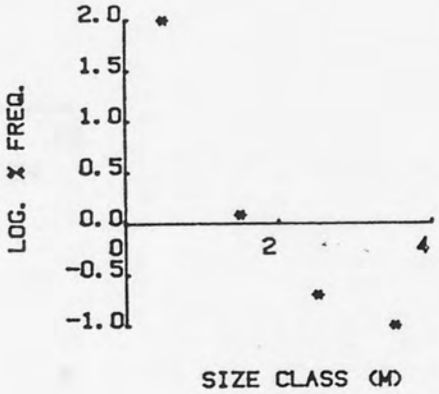
E9



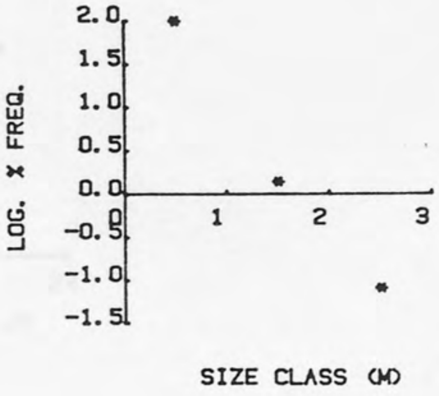
C5



C8



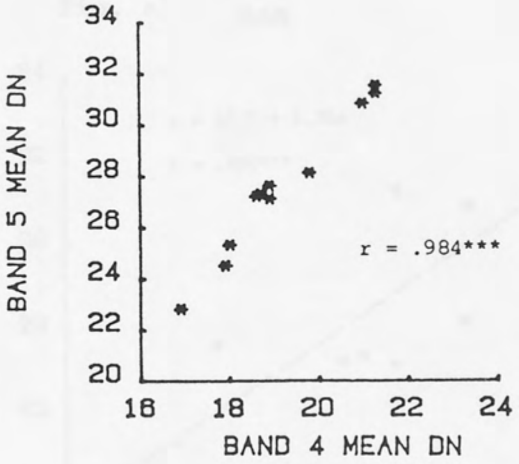
B10



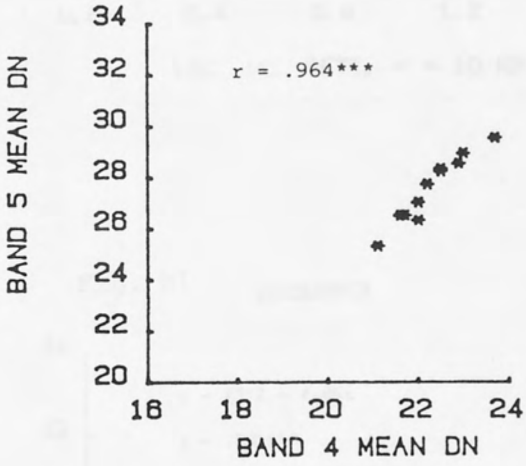
APPENDIX J

The relationship between band 5 (red reflectance) and band 4 (green reflectance) for each of the three LANDSAT images.

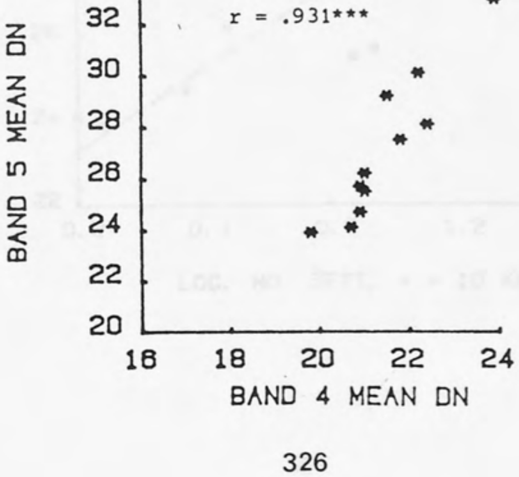
June



August



December



APPENDIX K

Plots of Band 5 (red reflectance) against the logarithm of the 1974 Model 1 10 km index value (that is, the $\log_{10}$ of the number of settlements within 10 km of the block) (see Figs. 9:8a) and e)).
Fig. a) June image.
Fig. b) December image.

Fig. a) JUNE

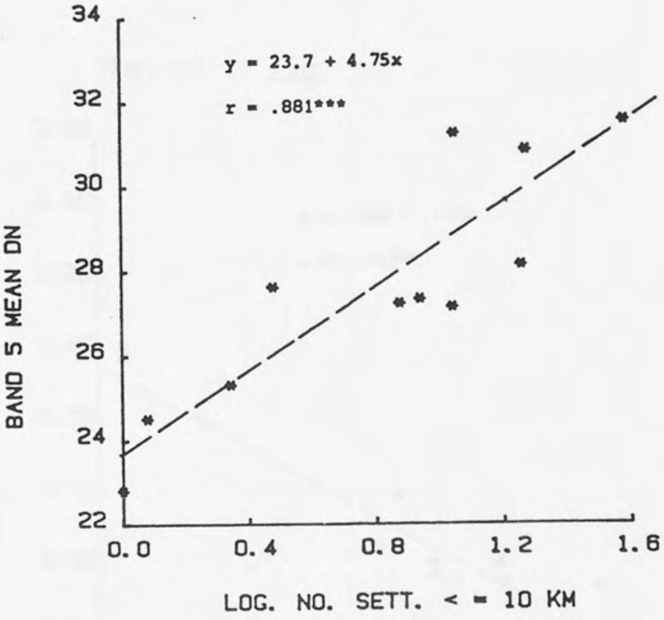
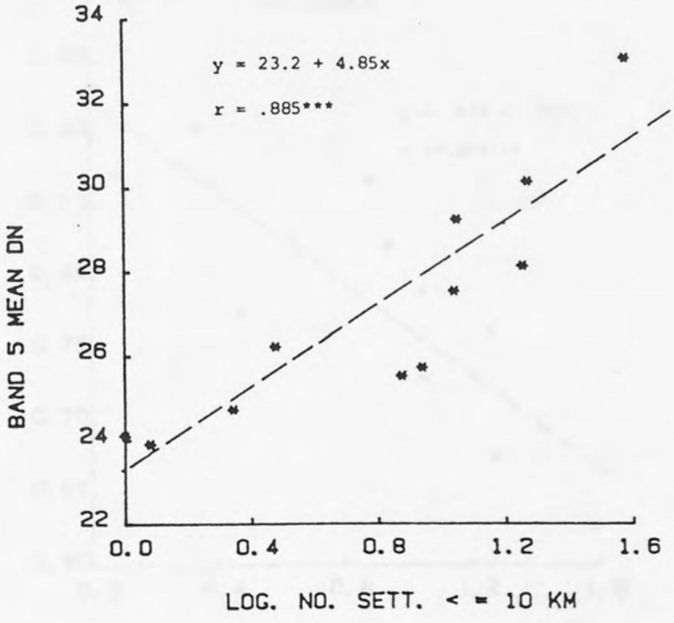


Fig. b) DECEMBER



APPENDIX L

Plots of the Band 7/Band 5 ratio against the logarithm of the 1974 Model 1 10 km index value (that is, the log.$_{10}$ of the number of settlements within 10 km range of the block).
Fig. a) June.
Fig. b) December.

Fig. a) JUNE

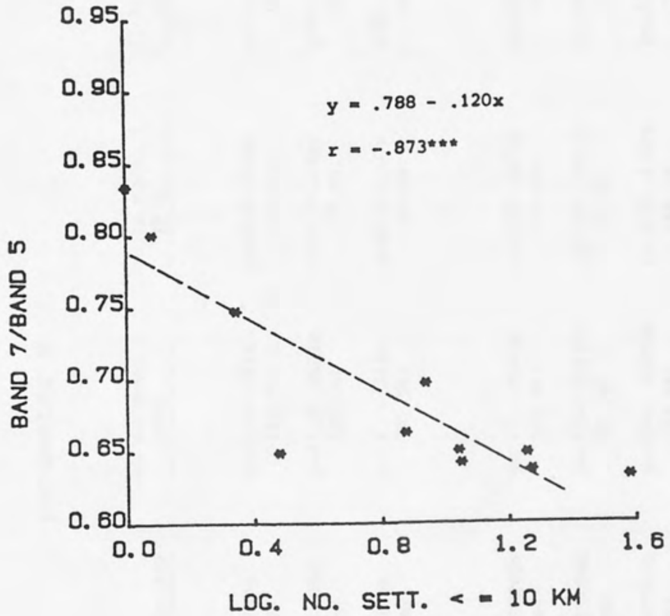
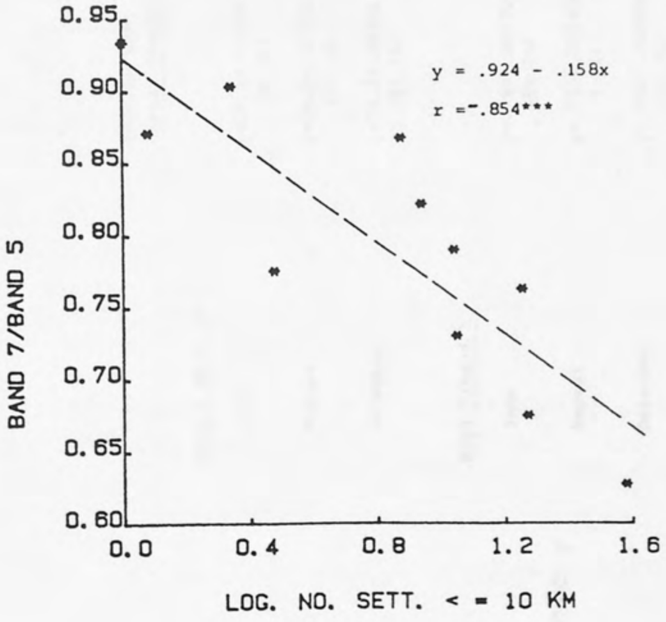


Fig. b) DECEMBER



APPENDIX M

Table giving the least-squares linear regressions of LANDSAT band parameters (dependent variables) and SRF cattle densities and Models 1 and 2 index values (predictor variables). The figures in brackets are the values of R^2 for the relationships.

parameter x

parameter y	1979-80 SRF cattle density	All SRF cattle density	10 km Model 1 1974	10 km Model 2 1974	15 km Model 1 1974	15 km Model 2 1974
Band 5 Mean DN						
June	$y=25.1+.0731x$ (60.8%)	$y=24.4+.104x$ (57.9%)	$y=25.6+.197x$ (60.9%)	$y=26.0+.854x$ (54.5%)	$y=24.5+.150x$ (83.3%)	$y=25.2+.829x$ (70.2%)
August	$y=26.9+.0178x$ (16.7%)	$y=26.6+.0305x$ (23.1%)	$y=27.0+.0529x$ (20.1%)	$y=27.1+.226x$ (17.6%)	$y=26.5+.0476x$ (39.1%)	$y=26.8+.244x$ (28.1%)
December	$y=24.2+.0858x$ (81.1%)	$y=23.4+.119x$ (74.1%)	$y=24.7+.242x$ (87.5%)	$y=25.0+1.07x$ (83.0%)	$y=23.6+.162x$ (94.3%)	$y=24.3+.970x$ (93.2%)
Band 7/Band 5						
June	$y=.749-.00170x$ (50.3%)	$y=.771-.00263x$ (56.6%)	$y=.731-.0041x$ (39.6%)	$y=.723-.017x$ (33.0%)	$y=.760-.00321x$ (58.3%)	$y=.738-.0169x$ (44.8%)
August	$y=.737-.00043x$ (7.3%)	$y=.747-.00084x$ (12.9%)	$y=.734-.00123x$ (8.1%)	$y=.731-.0051x$ (6.6%)	$y=.748-.00121x$ (18.7%)	$y=.738-.0059x$ (12.1%)
December	$y=.887-.00268x$ (69.3%)	$y=.912-.00377x$ (64.8%)	$y=.870-.00749x$ (73.6%)	$y=.858-.0329x$ (68.7%)	$y=.913-.00539x$ (91.8%)	$y=.884-.0309x$ (83.1%)
Band 7 - Band 5						
June	$y=-6.39-.0674x$ (58.6%)	$y=-5.61-.100x$ (61.2%)	$y=-7.00-.171x$ (51.3%)	$y=-7.31-.727x$ (44.6%)	$y=-5.84-.132x$ (72.9%)	$y=-6.67-.713x$ (58.8%)
August	$y=-7.17-.0158x$ (8.3%)	$y=-6.78-.0303x$ (14.4%)	$y=-7.25-.0459x$ (9.5%)	$y=-7.34-.191x$ (8.0%)	$y=-6.73-.0453x$ (22.3%)	$y=-7.08-.220x$ (14.5%)
December	$y=-2.52-.0949x$ (73.8%)	$y=-1.71-.0132x$ (67.2%)	$y=-3.09-.270x$ (81.0%)	$y=-3.48-1.20x$ (77.6%)	$y=-1.71-.187x$ (93.6%)	$y=-2.63-1.10x$ (89.7%)

REFERENCES

Adams, M.E. (1967) A study of the ecology of *Acacia mellifera*, *A. seyal* and *Balanites aegyptiaca* in relation to land-clearing. J. appl. Ecol. 4: 221-237.

Agnew, A.D.Q. (1968) Observations on the changing vegetation of Tsavo National Park (East). E. Afr. Wildl. J. 6: 75-80.

Allan, J.A. & Richards, T.W. (1983) Remote sensing for identifying low density vegetation cover in semi-arid coastal north-west Egypt. Proceedings of the 9th Annual Conference of the Remote Sensing Society on Remote Sensing for Rangeland Monitoring and Management, Silsoe, Bedfordshire, 69-79.

Allaway, J.D. (1969) Elephants and their interactions with people in the Tana River Region of Kenya. Unpubl. Ph.D. Thesis, Cornell Univ.

Anderson, R.A., McFaden, D. & Kramer, R.J. (1978) Analysis of plant community structure and successional stage using multispectral and multidate aerial photography. Proceedings of the American Society of Photogrammetry, Fall Technical Meeting, Albuquerque, New Mexico, 1-9.

Archives (1934) The Carter Land Commission. Kenya Archives Document DC/NRK.2/6/2/

Archives (1939) District Officer Reports. Kenya Archives Document DC/NRK.1/1/1.

Archives (1942) District Officer Reports. Kenya Archives Document DC/NRK.1/1/1.

Ashley, M.D. & Rea, J. (1975) Seasonal vegetation differences from ERTS imagery. Photogrammetric Engineering and Remote Sensing 41: 713-719.

Astle, W.L., Webster, R. & Lawrence, C.J. (1969) Land classification for management planning in the Luangwa Valley of Zambia. J. appl. Ecol. 66: 143-169.

Atang, P.G. & Plowright, W. (1969) Extension of the JP-15 rinderpest control campaign to Eastern Africa: the epizootiological background. Bull. epizoot. Dis. Afr. 17: 161-170.

Bailey, N.T.J. (1959) Statistical Methods in Biology. English Universities Press.

Barkham, J.P. & Rainy, M.E. (1976) Vegetation of Samburu Game Reserve. E. Afr. Wildl. J. 14: 297-329.

Barnes, D.L. (1982) Management strategies for the utilization of southern African savanna. In: Huntley, B.J. and Walker, B.H. (eds.) Ecology of Tropical Savannas. Ecological Studies 42, Springer-Verlag, Berlin.

Barry, R.G. & Chorley, R.J. (1976) Atmosphere, Weather and Climate. Methuen and Co.

Baxter, P. (1975) Some consequences of sedentarization for social relationships. In: Monod, T. (ed.) Pastoralism in Tropical Africa. Oxford University Press.

Beaumont, B. (1945) Control of east coast fever in the Masai District - a general survey of the Lemek Valley, Narok District. Kenya Archives Document DC/NRK.2/6/2.

Bekure, S. (1984) Research design. Data presented at seminar on "Livestock Production Systems Research: the Maasai". International Livestock Centre for Africa, Nairobi.

Bell, R.H.V. (1971) A grazing ecosystem in the Serengeti. Scient. Am. 224(1): 86-93.

Bell, R.H.V. (1982) The effect of soil nutrient availability on community structure in African ecosystems. In: Huntley, B.J. & Walker, B.H. (eds.). Ecology of Tropical Savannas. Ecological Studies 42, Springer-Verlag, Berlin.

Bentley, R.G., Salmon-Drexler, B.C., Bonner, W.J. & Vincent, R.K. (1976) A LANDSAT study of ephemeral and perennial rangeland vegetation and soils. The Bureau of Land Management of the U.S. Dept. of the Interior Report to NASA No. YA-300-1700-1012.

Betts, F.N. (1953) Report on the forest areas of Narok. Kenya Archives Document DC/NRK.3/4.

Blacker, J.G.C. (1972) Demography. In: Morgan, W.T.W. (ed.) East Africa: its Peoples and Resources. Oxford University Press.

Blair Rains, A. (1973) The aerial photograph and the interpretation of vegetation. Misc. Report 164, Land Resources Division, Ministry of Overseas Development, London.

Bogdan, A.V. (1977) Tropical Pasture and Fodder Plants. Tropical Agriculture Series. Longmans, London.

Boudet, G. & Riviere, R. (1968) Emploi practique des analyses fourrageres pour l'appreciation des paturages tropiceaux. Revue Elev. Med. vet. Pays trop. 21: 227-266.

Bourn, D. (1978) Cattle, rainfall and tsetse in Africa. Journal of Arid Environments 1: 49-61.

Braun, H.M.H. (1973) Primary production in the Serengeti: purpose, methods and some results of research. Ann. Univ. d'Abidjan (E) 6: 171-188.

Braun, H.M.H. (1977) Ecological zones: a critical evaluation of the systems in use in Kenya. Internal Communication IC8, Kenya Soil Survey, Nairobi.

Breman, H. (1982) La productivite des herbes perennes et des arbres. In: Penning de Vries, F.W.T. & Djiteye, M.A. (eds.) La Productivite des Paturages Saheliens. Centre for Agricultural Publishing and Documentation, Wageningen, the Netherlands.

Brenan, J.P.M. & Greenway, P.J. (1949) Check Lists of the Forest Trees and Shrubs of Tanganyika Territory: No.5, Tanganyika Territory

Part II. Imperial Forest Institute, Holywell Press.

Brown, L.H. (1971) The biology of pastoral man as a factor in conservation. Biol. Conserv. 3: 93-100.

Brown, L.H. & Cocheme, J. (1973) A study of the agroclimatology of the highlands of Eastern Africa. Technical Note No. 125 (WMO 339) World Meteorological Organization, Geneva.

Buechner, H.K. & Dawkins, H.C. (1961) Vegetation change induced by elephants and fire in Murchison Falls National Park, Uganda. Ecology 42: 752-766.

Buxton, P.A. (1955) The Natural History of Tsetse Flies. H.K. Lewis, London.

Canfield, R.H. (1941) Application of the line interception method in sampling range vegetation. J. For. 39: 338-394.

Carneggie, D.M. (1968) Interpretation of color photography for range management. In: Smith, J.T. & Anson, A. (eds.) Manual of Color Aerial Photography. American Society of Photogrammetry.

Carneggie, D.M. & Reppert, J.N. (1969) Large scale 70 mm aerial color photography. Photogrammetric Engineering 35: 249-257.

Carneggie, D.M., Wilcox, D.G. & Hacker, R.B. (1971) The use of large-scale aerial photographs in the evaluation of western Australian rangelands. Dept. of Agriculture, Western Australia, South Perth, Technical Bulletin 10.

Carneggie, D.M., De Gloria, S.D. & Colwell, R.N. (1974) Usefulness of ERTS and supporting aircraft data for monitoring plant development and range conditions in California's annual grasslands. University of California, Berkeley School of Forestry and Conservation, Final Report to the U.S. Dept. of the Interior Bureau of Land Management.

Casebeer, R.L. & Koss, G.G. (1970) Food habits of wildebeest, zebra, hartebeest and cattle in Kenya Maasailand. E. Afr. Wildl. J. 8: 25-36.

Cassady, J.T. (1973) The effect of rainfall, soil moisture and harvesting intensity on grass production on two rangeland sites in Kenya. E. Afr. agric. For. J. 34: 26-36.

Caughley, G. (1974) Bias in aerial survey. J. Wildl. Mgmt. 38: 921-933.

Caughley, G. (1976) The elephant problem - an alternative hypothesis. E. Afr. Wildl. J. 14: 265-284.

Challier, A. (1982) The ecology of tsetse (Glossina spp.) (Diptera, Glossinidae): a review (1970-1981). Insect Science and its Application 3 (2/3): 97-143.

Cobb, S. (1976) The distribution and abundance of the large herbivore community of Tsavo National Park, Kenya. Unpubl. D.Phil. Thesis, Univ. of Oxford.

Cochran, W.G. (1963) Sampling Techniques. John Wiley, New York.

Coe, M.J., Cumming, D.H. & Phillipson, J. (1976) Biomass production of large African herbivores in relation to rainfall and primary production. Oecologia 22: 341-354.

Cole, L.C. (1949) The measurement of interspecific association. Ecology 30: 411-424.

Colwell, J.E. (1974) Grass canopy bidirectional spectral reflectance. Proceedings of the 9th International Symposium on Remote Sensing of the Environment, Ann Arbor, Environmental Research Institute of Michigan, 1061-1085.

Computer Aided Design Centre (CADS) (1976) GINO-SURF User Manual. CADS, Cambridge.

Condit, H.K. (1970) The spectral reflectance of American soils. Photogrammetric Engineering 36: 955-966.

Cooper, C.F. (1957) The variable plot method for estimating shrub density. J. Range Mgmt. 10: 111-115.

Cooper, C.F. (1963) An evaluation of the variable plot in shrub and herbaceous vegetation. Ecology 44: 565-569.

Cottam, G.T. & Curtis, J.T. (1956) The use of distance measures in phytosociological sampling. Ecology 37: 451-460.

Croze, H. (1974a) The Seronera bull problem. I. The elephants. E. Afr. Wildl. J. 12: 1-27

Croze, H. (1974b) The Seronera bull problem. II. The trees. E. Afr. Wildl. J. 12: 29-48.

Croze, H., Mumiukha, P.W., Mbai, H.T.M. & Owaga, M.L. (1978) Estimates of grazer food supply and demand in the Athi-Kapiti ecosystem of Kajiado District, Kenya. Project Working Document No. 17, UNDP/FAO Wildlife Management Project, Nairobi.

Curran, P.J. (1980) Multispectral remote sensing of vegetation amount. Progress in Physical Geography 4: 315-341.

Curran, P.J. & Milton, E.J. (1983) The relationship between the chlorophyll concentration, LAI and bidirectional reflectance of a simple vegetation canopy. International Journal of Remote Sensing 4(2): 247-255.

Dahl, G. & Hjort, A. (1976) Having Herds: Pastoral Herd Growth and Household Economy. Stockholm Studies in Social Anthropology 2, Univ. of Stockholm.

Dale, I.R. & Greenway, P.J. (1961) Kenya Trees and Shrubs. Univ. of Glasgow.

Darch, J.P. (1984) Remote sensing in biogeography. In: Taylor, J.A. (ed.) Themes in Biogeography. Croom Helm, London.

Darling, F.F. (1960) An ecological reconnaissance of the Mara Plains in Kenya Colony. Wildl. Monogr., Chestertown, No. 5.

Daubenmire, R. (1968a) Ecology of fire in grasslands. Adv. Ecol. Res. 5: 209-266.

Daubenmire, R. (1968b) Plant Communities. Harper and Row, New York.

Davis, J.C. (1973) Statistics and Data Analysis in Geology. John Wiley, New York.

Davis, R.K. (1970) Some issues in the evolution, organization and operation of group rauches in Kenya. Working Paper 93, Institute of Development Studies, Univ. of Nairobi.

Deering, D.W. (1978) Rangeland reflectance characteristics measured by aircraft and spacecraft sensors. Unpubl. Ph.D. Thesis. Texas A. & M. University.

Deering, D.W., Rouse, J.W., Haas, R.H. & Schell, J.A. (1975) Measuring "forage production" of grazing units from LANDSAT MSS data. Proceedings of the 10th International Symposium on Remote Sensing of the Environment, Ann Arbor, Environmental Research Institute of Michigan, 1169-1176.

Deshmukh, I.K. (1984) A common relationship betwen precipitation and grassland peak biomass for East and southern Africa. Afr. J. Ecol. 22: 181-186.

De Vos, A. (1969) Ecological conditions affecting the production of wild herbivorous mammals on grasslands. Adv. Ecol. Res. 6: 137-183.

De Wit, H.A. (1978) Soils and grassland types of the Serengeti Plain, Tanzania. Unpubl. Ph.D. Thesis, Landbonwhogeschool, Wageningen, the Netherlands.

Dix, R.L. (1961) An application of the point-centred quarter method to the sampling of grassland vegetation. J. Range Mgmt. 14: 63-69.

Doherty, D. (1979) A preliminary report on group ranching in Narok District. Working Paper 350, Institute of Development Studies, Univ. of Nairobi.

Donker, N.H.W. & Mulder, N. (1977) Analysis of MSS digital imagery with the aid of principal components transforms. I.T.C. Journal (1977): 434-466.

Dougall, H.W., Drysdale, V.M. & Glover, P.E. (1964) The chemical composition of Kenya browse and pasture herbage. E. Afr. Wildl. J. 2: 82-125.

Driscoll, R.S., Reppert, J.N., Heller, R.C. & Carneggie, D.M. (1970) Identification and measurement of herbland and shrubland vegetation from large-scale aerial colour photographs. Proceedings of the 11th International Grassland Congress, Univ. of Queensland, Australia, 95-98.

Duggin, M.J. (1977) Likely effects of solar elevation on the quantification of changes in vegetation with maturity using sequential imagery. Appl. Opt. 16: 521-533.

Dyson-Hudson, N. (1980) Strategies of resource exploitation among East African savanna pastoralists. In: Harris, D.R. (ed.) Human Ecology in Savanna Environments. Academic Press, New York.

Edwards, D.C. & Bogdan, A.V. (1951) Important Grassland Plants of Kenya. Pitman, Nairobi,

Epp, H. & Agatsiva, J. (1980) Habitat types of the Mara-Narok area, western Kenya. Technical Report Series No. 20, KREMU, Nairobi.

Epp, H., Herlocker, D. & Peden, D. (1981) The use of large-scale aerial photography to determine wood biomass in arid and semi-arid areas of Kenya. Technical Report Series No. 51, KREMU, Nairobi.

Everitt, J.H., Gerbermann, A.H. & Alaniz, M.A. (1981) Microdensitometry to identify saline rangelands on 70 mm color-infrared aerial film. Photogrammetric Engineering and Remote Sensing 47: 1357-1362.

FAO (1978) Report on the agro-ecological zones project. Vol. 1 Methodology and results for Africa. Report No. 48, World Soil Resources, FAO, Rome.

FAO/UNESCO (1977) Desertification Map of the World. UNEP, Nairobi.

Field, A.C. (1978) Preliminary report on the impact of sheep and goats on the vegetation in the arid zone of northern Kenya. Technical Report E-2, UNEP-MAB Integrated Project in Arid Lands, Nairobi.

Field, C.R. (1971) Elephant ecology in the Queen Elizabeth National Park, Uganda. E. Afr. Wildl. J. 9: 99-123.

Field, C.R. & Laws, R.M. (1970) The distribution of the larger herbivores in the Queen Elizabeth National Park, Uganda. J. appl. Ecol. 7: 273-294.

Fleming, J. & Dixon, R.G. (1981) Basic guide to small-format hand-held oblique aerial photography. Research Report 81-2, Canada Centre for Remote Sensing, Dept. of Energy, Mines and Resources, Ottawa, Canada.

Ford, J. (1971) The Role of the Trypanosomiases in African Ecology. Clarendon Press, Oxford.

Ford, J. & Clifford, H.R. (1968) Changes in the distribution of cattle and of bovine trypanosomiasis associated with the spread of tsetse flies (Glossina) in south-west Uganda. J. appl. Ecol. 5: 301-337.

Fosbrooke, H.A. (1948) An administrative survey of the Maasai social system. Tanganyika Notes Rec. 26: 1-50.

Gates, D.M. (1965) Characteristics of soil and vegetated surfaces to reflected emitted radiation. Proceedings of the 3rd International Symposium on Remote Sensing of the Environment, Ann Arbor, Environmental Research Institute of Michigan, 573-600.

Gerresheim, K. (1974) The Serengeti landscape classification. African Wildlife Leadership Foundation, Nairobi.

Glover, J. (1963) The elephant problem at Tsavo. E. Afr. Wildl. J. 1: 30-39.

Glover, P.E. (1966) An ecological survey of the Narok District of Kenya Maasailand, 1961-1965. Part 1: geology, soils, climate and hydrology. Kenya National Parks, Nairobi (typescript).

Glover, P.E. (1967) The importance of ecological studies in the control of tsetse flies. Bull. Wld. Hlth. Org. 37: 581-614.

Glover, P.E. (1968) The role of fire and other influences on the savannah habitat, with suggestions for further research. E. Afr. Wildl. J. 6: 131-137.

Glover, P.E. & Gwynne, M.D. (1961) The destruction of Maasailand. New Scient. 2(249): 450-453.

Glover, P.E., Stewart, J. & Gwynne, M.D. (1966) Maasai and Kipsigis notes on East African plants. E. Afr. agric. For. J. 22: 200-207.

Glover, P.E., Trump, E.C. & Wateridge, L.E.D. (1964) Termitaria and vegetation patterns on the Loita plains of Kenya. J. Ecol. 52: 367-377.

Glover, P.E. & Trump, E.C. (1970) An ecological survey of the Narok District of Kenya Maasailand. Part II: vegetation. Kenya National Parks, Nairobi.

Glover, P.E. & Wateridge, L.E.D. (1968) Erosion terraces in the Loita-Aitong areas of Kenya Masailand. E. Afr. Wildl. J. 6: 123-129.

Good, R.E. & Good, N.F. (1971) Vegetation of a Minnesota prairie and a comparison of methods. Am. Midl. Nat. 85: 228-231.

Goodall, D.W. (1952) Some considerations in the use of point quadrats for the analysis of vegetation. Aust. J. Scient. Res. Ser. B. 5: 1-41.

Graetz, R.D., Gentle, M.R., Pech, R.P. & O'Callaghan, J.F. (1982) The development of a land image-based resource information system (LIBRIS) and its application to the assessment and monitoring of Australian arid rangelands. Proceedings of the International Symposium on Remote Sensing of the Environment, First Thematic Conference on Remote Sensing of Arid and Semi-arid Lands, Cairo, Egypt. Ann Arbor, Environmental Research Institute of Michigan, 257-275.

Graetz, R.D. & Gentle, M.R. (1982) The relationship between reflectance in the LANDSAT wavebands and the composition of an Australian semi-arid shrub rangeland. Photogrammetric Engineering and

Remote Sensing 48: 1721-1730.

Greig-Smith, P. (1964) Quantitative Plant Ecology. Butterworth, London.

Griffiths, G.H. & Collins, W.G. (1983) Mapping the greenness of semi-arid rangeland vegetation in northern Kenya from LANDSAT digital data. Proceedings of the 9th Annual Conference of the Remote Sensing Society, on Remote Sensing for Rangeland Monitoring and Management, Silsoe, Bedfordshire, 108-122.

Grimwood, I (1960) The future status of Kenya's National Parks. Wild Life, Nairobi. 2(3): 25-26.

Groeneveld, S. (1968) Traditional farming and coconut-cattle schemes in the Tanga region. In: Ruthenberg, H. (ed.) Smallholder Farming and Smallholder Development in Tanzania. Afrika-Studien No. 24. IFO Institut, Munchen.

Guy, P.R. (1976) The feeding behaviour of elephant (Loxodonta africana) in the Sengwa area, Rhodesia. South African Journal of Wildlife Research 6: 55-63.

Gwynne, M.D. (1977) LANDSAT image studies of green flush events in Kajiado District, Kenya. Project Working Document No. 15, UNDP/FAO Wildlife Management Project, Nairobi.

Gwynne, M.D. & Bell, R.H.V. (1968) Selection of vegetation components by grazing ungulates in the Serengeti National Park. Nature, Lond. 220: 390-393.

Gwynne, M.D. & Croze, H. (1975) East African habitat monitoring practice: a review of methods and applications. Proceedings of the Seminar on Evaluation and Mapping of Tropical African Rangelands, Bamako, Mali, 95-135. ILCA, Addis Ababa.

Halderman, J.M. (1972) An analysis of continued semi-nomadism on the Kaputei Maasai group ranches: sociological and ecological factors. Discussion Paper No. 152, Institute of Development Studies, Univ. of Nairobi.

Hardin, G. (1968) The tragedy of the commons. Science 162: 1243-1248.

Harker, K.W. (1959) An Acacia weed of Uganda grasslands. Trop. Agric., Trin. 36: 45-51.

Harrington, G.N. & Ross, I.C. (1974) The savanna ecology of Kidepo Valley National Park. I. The effects of burning and browsing on the vegetation. E. Afr. Wildl. J. 12: 93-105.

Harris, R.W. (1951) Use of aerial photographs and subsampling in range inventories. J. Range Mgmt. 4: 270-278.

Heady, H.F. (1966) Influence of grazing on the composition of Themeda triandra grassland, East Africa. J. Ecol. 54: 705-727.

Heady, H.F. (1960) Range Management in East Africa. Govt. Printer, Nairobi.

Hedlund, H.G.B. (1971) The impact of group ranches on a pastoral society. Staff Paper No. 100, Institute of Development Studies, Univ. of Nairobi.

Helland, J. (1978) Sociological aspects of pastoral livestock production in Africa. In: Hyder, D.N. (ed.) Proceedings of the First International Rangeland Congress, Denver, Colorado, 79-81.

Helland, J. (1980) An outline of group ranching in pastoral Maasai areas of Kenya. Working Document No. 24, International Livestock Centre for Africa, Nairobi.

Heller, R.C., Doverspike, G.D. & Aldrich, R.C. (1964) Identification of tree species on large-scale panchromatic and color aerial photographs. Agricultural Handbook No. 261, U.S. Dept. of Agriculture.

Herlocker, D.J. (1976) Structure, composition and environment of some woodland vegetation types of the Serengeti National Park, Tanzania. Unpubl. Ph.D. Thesis, Texas A & M Univ.

Heyting, A. (1968) Discussion and development of the point-centred quarter method of sampling grassland vegetation. J. Range Mgmt. 21: 370-380.

Hielkema, J.U. (1977) Application of LANDSAT data in desert locust survey and control. Desert Locust Satellite Application Project, FAO, Rome.

Hielkema, J.U. (1981) Desert locust habitat monitoring with satellite remote sensing. I.T.C. Journal (1981): 387-417.

Hollis, A.C. (1905) The Masai, their Language and Folklore. Clarendon Press, Oxford.

Hopkins, B. (1965) Observations on savanna burning in the Olokomeji Forest Reserve, Nigeria. J. appl. Ecol. 2: 367-381.

Howard, J.A. (1965) Small-scale photographs and land resources in Nyamweziland, East Africa. Photogrammetric Engineering 31: 287-293.

Humphrey, N. (1947) A note on the origins of the present inhabitants of trans-Mara. Kenya Archives Document DC/NRK.3/5.

Huntingford, G.W.B. (1953) The Southern Nilo-Hamites. The International African Institute, London.

Huntley, B.J. (1982) Southern African savannas. In: Huntley, B.J. & Walker, B.H. (eds.) Ecology of Tropical Savannas. Ecological Studies 42, Springer-Verlag, Berlin.

Idso, S.B., Reginato, R.J. & Jackson, R.D. (1977) Albedo measurement for remote sensing of crop yields. Nature, Lond. 266: 625-628.

Ivens, G.W. (1967) East African Weeds and their Control. Oxford University Press, Nairobi.

Jackson, M.J. & Plevin, J. (1983) Satellite imagery for environmental research - the next 10 years. In: Fuller, R.M. (ed.) Ecological Mapping from Ground, Air and Space: Proceedings of ITE Symposium No. 10, Natural Environment Research Council, Swindon, Wiltshire.

Jacobs, A.H. (1965) The traditional political organization of the pastoral Maasai. Unpubl. D.Phil. Thesis, Univ. of Oxford.

Jacobs, A.H. (1975) Maasai pastoralism in historical perspective. In: Monod, T. (ed.) Pastoralism and Development in Tropical Africa. Oxford Univ. Press.

Jacobs, A.H. (1980) Pastoral development in Tanzania Maasailand. Rural Africana 7: 1-14.

Jahnke, H.E., Ruthenberg, H. & Thimm, H. (1974) Range development in Kenya. A review of commercial, company, individual and group ranches. Studies in Employment and Development No. 4, International Bank for Reconstruction and Development, Washington DC.

Janza, L.J. (1975) Interaction Mechanisms. In: Manual of Remote Sensing. American Society of Photogrammetry, Falls Church, Virginia.

Jensen, C.L. (1982) The effect of settlement on shrub density by the Amboseli Masai. Typescript report, African Wildlife Leadership Foundation, Nairobi.

Jenson, S.K. & Waltz, F.A. (1979) Principal components analysis and canonical analysis in remote sensing. Proceedings of the American Society of Photogrammetry, 45th Annual Meeting, Washington DC, 337-348.

Jewell, P.A. (1980) Ecology and management of game animals and domestic livestock in African savannas. In: Harris, D.R. (ed.) Human Ecology in Savannah Environments. Academic Press, New York.

Jolly, G.M. (1969) Sampling methods for aerial censuses of wildlife populations. E. Afr. agric. For. J. 34: 46-49.

Jordan, C.F. (1969) Derivation of leaf area index from quality of light on the forest floor. Ecology 50: 663-666.

Kauth, R.G. & Thomas, G.S. (1976) The tasseled cap - a graphic description of the spectral-temporal development of agricultural crops as seen by LANDSAT. Proceedings of the Symposium on Machine Processing of Remotely Sensed Data, IEEE, Cat. No. 76, LARS, Purdue Univ., 41-51.

Kenya Government (1979) National Developmental Plan 1978-83. Govt. Printer, Nairobi.

Kershaw, K.A. (1964) Quantitative and Dynamic Ecology. Edward Arnold, London.

Kozlowski, T.T. & Ahlgren, C.F. (eds.) (1974) Fire and Ecosystems. Academic Press, New York.

Kuchar, P. (1981) Plants of Kenya. A handbook of uses and ecological status. KREMU, Nairobi.

Kurji, F. (1976) Human ecology. Annual Report 1974–75, Serengeti Research Institute, Arusha, 12–31.

Lamprey, H.F. (1963) Ecological separation of the large mammal species in the Tarangire Game Reserve, Tanganyika. E. Afr. Wildl. J. 1: 63–92.

Lamprey, H.F. & Field, C.R. (1983) Estimated carrying capacities and protein intake by small ruminants in relation to browse resources in arid rangelands of Marsabit District. Proceedings of the 2nd CRSP Small Ruminant Kenya Workship, Nairobi, 184–201.

Lamprey, H.F., Glover, P.E., Turner, M.I.M. & Bell, R.H.V. (1967) Invasion of the Serengeti National Park by elephants. J. appl. Ecol. 5: 151–166.

Langridge, W.P. (1960) In tsetse control, game slaughter is outdated. Wild Life, Nairobi. 2(1): 13–17.

Langridge, W.P., Smith, J.A. & Wateridge, L.E.D. (1970) Some observations on the ecology of Glossina swynnertoni Austen in the Mara region of Kenya. Proceedings of the 12th Meeting of the International Scientific Council for Trypanosomiasis Research, Bangui, Central African Republic. Organization of African Unity/Scientific and Technical Research Commission. Publ. No. 102, 203–211.

Lawrence Report (1966) Report of the Mission on Land Consolidation and Registration in Kenya, 1965–66. Government Printer, Nairobi.

Laws, R.M. (1970) Elephants as agents of habitat and landscape change in East Africa. Oikos 21: 1–15.

Laws, R.M., Parker, I.S.C. (1968) Recent studies on elephant populations in East Africa. Symp. zool. Soc. Lond. 21: 319–359.

Laws, R.M., Parker, I.S.C. & Johnstone, R.C.B. (1975) Elephants and their Habitats. Clarendon Press, Oxford.

Le Houerou, H.N. & Corra, M. (1980) Some browse plants of Ethiopia. In: Le Houerou, H.N. (ed.) Browse in Africa: the Current State of Knowledge. International Livestock Centre for Africa, Addis Ababa, Ethiopia.

Le Houerou, H.N. & Hoste, C.H. (1977) Rangeland production and annual rainfall relations in the Mediterranean Basin and in the African Sahelo–Sudanian zone. J. Range Mgmt. 30: 183–189.

Leuthold, W. & Sale, J.B. (1973) Movements and patterns of habitat utilisation of elephants in Tsavo National Park, Kenya. E. Afr. Wildl. J. 11: 369–384.

Lewis, E.A. (1935) Tsetse flies in the Maasai Reserve, Kenya Colony. Bull. ent. Res. 25: 439–455.

Lewis, J.G. (1980) Report of a short term consultancy on the grazing ecosystem in the Mt. Kulal region, northern Kenya. Technical Report E-3 UNESCO-UNEP Integrated Project in Arid Lands, Nairobi.

Lewis, R.W. (1965) A plan for the development of Kenya Maasailand. Typescript report to Dept. Veterinary Services, Kabete, Nairobi.

Lillesand, T.M. & Kiefer, R.W. (1979) Remote Sensing and Image Interpretation. John Wiley, New York.

Lind, E.M. & Morrison, M.E.S. (1974) East African Vegetation. Longmans, London.

Lock, J.M. & Milburn, T.R. (1971) The seed biology of Themeda triandra Forsk in relation to fire. Symp. Br. Ecol. Soc. 11: 337-49.

Lusigi, W.J. (1981) Combatting desertification and rehabilitating degraded production systems in northern Kenya. Technical Report A-4, UNESCO-UNEP Integrated Project in Arid Lands, Nairobi.

Lyon, L.J. (1968) An evaluation of density sampling methods in a shrub community. J. Range Mgmt. 21: 16-20.

Maddock, L. (1979) The "migration" and grazing succession. In: Sinclair, A.R.E. & Norton-Griffiths, M. (eds.). Serengeti: Dynamics of an Ecosystem. Univ. of Chicago Press.

Marshall, B. & Bredon, R.M. (1967) The nutritive value Themeda triandra. E. Afr. agric. For. J. 32: 375-379.

Marshall, F. & Robertshaw, P. (1982) Preliminary report on archaeological research in the Loita-Mara region, S.W. Kenya. Azania XVII: 173-180.

Mathews, H.L., Cunningham, R.L. & Petersen, G.W. (1973) Spectral reflectance of selected Pennsylvania soils. Proc. Soil Sci. Soc. Am. 37: 421-424.

Maxwell, E.L. (1976) A remote rangeland analysis system. J. Range Mgmt. 29: 66-73.

McCoy, R.M. & Witt, R.G. (1978) Mapping vegetation with low cover density from LANDSAT data. Proceedings of the American Society of Photogrammetry, Fall Technical Meeting, Albuquerque, New Mexico, 379-385.

McIntyre, G.A. (1978) Statistical aspects of vegetation sampling. In: t'Mannetje, L. (ed.) Measurement of Grassland Vegetation and Animal Production. Bulletin 52, Commonwealth Bureau of Pastures and Field Crops, Hurley, Berkshire.

McNaughton, S.J. (1976) Serengeti migratory wildebeest: facilitation of energy flow by grazing. Science 191: 92-94.

McNaughton, S.J. (1979) Grassland-herbivore dynamics. In: Sinclair, A.R.E. & Norton-Griffiths, M. (eds.) Serengeti: Dynamics of an Ecosystem. Univ. of Chicago Press.

Meeuwig, R.O. & Budy, J.D. (1981) Point and line-intercept sampling in pinyon-juniper woodlands. General Technical Report INT-104, U.S. Forest Service, Fort Collins, Colorado.

Ministry of Agriculture, (1977) Narok Agricultural Development Plan. Typescript report, Kenya Soil Survey, Nairobi.

Mol, F. (1980) Maasai Mara. Prudential Printers, Nairobi.

Morgan, W.T.W. & Shaffer, N.M. (1966) Population of Kenya: density and distribution. Oxford Univ. Press, Nairobi.

Morrison, C.G.T., Hoyle, A.C. & Hope-Simpson, J.F. (1948) Tropical soil vegetation catenas and mosaics. J. Ecol. 36: 1-84.

Mukinya, J.G. (1973) Density, distribution, population structure and social organization of the black rhinoceros in the Maasai Mara Game Reserve. E. Afr. Wildl. J. 11: 385-400.

Mugambi, M. (1982) Botanical composition of diets of four livestock species and six wildlife species in south western Kenya. Unpubl. M.Sc. Thesis, Colorado State Univ.

Munsell, (1975) Munsell Soil Color Charts. Kollmorgen Corporation, Baltimore, Maryland.

Napper, D.M. (1965) Grasses of Tanganyika. Bulletin No. 18, East African Agricultural and Forest Research Organization, Ministry of Agriculture, Forests and Wildlife, Dar-es-Salaam, Tanzania.

NASA, (1977) LANDSAT Data Users Handbook. NASA-TM-74722, Greenbelt, Maryland.

National Academy of Sciences (NAS) (1977) Resource Sensing from Space: Prospects for Developing Countries. NAS, Washington DC.

National Research Council (NRC) (1962) Basic Problems and Techniques in Range Research. Publ. No. 890, National Academy of Sciences, National Research Council, Washington DC.

Naveh, Z. (1966) The need for integrated range research in East Africa. Trop. Agric., Trin. 43: 91-98.

Nestel, P. (1984) Milk offtake and consumption. Data presented at seminar on "Livestock Production Systems Research: the Maasai". International Livestock Centre for Africa, Nairobi.

Norton-Griffiths, M. (1978) Counting Animals. Handbook No. 1, African Wildlife Leadership Foundation, Nairobi.

Norton-Griffiths, M. (1979) The influence of grazing, browsing and fire on the vegetation dynamics of the Serengeti. In: Sinclair, A.R.E. & Norton-Griffiths, M. (ed.) Serengeti: Dynamics of an Ecosystem. Univ. of Chicago Press.

Norton-Griffiths, M., Herlocker, D.J. & Pennycuick, L. (1975) The patterns of rainfall in the Serengeti ecosystem. E. Afr. Wildl. J. 13: 347-374.

Norwood, V.T., Fermelia, L.R. & Tadler, G.A. (1972) Multispectral scanner system for ERTS. Report No. NAS 5-11255 of Hughes Aircraft Corporation to NASA.

Odenyo, V. (1978) Application of LANDSAT data to the study of land and range resources in the Narok area, Kenya. Research Report 79-4, Canada Centre for Remote Sensing, Department of Energy, Mines and Resources, Ottawa, Canada.

Olang, M.O. (1984) The endangered grasslands of the Masai Mara and Loita plains. Paper presented at the Workshop on Plant Communities of Kenya, Environmental Training and Management for Africa, USAID, Nairobi.

Onyeanusi, A.E. (1983) The production and fate of grasslands in Masai Mara National Reserve, Kenya. Unpubl. M.Sc Thesis, Univ. of Nairobi.

Oxby, C. (1982) Group Ranches in Africa. Pastoralist Network Paper 13d, Overseas Development Institute, London.

Pearson, R.L. & Miller, L.D. (1972) Remote mapping of standing crop biomass for estimation of the productivity of the short grass prairie. Proceedings of the 8th International Symposium on Remote Sensing of the Environment, Ann Arbor, Environmental Research Institute of Michigan, 1355-1381.

Pearson, R.L., Tucker, C.J. & Miller, L.D. (1976) Spectral mapping of shortgrass prairie biomass. Photogrammetric Engineering and Remote Sensing 42: 317-323.

Peden, D. & Olang, M.O. (1982) An evaluation of the PCQ method of sampling tree density. Technical Report Series No. 74, KREMU, Nairobi.

Pellew, R.A.P. (1981) The giraffe (Giraffa camelopardalis tippelskirchii Matschie) and its Acacia food resource in the Serengeti National Park. Unpubl. Ph.D. Thesis, Univ. of London.

Pellew, R.A.P. (1983) The impact of elephant, giraffe and fire upon the Acacia tortilis woodlands of the Serengeti. Afr. J. Ecol. 21: 41-74.

Pennycuick, C.J., Sale, J.B., Stanley Price, M. & Jolly, G.M. (1977) Aerial systematic sampling applied to censuses of large mammal populations in Kenya. E. Afr. Wildl. J. 15: 139-146.

Pennycuick, C.J. & Western, D. (1972) An investigation of some sources of bias in aerial transect sampling of large mammal populations. E. Afr. Wildl. J. 10: 175-191.

Pennycuick, L. (1975) Movements of the migratory wildebeest population in the Serengeti area between 1960 and 1973. E. Afr. Wildl. J. 13: 65-87.

Philip, M.S. (1983) Measuring Trees and Forests. Univ. of Dar-es-Salaam.

Poissonet, P.S., Poissonet, J.A., Godron, M.P. & Long, G.A. (1973) A comparison of sampling methods in dense herbaceous pasture. J. Range Mgmt. 26: 65-67.

Pratt, D.J. (1966) Bush-control studies in the drier areas of Kenya. III Control of Disperma in semi-desert dwarf-shrub grassland. J. appl. Ecol. 3: 277-291.

Pratt, D.J., Greenway, P.J. & Gwynne, M.D. (1966) A classification of East African rangeland, with an appendix on terminology. J. appl. Ecol. 3: 369-382.

Pratt, D.J. & Gwynne, M.D. (eds.) (1977) Rangeland Management and Ecology in East Africa. Hodder and Stoughton, London.

Pratt, D.J. & Knight, J. (1971) Bush-control studies in the drier areas of Kenya. V. Effects of controlled burning and grazing management on Tarchonanthus/Acacia thicket. J. appl. Ecol. 8: 217-237.

Pratt, W.K. (1978) Digital Image Processing. John Wiley, New York.

Prole, J.H.B. (1976) Pastoral land use. In: Morgan, W.T.W. (ed.) Nairobi: City and Region. Oxford Univ. Press, Nairobi.

Rattray, J.M. (1960) The Grass Cover of Africa. Agricultural Studies No. 49, FAO, Rome.

Richardson, A.J. & Wiegand, C.L. (1977) Distinguishing vegetation from soil background. Photogrammetric Engineering and Remote Sensing 43: 1541-1552.

Risser, P.G. & Zedler, P.H. (1968) An evaluation of the grassland quarter method. Ecology 49: 1006-1009.

Rosenzweig, M.L. (1968) Net primary productivity of terrestrial communities: prediction from climatological data. Am. Nat. 102: 67-74.

Rossiter, P. (1981) The wildebeest disease. Swara (Magazine of East African Wild Life Society) 4: 22-24.

Rouse, J.W., Haas, R.H., Schell, J.A. & Deering, D.W. (1973) Monitoring vegetation systems in the Great Plains with ERTS imagery. Proceedings of the 3rd ERTS Symposium, NASA Special Publication 351: 309-317.

Ruthenberg, H. (1976) Farming Systems in the Tropics. Oxford Univ. Press.

Ryan, T.A., Joiner, B.L. & Ryan, B.F. (1981) MINITAB Reference Manual. Pennsylvania State Univ.

Sachs, R. & Debbie, J.G. (1969) A field guide to the recording of parasitic infestation of game animals. E. Afr. Wildl. J. 7: 27-38.

Saggerson, E.P. (1972) Geology. In: Morgan, W.T.W. (ed.) East Africa: its Peoples and Resources. Oxford Univ. Press.

Sandford, G.R. (1919) An Administrative and Political History of the Masai Reserve. Waterlow and Sons, London.

Satterwhite, M.B. (1981) Changes in soil spectral reflectance by vegetative cover. Proceedings of the American Society of Photogrammetry 47th Annual Meeting, Washington DC, 70-86.

Scott, R.M., Webster, R. & Lawrence, C.J. (1971) A Land Systems Atlas of Western Kenya. MVEE, Christchurch, Hants.

Siegal, S. (1956) Nonparametric Statistics for the Behavioural Sciences. McGraw-Hill.

Siegal, B.S. & Goetz, A.R.H. (1977) Effect of vegetation on rock and soil type discrimination. Photogrammetric Engineering and Remote Sensing 43: 191-196.

Simon, N. (1963) Between the Sunlight and the Thunder: the Wildlife of Kenya. Collins, London.

Sinclair, A.R.E. (1974) The natural regulation of buffalo populations in East Africa. IV. The food supply as a regulating factor, and competition. E. Afr. Wildl. J. 12: 291-311.

Sinclair, A.R.E. (1975) The resource limitation of trophic levels in tropical grassland ecosystems. J. Anim. Ecol. 44: 497-520.

Sinclair, A.R.E. (1977) The African Buffalo. Univ. of Chicago Press.

Sinclair, A.R.E. (1979a) Dynamics of the Serengeti ecosystem: process and pattern. In: Sinclair, A.R.E. & Norton-Griffiths, M. (eds.) Serengeti: Dynamics of an Ecosystem. Univ. of Chicago Press.

Sinclair, A.R.E. (1979b) The Serengeti environment. In: Sinclair, A.R.E. & Norton-Griffiths, M. (eds.) Serengeti: Dynamics of an Ecosystem. Univ. of Chicago Press.

Sinclair, A.R.E. (1979c) The eruption of the ruminants. In: Sinclair, A.R.E. & Norton-Griffiths, M. (eds.) Serengeti: Dynamics of an Ecosystem. Univ. of Chicago Press.

Skovlin, J.M. (1980) An evaluation of 10-year rangeland changes at selected sites throughout Kenya. Unpubl. Report, KREMU, Nairobi.

Skovlin, J.M. & Williamson, D.L. (1978) Bush control and associated tsetse fly problems of rangeland development on the coastal plain of East Africa. In: Hyder, D.N. (ed.) Proceedings of the First International Rangeland Congress, Denver, Colorado, 581-583.

Slater, P.N. (1979) A re-examination of the LANDSAT MSS. Photogrammetric Engineering and Remote Sensing 45: 1479-1485.

Sokal, R.R. & Rohlf, F.J. (1969) Biometry. W.H. Freeman.

Sombroek, W.G., Braun, H.M.H. & van der Pouw, B.J.A. (1980) Exploratory soil map and agro-climatic zone map of Kenya, 1980: scale 1:1,000,000. Exploratory Soil Survey Report No. E1, Kenya Soil

Survey, Nairobi.

Spence, D.H.N. & Angus, A. (1971) African grassland management - burning and grazing in Murchison Falls National Park, Uganda. In: Duffey, E. & Watt, A.S. (eds.) The Scientific Management of Animal and Plant Communities for Conservation. Blackwell, Oxford.

Spencer, P. (1973) Nomads in Alliance: Symbiosis and Growth Among the Rendille and Samburu of Kenya. Oxford Univ. Press.

Spinage, C.A. & Guiness, F.E. (1972) Effects of fire in the Akagera National Park and Mutara Game Reserve, Rwanda. Revue Zool. Bot. afr. LXXXVI: 302-336.

Stelfox, J.G. & Peden, D.G. (1981) The aerial survey programme of the Kenya Rangeland Ecological Monitoring Unit: 1976-79. In: Low-Level Aerial Survey Techniques. ILCA Monograph 4, International Livestock Centre for Africa, Addis Ababa, 69-83.

Stelfox, J.G., Pecen, D.G., Mbugua, S.W., Amuyunzu, C.L. & Hudson, R.J. (1980) Populations, stocking rates and distributions of wildlife and livestock on Mara and Loita plains: December 1978 - November 1979. Technical Report Series No. 19, KREMU, Nairobi.

Stewart, D.R.M. & Talbot, L.M. (1962) Census of wildlife on the Serengeti, Mara, and Loita plains. E. Afr. agric. For. J. 28: 58-60.

Strang, R.M. (1973) Bush encroachment and veld management in South Central Africa: the need for a reappraisal. Biol. Conserv. 5: 96-104.

Strickland, R.D.W. (ed.) (1973) Narok District Plan. Narok Planning Team, Kenya Soil Survey, Nairobi.

Taiti, S.W. (1973) A vegetation survey of the Maasai Mara National Reserve, Narok District, Kenya. Unpubl. M.Sc. Thesis, Univ. of Nairobi.

Talbot, L.M. (1960) Land use survey of Narok District. Office of the District Administration, Narok (also reproduced by Humbolt State College, Arcata, California).

Talbot, L.M. (1970) Ecology of western Maasai. Unpubl. Ph.D. Thesis, Univ. of California, Berkeley.

Talbot, L.M. & Talbot, M.H. (1963) Wildebeest in western Maasailand. Wildl. Monogr., Chestertown, No. 12.

Talbot, L.M., Talbot, M.H. & Lamprey, H.F. (1961) An introduction to the landscape: wildlife and land-use ecology and conservation in Maasailand and other areas of the southern Rift Valley and central provinces in Kenya and northern Tanzania. Guide for field trips of the Symposium on Conservation of Nature and Natural Resources in Modern African States: IUCN and CCTA, Arusha, Tanganyika.

Thalen, D.C.P. (1981) An approach to evaluating techniques for surveying vegetation on arid rangelands. In: Low-Level Aerial Survey Techniques. ILCA Monograph 4, International Livestock Centre for Africa, Addis Ababa, 85-97.

Thomas, A.S. (1945) The vegetation of some hillsides in Uganda. Illustrations of human influence in tropical ecology. II. J. Ecol. 33: 10-43.

Thornthwaite, C.W. (1948) An approach to a rational classification of climate. Geogrl. Rev. 38: 55-95.

Thornthwaite, C.W. & Mather, J.R. (1957) Instructions and tables for computing potential evaporation and the water balance. Publications in Climatology 10: 185-311.

Townshend, J.R.G. & Tucker, C.J. (1981) The utility of AVHRR of NOAA 6 and 7 for vegetation mapping. Proceedings of the 8th Annual Conference of the Remote Sensing Society on Matching Remote Sensing Technologies and their Applications, London, 97-109.

Trapnell, C.G. (1959) Ecological results of woodland burning experiments in Northern Rhodesia. J. Ecol. 47: 129-168.

Trapnell, C.G., Brunt, M.A., Birch, W.R. & Trump, E.C. (1969) Vegetation Land Use Survey of South-Western Kenya. Map Sheet No. DOS (D.R.) 3006 (Sheet 3), Directorate of Overseas Surveys, London.

Trump, E.C. (1972) Vegetation and land use survey of Narok District. Working Paper 10, UNDP/FAO, Nairobi.

Tucker, C.J. (1977) Use of near infrared/red radiance ratios for estimating vegetation biomass and physiological status. NASA/GSFC Report X-923-77-183, Greenbelt, Maryland.

Tucker. C.J. (1979) Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment 8: 127-150.

Tucker, C.J. & Maxwell, E.L. (1976) Sensor design for monitoring vegetation canopies. Photogrammetric Engineering and Remote Sensing 42: 1399-1410.

van Zee, C.J. & Bonner, K.G. (1981) Estimating rangeland cover proportions with large scale colour infrared aerial photographs. Proceedings of the 8th Biennial Workshop on Colour Aerial Photography in the Plant Sciences and Related Fields, American Society of Photogrammetry, 73-82.

Verdcourt, B. & Trump, E.C. (1969) Common Poisonous Plants of East Africa. Collins, London.

Vesey-Fitzgerald, L.D.E.F. (1969) Vegetation dynamics, Mara valley, Serengeti National Park: safari report August-September, 1969. Typescript report to Tanzania National Parks, Arusha, Tanzania.

Vesey-Fitzgerald, L.D.E.F. (1971) Fire and animal impact on vegetation in Tanzania National Parks. Proceedings of the Annual Tall Timbers Fire Ecology Conference 11: 297-317.

Vogl, R.J. (1974) Effects of fire on grasslands. In: Kozlowski, T.T. & Ahlgren, C.E. (eds.) Fire and Ecosystems. Academic Press, New York.

Wakefield, T. (1870) Routes of native caravans from the coast to the interior of eastern Africa, chiefly from information given by Sadi Bin Ahedi, a native of a district near Gazi, in Udigo, a little north of Zanzibar. J. Roy. Geog. Soc. XL: 303-339.

Walker, B.H. (1970) An evaluation of eight methods of botanical analysis on grasslands in Rhodesia. J. appl. Ecol. 7: 403-416.

Walker, B.H. (1980) A review of browse and its role in livestock production in southern Africa. In: Le Houerou, H.N. (ed.) Browse in Africa: the Current State of Knowledge. International Livestock Centre for Africa, Addis Ababa, Ethiopia.

Walker, B.H. & Noy-Meir, I. (1982) Aspects of the stability and resilience of savanna ecosystems. In: Huntley, B.J. & Walker, B.H. (eds.) Ecology of Tropical Savannas. Ecological Studies 42. Springer-Verlag, Berlin.

Walter, H. (1964) Productivity of vegetation in arid countries: the savannah problem and bush encroachment after overgrazing. IUCN New Series No. 4: 221-229.

Watson, R.M. (1972) Results of aerial livestock surveys of Kaputei Division, Samburu District and North-Eastern Province. Statistics Division, Ministry of Finance and Planning, Nairobi.

Watson, R.M. & Bell, R.H.V. (1969) The distribution, abundance and status of elephant in the Serengeti region of northern Tanzania. J. appl. Ecol. 6: 115-132.

Webster, R. & Beckett, P.H.T. (1970) Terrain classification and evaluation using air photography: a review of recent work at Oxford. Photogrammetria 26: 51-75.

Welch, J.R. (1960) Observations of deciduous woodland in the Eastern Province of Tanganyika. J. Ecol. 48: 557-573.

Werger, M.J.A. (1977) Effects of game and domestic livestock on vegetation in east and southern Africa. In: Krause, W. (ed.) Handbook of Vegetation Science, Vol. 13, W. Junk, The Hague.

West, O. (1965) Fire in vegetation and its use in pasture management with special reference to tropical and subtropical Africa. Publication No. 1, Commonwealth Agricultural Bureau, Hurley, Berkshire.

Western, D. (1973) The structure, dynamics and changes of the Amboseli ecosystem. Unpubl. Ph.D. Thesis, Univ. of Nairobi.

Western, D. (1982) The environment and ecology of pastoralists in arid savannas. Development and Change. 13: 183-211.

Western, D. & Dunne, T. (1979) The location of Maasai settlements in relation to geomorphology, hydrology and vegetation. Human

Ecology 7: 75-98.

Western, D. & van Praet, C. (1973) Cyclical changes in the habitat and climate of an East African ecosystem. Nature, Lond. 241: 104-106.

White, S.E. (1915) The Rediscovered Country. Doubleday, New York.

Whitelaw, D.D. (1983) Experimental studies on genetic resistance to the African trypanosomiasis in small East African ruminants. Proceedings of the 2nd CRSP Small Ruminant Kenya Workshop, Nairobi, 222-225.

Whiteside, E.F. and Langridge, W.P. (1960) Tsetse survey report in Kenya Veterinary Annual Report, 1959. Govt. Printer, Nairobi.

Whittingham, C.P. (1974) The Mechanisms of Photosynthesis. Edward Arnold, London.

Wildlife Planning Unit (WPU) (1983) Maasai Mara National Reserve Management Plan. Wildlife Planning Unit, Ministry of Environment and Natural Resources, Nairobi.

Williams, L.A.J. (1964) Geology of the Mara river - Sianna area. Report No. 66, Geological Survey of Kenya, Ministry of Natural Resources, Nairobi.

Williamson, H.D. & Keech, M.A. (1983) Evaluation of bush encroachment in Zimbabwe. Proceedings of the 9th Annual Conference of the Remote Sensing Society on Remote Sensing for Rangeland Monitoring and Management, Silsoe, Bedfordshire, 93.

Willis, T.G., Williams, C.M., Denike, G.N., McBean, D.S. & Ukrainetz, H. (1969) Report of the agricultural feasibility study team, Narok District, Kenya, to the External Aid Office, Government of Canada, Ottawa.

Wing, L. & Buss, I.O. (1970) Elephants and forests. Wildl. Monogr., Chestertown, No. 19.

Woodhead, T. (1968) Studies of potential evapotranspiration in Kenya. East African Agricultural and Forestry Research Organization, Muguga, Kenya.

Woosnam, R.B. (1914) Report on a search for Glossina on the Amala (Engabei) river, southern Masai Reserve, East Africa protectorate. Bull. ent. Res. 4: 271-278.

Zonneveld, I.S. (1978) A critical review of survey methods in the Third World with special emphasis on remote sensing. In: Hyder, D.N. (ed.) Proceedings of the First International Rangeland Congress, Denver, Colorado, 510-513.