Spatial and Temporal Modelling for Sustainable Management of Semi-Arid Rangelands

The Wildlife versus Livestock Issue in the Amboseli Ecosystem, Southern Kenya

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1. Summary

The aim of this research was to develop a methodology to integrate information on the spatial and temporal diversity of tropical rangelands ecosystems, e.g., the Amboseli ecosystem in South East Kenya, including both biophysical and human aspects, and to apply this information in integrated environmentally sound management of natural resources. Furthermore, the model should not only consider the "protected" area itself, e.g., the Amboseli National Park, but should take the surrounding areas (Maasai controlled group-ranches) with human activities (where the impact is often coming from) in consideration as well.

Therefore, a spatial and temporal modelling system has been developed as a user friendly tool for decision makers e.g., managers, planners and others involved in the (sustainable) management of the Amboseli ecosystem. The developed modelling system combines both spatial and temporal data together with other attribute (e.g., statistical) data in such a way, that it is able to simulate the processes going on in the ecosystem, in space and in time, and the result will be a spatial presentation (with qualitative and quantitative data) of the expected result of a certain management simulation. In that way the user should be able to examine and evaluate the effects of certain management decisions on the ecosystem functioning, before taking them into practice.

Such a modelling system has been developed for and implemented in the Amboseli Biosphere Reserve in South Kajiado District, Kenya. The Amboseli Biosphere Reserve is a semi-arid rangelands ecosystem with the Amboseli National Park in the centre of it. Limited forage- and water availability for both wildlife and livestock as well as expanding agricultural activities are the main topics causing conflicts between conservationists and the local population. The result of the model for the Amboseli Biosphere Reserve indicates clearly where and in what extend the rangelands of the Amboseli ecosystem will become overgrazed during the dry season. Again, several simulations of different management options were carried out demonstrating which management option will or will not improve the grazing situation in the Amboseli ecosystem. An appropriate herding strategy between different group ranches seems to be essential and sub-dividing of the group ranches might, at the end, lead to severe degradation of the rangelands of the Amboseli ecosystem.

2. The concept of the rangelands management model for the Amboseli Biosphere Reserve

Variability of the climatic and the drought phenomena, makes range productivity a function of climate. In the Amboseli Biosphere Reserve climate is very variable, and drought is a major characteristic. Therefore, the pastoralists (Maasai) make great use of movements to take stock to favourable areas for grazing as forage declines in one area. But herd movements are "in principle" restricted to the boundaries of the group ranches.

To be able to construct a model, which is calculating and displaying the spatial and temporal variation of the expected impact of the grazing activities of both wildlife and livestock in the Amboseli Biosphere Reserve, data has to be collected concerning animal distribution and density per wet and or dry season, the Maasai herding strategies, wildlife migratory routes, the forage production of various land cover types, the water availability during the dry season, rainfall, etc. The model consists out of three parts, the (forage) availability, the (forage) demand and the accessibility for both wildlife and livestock.

The forage availability is closely related to the productivity of the rangelands under certain climatological and biophysical conditions. Most of the, for the model considered, biophysical conditions are not changing very fast or varying much in time, but the climatological aspect e.g., rainfall, has a most significant contribution to the productivity of the rangelands. The variability of the rainfall is very high and varies each (rainy) season. Therefore, the availability (or production)-aspect is the yearly (seasonal) variable in time. The forage demand is related to the distribution and density of both wildlife and livestock during different periods (e.g., wet- and or dry season). These densities and distributions are determined by the actual census data (DRSRS) and relatively constant, if considered on long term base (DRSRS census data, from 1977 till 1991). The accessibility is a matter of the availability of drinking water for especially the water dependent wildlife species and livestock during the dry season, but also other aspects like topography, landcover and surface roughness play a role. Again, changes in this aspect are of a more long term character and if changes occur, they are relatively easily to update in the model.

Changes are fast and unpredictable (in fact each growing season is different because of the fluctuating rainfall) with as a consequence, that management actions have to be adopted relatively fast as well. Therefore, a model has been constructed, which will be able to calculate and display the spatial and temporal variation of the expected impact of grazing in the Amboseli Biosphere Reserve for each long dry season. To be able to do so, data concerning the forage production of the rangelands during a specific season/year, the forage demand or consumption and the accessibility to the rangelands in the Amboseli Biosphere Reserve has been analyzed. A description about the analysis and procedures followed to build the model, is given in the following sections. Furthermore, a demonstration package AMBODEMO is added to this article and a detailed description in the theoretical background of modelling is given in Toxopeus, 1996.

2.1 The availability (production of forage) aspect

The productivity of rangelands can be described as a function of rainfall, soil condition, land cover and topography. A brief description of the major procedures followed to estimate the forage production of the rangelands in the Amboseli Biosphere Reserve is given in the following sections.

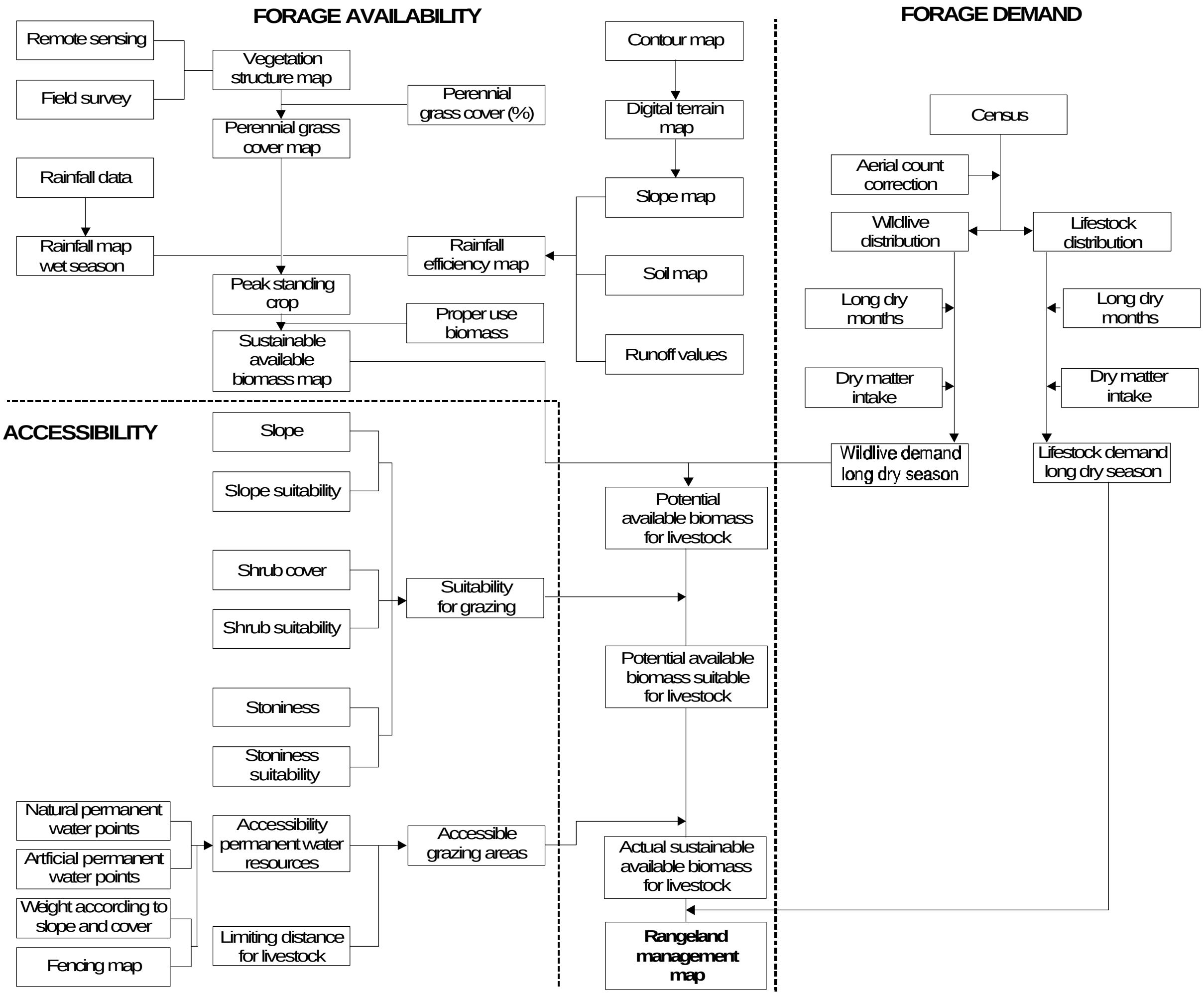

Figure 1. Basic structure of the Amboseli Rangelands Management model.

2.1.1 Perennial Grass Cover

The perennial grass cover map has been compiled with the use of interpretation of satellite images (TM: 01-10-1988, SPOT: 05-10-1991), aerial photographs, data collected during field surveys (in 1992 and 1993) and other relevant data (Gwynne, 1977, Nyakweba, 1987, Touber, 1983). During field surveys over 75 samples has been taken, estimating the percentage cover of the ground-, shrub- and tree layer, according to the survey methodology described by Van Gils and Van Wijngaarden, 1984 and Van Gils et al., 1985. Identification of the different grass species has been done by experienced botanists from DRSRS and literature (Bogdan, 1958, Edwards and Bogdan, 1951, Gwynne, 1976, Napper, 1965, Weiss, 1987). Each mapping unit represents the percentage cover of the different layers (e.g., perennial grasses).

2.1.2 Rainfall Distribution

A long term rainfall distribution map for the wet season can be calculated by interpolation of rainfall data (Bocco et al, 1991) from about 60 different rainfall stations, starting at 1959 up till 1989. The main source of the rainfall data was the Kenya Meteorological Department at Ngong. Additional data was collected or abstracted from sources like Altmann et al. (1992), East African Meteorological Department (1972 and 1975), Mugai and Kanake (1978), Njeru (1980), Woodhead

(1968) and data concerning the seasonal distribution of rainfall in Kenya by Braun (1986), Norton-Griffiths (1977) and Western (1973).

As soon as rainfall data from a particular season of interest comes available, an actual rainfall distribution map for that particular season can be calculated. When data of certain rainfall stations are missing, the long term rainfall data of these stations will be used as well. But the long term data might be different from the data of the wet season of interest. Therefore, the available rainfall data of the season of interest will be compared with the long term data of the same rainfall stations. The factor of difference will be applied for the long term rainfall data of the stations, of which the rainfall data for the particular season is missing, before the interpolation of rainfall data for the season of interest will take place. Further more, there will be the possibility to update the "long term" rainfall data base. This includes not only new data for already existing stations, but new stations can be added as well. During the next (model) run the new data will also be used to give a more accurate or up to date prediction of the expected (long term) rainfall distribution.

The calculation starts with a gridding operation (in the case that new rainfall values have been defined), using the moving average operation with Weight Method $1/d^5$ -1, in order to create the rainfall map.

2.1.3 Conversion of Rainfall to Water Availability for Vegetation

Below an annual precipitation of approximately 700 mm, primary production seems to be linear correlated with rainfall (Cole et al., 1976). Other authors found good relationships between rainfall and vegetation production as well (Braun, 1973, Breman, 1975, Houerou and Hoste, 1977, Walter, 1971). According to Van Wijngaarden (1985) the availability of water can be directly related to the rainfall for different groups of soils, because run-off and run-on and the water holding capacity for these groups of soils are about the same. The area has been divided into four different "physical" soil groups, taking topography in account as well, where some run-off occurs occasionally (1), where run-off is rather common (2), where run-on occurs regular (3) and swamp areas (4).

Table 1: Rainfall affectivity factors per "physical" group, to be used in the equation: PSC/R (gr/m2/mm)="factor"*PGC(%)

	Physical groups	Factor
1.	imperfectly to poorly drained soils with a flat or slightly depressional; topography; in general no run-off; occasionally some run-on	0.0137
2.	well to excessively drained shallow soils with a sloping topography; run-off is common and during heavy storm may be considerable	0.0059
3.	well drained deep soils with a flat or gently undulating topography; in general only slight run-off occurs	0.0120
4.	Swamps	0

The rainfall affectivity map is created by combining the rainfall affectivity values with the soil map (containing the 4 physical soil groups).

2.1.4 Peak Standing Crop of the perennial grasses:

Several methodologies are used to estimate the production of forage for large herbivores, which are summarized by Mwichabe (1988). The forage production is always directly or indirectly a product of the amount of rainfall and grass cover (Van Wijngaarden, 1985), but the final peak standing crop at the end of the rainy season is depending on a number of other factors as well, like nutrient availability (Penning de Vries and Djiteye, 1982), the contribution of perennial and or annual grasses and forbs (Kelly and Walker, 1976, Leuthold, 1972, Prins, 1987, Van Wijngaarden, 1985), the amount of rainfall during the growing season and the length of the growing season (Herlocker, 1980, Van Wijngaarden, 1985) and the (non) utilization of swamp vegetation (Western and Lindsay, 1984).

According to Bell (1982) and Penning de Vries and Djiteye (1982) the nutrient supply in the relatively poor west African savanna soils is often a limiting factor in plant growth, as especially nitrogen and phosphorus limit the primary production at a rainfall of more than 300 mm per growing period. For the more comparable Tsavo-ecosystem nutrient availability only becomes limiting in wet years with rainfall more than 400 mm per growing period (Van Wijngaarden, 1985). As in Amboseli rainfall generally never exceeds 400 mm per growing season, the nutrient availability in the Amboseli ecosystem is assumed not to be limiting for the growth of perennial grasses during the growing season.

Swamp vegetation and annual grasses are not used for the estimation of the peak standing crop, because of their very limited contribution to the total forage to be used by the large herbivores during the dry season. The sum of the rainfall during the growing season will determine the peak standing crop according to the equations used by Van Wijngaarden (1985).

The peak standing crop map is calculated by multiplying the seasonal rainfall map with the grass cover- and rainfall affectivity map:

$$PSC = RF_{distribution} * PGC * RF_{effectivity}$$

PSC = Peak standing crop (gr/m2).
$RF_{seasonal\ rf}$ = Seasonal rainfall (mm).
PGC = Perennial grass cover (%).
$RF_{affectivity}$ = Rainfall affectivity factor.

2.1.5 Availability of Forage for the Large Herbivores

According to the FAO (1988) a combined factor, called "edible forage", should be reduced from the herbaceous peak standing crop to account for grazing efficiency, forage loss and a "proper use factor" to account for sustainability. This factor may vary according to different researchers and the different situations from 30% in South Ethiopia (Cossins and Upton, 1987) to 45% in Tsavo, Eastern Kenya (Van Wijngaarden, 1985). The situation described by Van Wijngaarden (1985) for Tsavo, Kenya is most comparable with the situation in the Amboseli Biosphere Reserve and, therefore, his estimations will be used. He estimates that not more than 55% of the grass cover should be removed in one way or the other to keep the grasslands at least in the same condition as it was before. So, if utilizing the grasslands should be sustainable, to prevent degradation, at least 45% of the peak standing crop should be left at the beginning of the next rainy season. But additionally about 10% of the peak standing crop will be reduced because of invertebrate consumption and natural decay (van Wijngaarden, 1985), resulting in 45% of the peak standing crop to be used.

The proper use factor can be combined with the peak standing crop map, to create a map with the amount of forage that can be used for grazing on a sustainable basis:

$$SABM = PSC * \frac{PUseBM[\%]}{100[\%]}$$

SABM = Sustainable available forage (gr/m2).
PUseBM = Proper use factor (45%).

2.2 The Forage Demand (of Wildlife and Livestock) Aspect

2.2.1 Relevant Large Herbivores

The selection of the large herbivores species (including livestock), who are inhabiting the Amboseli ecosystem is based on survey's and animal-counts carried out by DRSRS (Peden, 1984) and by Western (1976). The separation between the different feeding habitats is made according to Andere (1981), Ayeni (1975), Cobb (1976), Drent and Prins (1987), Glover and Trump (1970), Goddard (1970), Grimsdell and Field (1976), Hofmann (1973), Jarman (1974), Laws et al. (1975), Leuthold (1970), Leuthold (1971), Leuthold and Leuthold (1972), McDowell et al. (1983), McKay (1983), Okiria (1980), Olivier (1982), Soest (1982), Ungar and Noy-Meir, (1986), Van Wijngaarden (1985) and Western (1975).

For the model the herbivores monitored by DRSRS are used to estimate the density and distribution of the herbivores. Browsers are excluded in the forage need for the dry season, because the model is calculating the forage needs for grazers and mixed feeders only. For grazers the total forage need will be used, but for the mixed feeders only that proportion of their forage need will be used, that is covered by grass. If they have a preference for grass, 65% of their diet will be considered, if there is a preference for browse, only 35% of their diet will be considered. But if it is know for a certain species a more exact percentage of grass consumption in relation to the total consumption, then that figure will be used.

Figure 2: A typical grazer like buffalo (Syncerus caffer) in the Amboseli ecosystem.

Figure 3: A typical mixed feeder like Impala (Aepyceros melampus) in the Amboseli ecosystem.

2.2.2 Body Weight versus Energy Intake

The estimated average (life) body weight (in KG) of adult animals is a compilation of the estimates, given by several authors (Cobb, 1976, Drent and Prins, 1987, Mckay, 1983, Peden, 1984, Sinclair, 1975, Van Wijngaarden, 1985).

Forage requirements are relatively well studied for domestic herbivores, but less for wildlife. The quantity and quality of food required by specific animals are indicated at specific performances. Different methodologies are applied to estimate the forage need (daily DM requirement) for herbivores (Coe, 1972, Guy, 1975, Kleiber, 1975, Leuthold, 1971 and 1977, Ndumo, 1978, Prins, 1987, Sinclair, 1975, Soest, 1982, Western and Lindsay, 1984, Western and Finch, 1986, Van Wijngaarden, 1985). By comparing the different methodologies, an estimation has been made by taking the average of the values, resulting from the most relevant or comparable studies of the life body weight and their DM requirements per species (water dependent or independent, grazers or mixed feeders) under semi arid rangelands conditions during the long dry season.

Table 2. The daily dry matter intake of grass of free ranging herbivores during the dry season and the percentages of the daily dry matter intake in relation to their life body weight

Species	Life bodyweight kg/animal	% grass in diet %/animal	DM grass requirement kgDM/day	% life bodyweight %
Cattle	205	100	3.1	1.5
Shoat	25	50	0.6	2.4
Donkey	140	100	3.5	2.5
Elephant	1725	20	8.3	0.5
Buffalo	420	100	8.5	2.0
Wildebeest	170	100	4.5	2.6
Zebra	210	100	5.2	2.5
Thompson	15	65	0.5	3.3
Grant's	45	75	1.0	2.2
Kongoni	125	100	3.0	2.4
Impala	45	65	0.9	2.0
Eland	340	65	2.9	0.9
Oryx	140	100	3.5	2.5
Waterbuck	170	100	4.3	2.5
Warthog	45	50	0.7	1.6
Ostrich	115	100	2.8	2.4

2.2.3 Census Data (animal counts and distribution)

DRSRS carried out aerial census on seasonal/yearly base both on livestock and on wildlife to estimate the distribution and the number of large herbivores in the Amboseli ecosystem. The methodology of estimating the "real" animal numbers are described in various papers (Caughley, 1972, Croze, 1978, ESRI, 1985 and 1986, Grunblatt et al., 1989, Gwynne and Croze, 1975, Norton-Griffiths, 1978, Peden et al., 1980, Said et al., 1989, Western, 1976, Western and Grimsdell, 1979, Wetmore and Townsend, 1977).

When comparing DRSRS aerial census data with ASAL ground census data (Ole Katampoi et al., 1990), the difference per group ranch is varying. In some group ranches higher, in others lower or equal. This might be due to the fact, that the census data is reflecting the presence of animals in a very specific period. Because of the herding strategies of the Maasai livestock will move from one place to another, depending of forage availability, water etc., and move even over the borders of different group ranches. Nevertheless, comparing the number of livestock per summed group ranches (group ranches surrounding the ABR and also the group ranches surrounding the previous ones), the average difference was less than five percent. Therefore, the aerial counts done by DRSRS, when comparing it with the ground counts done by ASAL, are considered to be reliable enough to be used for the model without corrections.

2.2.4 Wildlife Forage Demand for the Long Dry Season

The presence of wildlife is considered a fact of life and in principle not to be managed. Therefore, the forage consumption by wildlife is abstracted from the plant forage available. What is left can in principle be utilized by livestock. By determining the length of the dry season, depending on the date of the end of the wet season the expected forage consumption by wildlife during the dry season can be calculated.

In order to determine the location and extent of the forage demand by wildlife for the long dry season, the length of the long dry season has been combined with average number of days per months (30.4), the dry matter intake value of a species and linked to the map with the distribution and density of each wildlife species:

$$\overset{ZB}{\underset{xx=BF}{DM_{xx}}}[kg] = LDS\ [month] * 30.4 \left[\frac{day}{month}\right] * DMfact_{xx} \left[\frac{kg}{day}\right] * Density_{xx}\ [N]$$

DM_{xx} = Forage demand by wildlife for the long dry season (kg).
LDS = Length of the long dry season (nr. of months).
$DMfact_{xx}$ = Dry matter intake value for wildlife (kg/day).
$Density_{xx}$ = Density of wildlife (N) per gridcell.
xx = A specific wildlife species.

For wildlife the forage demand is summed to obtain a map with the location and extent of the total wildlife forage demand:

$$DMWL_{tot}\ [kg] = \sum_{xx=BF}^{ZB} DM_{xx}$$

$DMWL_{tot}$ = The total forage demand by wildlife (kg).

2.2.5 Livestock Forage Demand for the Long Dry Season

In order to determine the location and extent of the forage demand by livestock for the long dry season, the length of the long dry season has to be combined with average number of days per months (30.4), the dry matter intake value of a species and the distribution and density of a species :

$$\overset{SH}{\underset{xx=CS}{DM_{xx}}}[kg] = LDS\ [month] * 30.4 \left[\frac{day}{month}\right] * DMfact_{xx} \left[\frac{kg}{day * N}\right] * Density_{xx}\ [N]$$

DM_{xx} = Forage demand by livestock for the long dry season (kg).
LDS = Length of the long dry season (nr. of months).
$DMfact_{xx}$ = Dry matter intake value for livestock (kg/day).
$Density_{xx}$ = Density of livestock (N) per gridcell.
xx = A specific livestock species.

For livestock the forage demand is aggregated per group ranch per gridcell to be able to calculate at a later stage the **potential** location and extent of livestock forage demand per pixel:

$$DMLV_{tot}\,[kg] = \sum_{xx=CS}^{SH} DM_{xx}$$

$DMLV_{tot}$ = The total forage demand by livestock (kg).

2.3 The Forage Availability Aspect for Livestock

2.3.1 Sustainable Available Forage

When combining the group ranch map and the sustainable available forage map, information is generated containing information about unique areas within each group ranch with the sustainable available forage for each unique area (each unique area is a different mapping unit within a group ranch, based on the perennial grass cover map). The sustainable available forage is recalculated in kilograms per unique area within each group ranch:

$$SABM_{area}\,[kg] = \frac{SABM\left[\frac{gr}{m^2}\right] * area\,[m^2]}{1000\left[\frac{gr}{kg}\right]}$$

$SABM_{area}$ = Sustainable available forage (kg) per unique area.
area = Unique area (m2) within each group ranch.

The potential forage availability for livestock only is calculated as follows:

$$SABM_{tot}\,[kg] = \sum SABM_{area}\,[kg]$$

$SABM_{tot}$ = The total sustainable available forage (kg).

$$BMfact_{area} = \frac{SABM_{area}\,[kg]}{SABM_{tot}\,[kg]}$$

$BMfact_{area}$ = The fraction of forage (kg) in each unique area in relation to the total forage.

$$DM_{area} = BMfact_{area} * DMWL_{tot}$$

DM_{area} = The forage demand (kg) by wildlife for each unique area.

$$PotAvlBM_{area} = SABM_{area} - DM_{area}$$

$PotAvlBM_{area}$ = The potential available amount of forage for livestock (kg) for each unique area.

$$PotAvlBM_{pix}\left[\frac{gr}{m^2}\right] = \frac{PotAvlBM_{area}\,[kg] * 1000\left[\frac{gr}{kg}\right]}{area\,[m^2]}$$

$PotAvlBM_{pix}$ = The potential available amount of forage (gr/m2) for livestock for each pixel in the whole map.

In this way the potential forage availability (gr/m2) for livestock has been calculated for each pixel in the whole map of the Amboseli ecosystem.

2.3.2 The Suitability of the Rangelands for Livestock Grazing

After the calculation of the forage availability for livestock for the long dry season, the suitability of the rangelands for grazing has to be applied as well to abstract or reduce forage from those rangelands, which are not or less suitable for livestock grazing. Factors like slope steepness, surface roughness and hindrance by vegetation will reduce the amount of forage to what is actually available for grazing. The reduction factors and methodology applied to estimate the suitability of the rangelands for grazing are according to the FAO (1988) classifications (Allen et al., 1987, Breininger et al., 1991, FAO, 1988 and 1991, Pereira and Itami, 1991, Touber, 1983).

Table 3. The different slope steepness classes and the estimated suitability (%) for livestock grazing

	Slope steepness	Suitability
1.	0 - 15%	100%
2.	15 - 30%	75%
3.	30% and steeper	25%

Table 4. The different surface roughness classes and the estimated suitability (%) for livestock grazing

	Surface roughness	Suitability
1.	0 - 2% occupied by stones	100%
2.	2 - 10% occupied by stones	94%
3.	10 - 25% occupied by stones	83%
4.	25 - 50% occupied by stones	63%
5.	> 50% occupied by stones	25%

Table 5. The different shrub hindrance classes and the estimated suitability (%) for livestock grazing

	Shrub hindrance	Suitability
1.	0 - 2% shrub cover	100%
2.	2 - 20% shrub cover	89%
3.	20 - 40% shrub cover	70%
4.	40 - 60% shrub cover	50%
5.	> 60% shrub cover	20%

There are several other factors that prevent or impede livestock movements. Natural ones are for example extreme high or low temperature, often in relation to altitude, diseases, predators, flooding etc. But in the Amboseli ecosystem these limiting factors are not really relevant and therefore not considered as a limitation for grazing for livestock. Artificial ones (human made) are for instance arable farms, pipelines, roads, channels, fenced ranches or fences erected for other purposes etc.

The slope suitability map is generated by linking the user-defined slope suitability values [%] to the classified slope map. In a similar way the grazing suitability according to shrub hindrance and stoniness (surface roughness) are generated.

Finally the different suitability aspects are combined in order to create the grazing suitability according to the above mentioned aspects:

$$Suitability\ [\%] = \frac{Suitability_{stoniness}\ [\%] * Suitability_{shrubs}\ [\%] * Suitability_{slope}\ [\%]}{10000[\%]\ [\%]}$$

2.3.3 Potential Forage Available and Suitable for Livestock

The "combined" suitability factor map can be applied, as a reduction factor to the potential forage availability for livestock, to calculate the potential available forage left for livestock, taking the different suitability aspects of the rangelands into account:

$$PotAvlSt_{pix}\left[\frac{gr}{m^2}\right] = PotAvlBM_{pix}\left[\frac{gr}{m^2}\right] * Suitability\ [\%]$$

$PotAvlSt_{pix}$ = The potential available forage (gr/m2) for livestock, taking the different suitability aspects of the rangelands into account.

2.4 The Accessibility Aspect of Rangeland for Livestock Grazing

Climatic circumstances, like heat stress and the availability of permanent drinking water often determines the distribution of the various (water dependent and water independent) animals in the dry season, including livestock (Ayeni, 1975, Cobb, 1976, Van Wijngaarden, 1985, Western, 1975).

The availability of water is still a crucial point in the herding strategy of the Maasai, together with the availability of forage, the model should be able to develop such a herding strategy to minimize degradation (because of overgrazing) of the rangelands. Therefore, it is essential to know when, where and how much forage and water is available during the different seasons. The availability of forage at the beginning of the dry season can be estimated. The availability of water during the dry season is depending on the existence of artificial water supply (functional or not-functional boreholes (and watertanks), booster - and pipeline water supply) and natural water supply (permanent rivers and swamps, springs and wells). Estimating the water availability during the wet season is not relevant, because water is almost everywhere available because of the many additional seasonal rivers, waterholes, dams etc.).

2.4.1 Artificial Watering Points

The data available on existing boreholes and other artificial watering points is never up to date, because for example an existing functional borehole can become not-functional any time. The unreliability of the functionality of artificial watering points is a serious problem in management point of view. Nevertheless, to be able to give examples of alternative management options, it is assumed, that the artificial watering points, which were functional according to the Ministry of Livestock Development for group ranches like: Kuku (1989), Mbirikani (1989), Eselengei/Emotoroki (1989), Olgulului (1989), Kimana (1989), Mailua (1989) and Osilalei (1989), the Ministry of Water Development (1988 and 1990), Water Dept. Kajiado (1991), and during the field-survey in 1993 can be used for the development of alternative herding strategies for the maasai. On the other hand, if a functional artificial watering point becomes not-functional, this can be updated in the model.

Artificial watering points (like boreholes, booster - and pipeline water), functional according to recent literature or recent field-survey are considered to be operational for livestock use the whole year round.

2.4.2 Natural Watering Points

The natural watering point like permanent rivers and swamps, springs and wells are assumed to be reliable enough to provide water for livestock the whole year round. It is of cause possible that some of them become inaccessible for cattle because of fencing or other matters, but that will be considered as an alternative management option and the consequence of such a management option can be calculated in the scenario part of the model. Therefore, natural watering points (like permanent rivers and swamps, springs and wells) will provide water for livestock the whole year round and are considered to be reliable with no limitations for amount or quality of water (Umar, 1991, FAO, 1988 and 1991, Kuluo, 1991).

2.4.3 Limiting Distance from Water

Summarizing the results from FAO (1988 and 1991), Touber (1983), Western (1982) and field surveys in 1993, carried out by Kio (warden of Amboseli National Park), the accessibility classification according to drinking water availability in the dry season will be from 0 -5 km (daily regime) and from 5-12 km (every other day regime). More than 12 km (other day or third day regime, but under severe conditions) will be considered in principle as inaccessible, because the condition of livestock under these range conditions will become worse and worse.

By applying the distance calculation from the permanent artificial - and natural watering points in the Amboseli ecosystem with weight factors, according to the accessibility and (if) existing fences, an accessibility map according to the above mentioned classification has been generated. The final base map for the distance calculation is created by defining the fences in the area as inaccessible.

2.4.4 Exclusion of Areas Inaccessible to Water Points

Since livestock has a maximum walking distance to water, some areas of availability should be excluded. First, the user-defined limiting distance is translated to map format, before it is combined with the potential forage availability suitable for grazing by livestock, to exclude inaccessible areas and to create the actual forage availability:

$$ActAvl_{pix}\left[\frac{gr}{m^2}\right] = PotAvlSt_{pix}\left[\frac{gr}{m^2}\right] - InAcces_{pix}\left[\frac{gr}{m^2}\right]$$

$ActAvl_{pix}$ = Actual available forage (gr/m2).
$InAcces_{pix}$ = Forage (gr/m2) in inaccessible (excluded) areas.

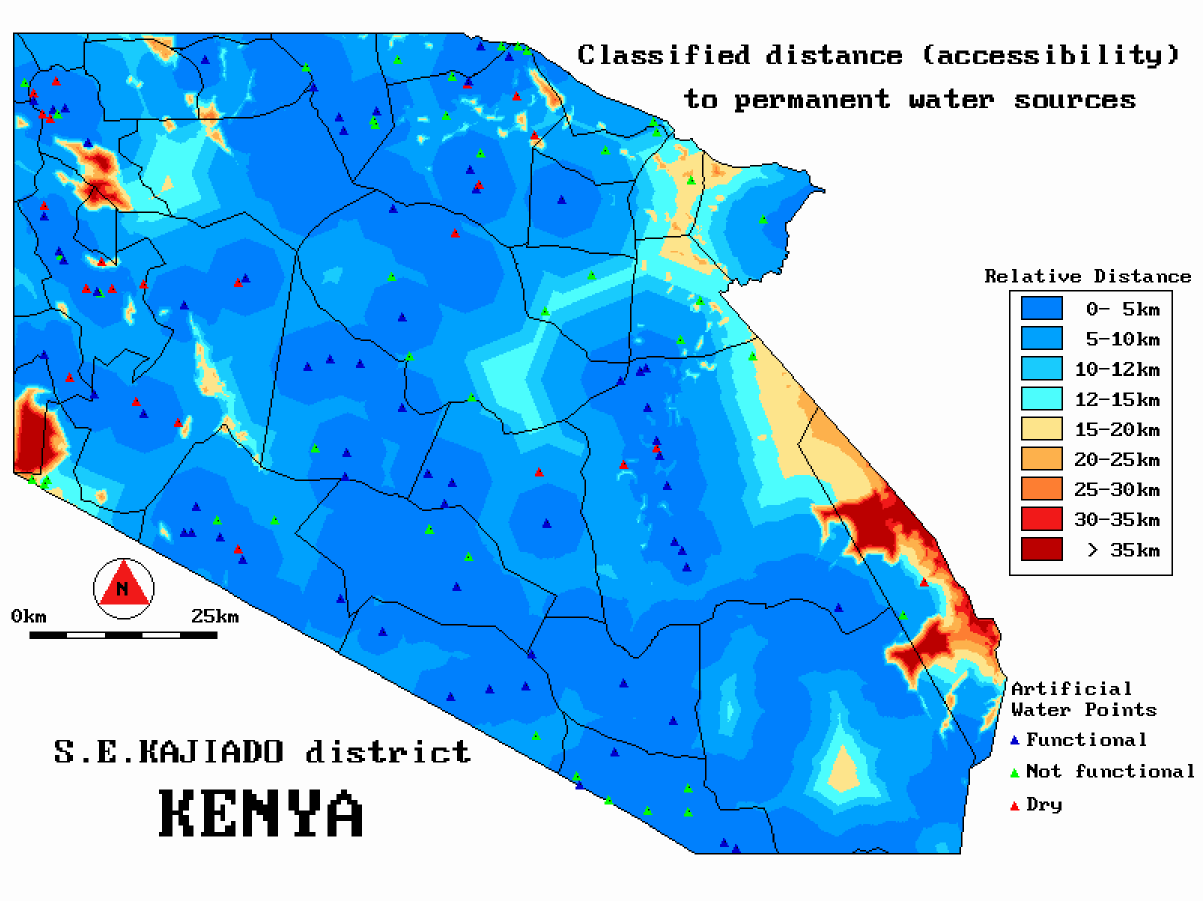

Figure 4. Map indicating the accessibility (indicated as the "relative distance") to grazing areas for livestock in relation to the suitability aspect for grazing and the distance to permanent watering points during the dry season 1992 in the Amboseli ecosystem.

2.5 Assessment of the Status of the Rangelands

Although many authors are using all kinds of methodologies and formulas to estimate the carrying capacity for a certain rangelands (Andere, 1981, Mwichabe, 1988, Pratt and Gwynne, 1977, Western and Praet, 1973), the estimation of the status of the rangelands (e.g., over- or under grazing) in the model will be based on the "final" forage availability in relation to the number of livestock (demand for forage) in that area. The forage availability for livestock will be calculated according to the procedures described previously.

2.5.1 Extraction of livestock forage demand of the actual forage availability

The actual forage availability map for livestock has been combined with the group ranch map, to calculate the redistribution of the livestock forage demand per group ranch over the actual forage availability within the group ranches, assuming that the status of the rangelands is an indicating for the distribution rate of the livestock forage demand within the group ranch:

$$ActAvlBM_{area}\,[kg] = \frac{ActAvl_{\int}0\left[\frac{gr}{m^2}\right] * area\,[\,m^2\,]}{1000\left[\frac{gr}{kg}\right]}$$

$ActAvlBM_{area}$ = Actual available forage (kg) for each unique area within the group ranches.
$ActAvl_{pix}$ = Actual available forage (gr/m2) .
area = Unique area (m2) within each group ranch.

$$BMRanch_{tot}\,[kg] = \sum ActAvlBM_{area}\,[kg]$$

$BMRanch_{tot}$ = Actual available forage (kg) per group ranch.

$$BMfact_{area} = \frac{ActAvlBM_{area}\,[kg]}{BMGroupRanch_{tot}\,[kg]}$$

$BMfact_{area}$ = The fraction of forage (kg) in each unique area in relation to the total forage of the group ranch.

$$DM_{area}\,[kg] = BMfact_{area} * DMLV_{tot}\,[kg]$$

DM_{area} = The forage demand (kg) by livestock for each unique area.

$$RStatus_{area}\,[kg] = ActAvlBM_{area}\,[kg] - DM_{area}\,[kg]$$

$RStatus_{area}$ = The actual status (+ or - forage values (kg)) of the rangelands for each unique area.

$$RStatus_{pix}\left[\frac{gr}{m^2}\right] = \frac{RStatus_{area}\,[kg] * 1000\left[\frac{gr}{kg}\right]}{area\,[\,m^2\,]}$$

$RStatus_{pix}$ = The actual status (+ or - forage values (gr/m2)) of the rangelands per pixel.

The result is the so called "rangelands management map", which is a classified map, with forage values ranging from -500 gr/m2 to + 500 gr/m2, indicating the amount of shortage or surplus of forage, according to the available forage (on a sustainable base) minus the demand for forage during the year (season) of calculation.

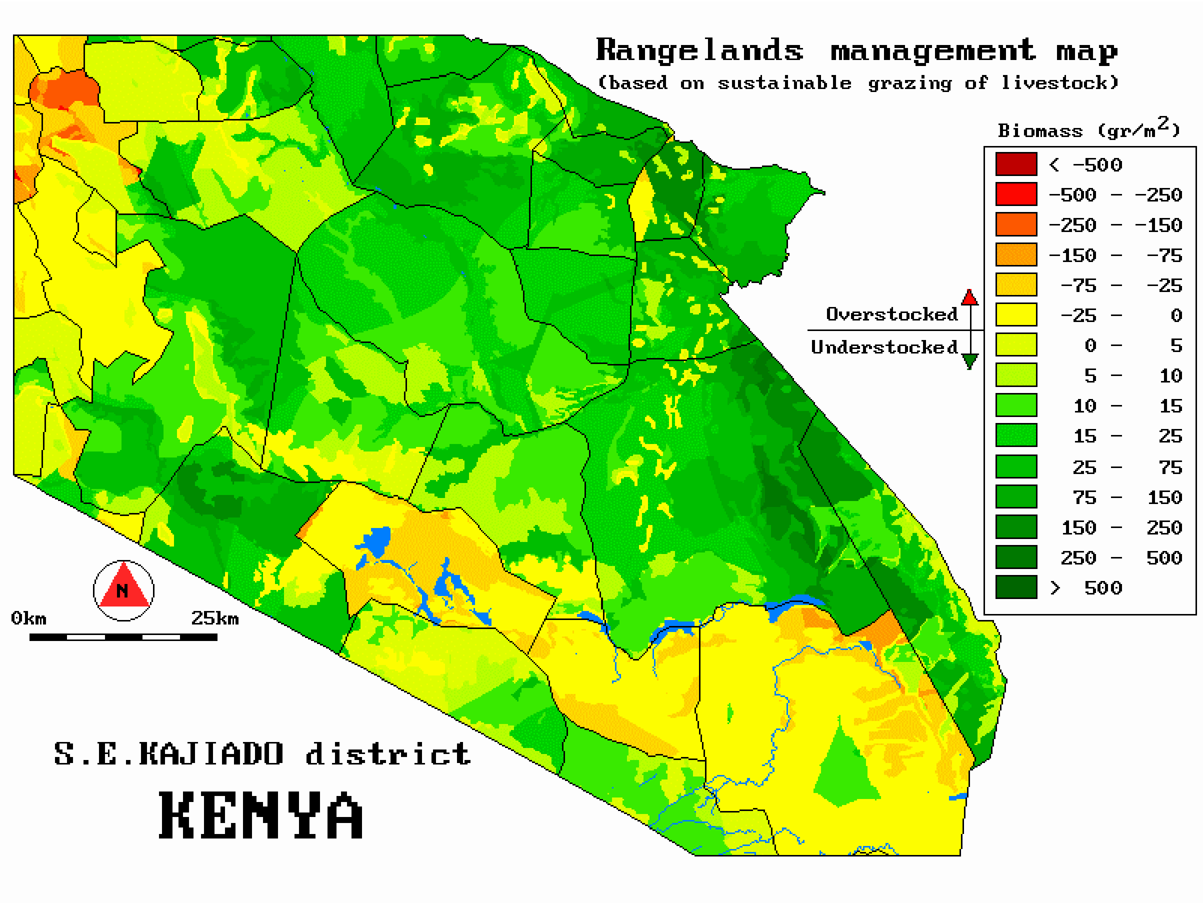

Figure 5: **The so called "rangelands management map", indicating over- and understocked areas during the long dry season of 1992, determined by the available biomass of forage in the Amboseli ecosystem and the demand by the present wildlife and livestock.**

2.6 The Human Aspect

In principle the status of the rangelands (over- or under grazing) is based on the biophysical situation, without taking the minimum number of livestock, that is needed to support the Maasai population on a traditional base, in consideration. Therefore an option to be able to consider the human aspect (concerning the human need for livestock) in the Amboseli ecosystem has been included as well.

According to Brown and Cocheme (1968) the most ideal relation between the human (Maasai) population and livestock is a metabolic weight ratio of 0.045 (this is including 50% addition for bad periods to be on the safe side). The average weight of a human being is estimated on 40 kg (the average weight of a family member of a Maasai household of 6 members). The metabolic weight is than $40^{0.75}$ = 15,9 kg. So each member needs 15.9 / 0.045 = 353.3 kg of metabolic weight of livestock per year. The average weight of cattle is 210 kg with a metabolic weight of $210^{0.75}$ = 55.2 kg and for shoat is 25 kg with a metabolic weight of $25^{0,75}$ = 11.9 kg.

2.6.1 Population Statistics of the Local Maasai

If the population size of the Maasai per group ranch is known, the minimum number of livestock that is needed to support the population on a traditional base can be calculated. By comparing this need (in metabolic livestock weight) with the estimated number of livestock per group ranch(which will be recalculated in total metabolic weight as well), the model will indicate, if a certain group ranch is overstocked or understocked according to the human need for livestock on subsistence level.

The estimated human population growth of 4.72 percent per year (based on data available up till 1992) has been taken in account as well. Unless new Maasai population statistics have been defined, the new Maasai population will be recalculated:

- when population growth has been defined for the scenario:

$$NewPop_{scenario} = PopStat_{model} * \left(1 + \frac{PopGr_{scenario}}{100} \right)^{(year_{scenario} - year_{model})}$$

$NewPop_{scenario}$ = The new Maasai population per group ranch for the defined year, according to the **new** growth rate.
$PopStat_{model}$ = The population number according to the model statistics for 1992.
$PopGr_{scenario}$ = The new population growth rate.

- when population growth has **not** been defined for the scenario:

$$NewPop = PopStat_{model} * \left(1 + \frac{PopGr_{model}}{100} \right)^{(year_{scenario} - year_{model})}$$

$NewPop$ = The new Maasai population per group ranch for the defined year, according to the model growth rate.
$PopStat_{model}$ = The population number according to the model statistics for 1992.
$PopGr_{scenario}$ = The new population growth rate.

2.6.2 Recommended and Required Livestock Numbers according to the Maasai Population

The recommended livestock values are based on sustainable grazing (carrying capacity of the rangelands). They will indicate the theoretically allowed numbers of livestock per group ranch on a sustainable base:

$$\underset{xx=cs}{\overset{sh}{Recommend_{xx}}} = xx * \left(\frac{BMRanch\ [kg]}{DMLV_{GroupRanch}\ [kg]} \right)$$

$Recommend_{xx}$ = The recommended number of a certain livestock species (per group ranch) according to the carrying capacity on a sustainable base.
Xx = A specific livestock species.
$BMRanch_{tot}$ = Actual available forage (kg) per group ranch.
$DMLV_{tot}$ = The total forage demand by livestock (kg) per group ranch.

The required livestock numbers are based on the metabolic intake of the Maasai:

$$Pop_{need}\left[\frac{kg}{year}\right] = NewPop\ [N] * 353.3\left[\frac{kg}{N * year}\right]$$

Pop_{need} = The total need for livestock, calculated in metabolic weight (kg/year) for the Maasai population per group ranch.
NewPop = The new Maasai population per group ranch (N) for the defined year, according to the model growth rate.
353.3 = The need of metabolic weight (kg) of livestock per Maasai member per year.

$$Metab_{avail}\left[\frac{kg}{year}\right] = Current_{cs}\left[\frac{N}{year}\right] * 55.2\left[\frac{kg}{N}\right] + Current_{sh}\left[\frac{N}{year}\right] * 11.9\left[\frac{kg}{N}\right]$$

$Metab_{avail}$ = The actual available metabolic weight (kg/year) for the Maasai per group ranch according to the present numbers of cattle and shoat.
$Current_{cs}$ = The current number of cattle (N) per group ranch.
55.2 = The metabolic weight (kg) of cattle .
$Current_{sh}$ = The current number of shoat (N) per group ranch.
11.9 = The metabolic weight (kg) of shoat.

$$\underset{xx=cs}{\overset{sh}{Required_{xx}}} = Current_{xx} * \left(\frac{Population_{need}\ [kg]}{Metab_{avail}\ [kg]}\right)$$

$Required_{xx}$ = The required number of a certain livestock species (per group ranch) according to the metabolic need of the Maasai population.
xx = A specific livestock species.
$Population_{need}$ = Actual need of metabolic livestock weight (kg) for the Maasai population per group ranch.
$Metab_{avail}$ = The current available metabolic weight (kg) by livestock per group ranch.

The tabular information of the actual number of livestock, the recommended number of livestock (according to the carrying capacity) and the required number of livestock (according to the Maasai population) is given per group ranch.

The result of the Amboseli rangelands management model is a presentation of the actual situation (in this case 1992) concerning the status of the rangelands (e.g., to be over- or undergrazed) during the long dry season. Again, this result should serve decision makers in the Amboseli Biosphere Reserve to develop plans for a better and sustainable management of the rangelands during the dry season.

3. Validation of the Rangelands Management Model for the Amboseli Biosphere Reserve

Models may be derived from some hypothesis of the physical causes and effects within a system or from data collection. However, when a model is developed, it must be validated before it may be confidently used. Validation means that the model accurately predicts the behaviour of the system (Whittaker, 1993). Models must be validated by comparing results from the model with experimental and other real-world (field) data. Validation is, in part, a subjective assessment of model performance. The data used for validation must be independent of the data used to formulate the model (ILCA, 1978).

By using the Amboseli rangelands management model the present situation (1992) was simulated. To validate these results, calculated by the model, independent field data was needed. No quantitative data concerning the range condition of the Amboseli ecosystem was available so far. Therefore, biomass samples taken by DRSRS at the end of the growing season in 1992 are compared with intermediate results of the model. Furthermore, a field survey (October, 1993) was carried out to collect independent quantitative data about the range condition of the Amboseli ecosystem and compared with the final output of the model as well (the rangelands management map).

3.1 Methodology

Since March 1992 DRSRS is carrying out a biomass estimation programme in south eastern Kajiado district. At 14 locations biomass samples have been taken spread all over the area, of which 7 were in the area of interest. In principle every 10 days the biomass has been estimated, unless there was no need for it during the dry season. Of each plot eight samples of 0.5x0.5m are taken to get a representative estimation of the biomass of a relevant cover type. To compare the biomass estimations with the biomass calculated based on the model, the biomass at the end of the long wet season per sample has been compared with the calculated biomass.

Furthermore, the results of the rangelands management map (the estimated biomass available for grazing or the amount of biomass to be overgrazed according to the model) have been compared with the results of the field survey (59 samples) carried out at the end of the long dry season (October) in 1993. The field-samples are classified according to the average rainfall in 4 different groups: less than 200 mm rainfall per year, between 200 and 400 mm, between 400 and 600 mm and above 600 mm rainfall per year. The relationship between trees+shrub cover (%) and perennial grass cover (%) indicates, if the perennial grass cover in a certain field-sample is reaching its maximum cover percentage or not. The relationship is established according to the procedure applied in van Wijngaarden, 1985 and van Wijngaarden and van Engelen, 1985.

3.2 Results of the Biomass (PSC) Estimations

A comparisment has been done of the estimation of biomass production by the model, both for the average long term rainfall and the rainfall in the wet season of 1992 and the biomass estimation in the field, carried out by DRSRS in 1992. The PSC estimations by the model (of perennial grasses only) per plot are expected to be lower than the measured biomass production in the field by DRSRS (of the whole herbaceous layer, including annual grasses and forbs as well). Furthermore, the rainfall fluctuates very much, in time, space and in intensity. As no exact data concerning the rainfall per plot is available, the results are still approximately.

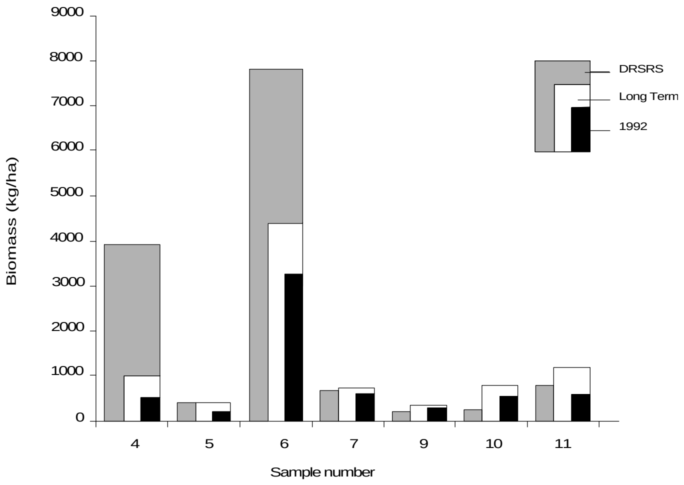

Figure 6. Results of biomass estimations at the end of the wet season. DRSRS estimations are based on estimations (weight) of the total biomass in 1992 in the field. Data of long term and of 1992 are model-estimations, based on the peak standing crop of the perennial grass cover only.

By comparing the estimated PSC with other comparable estimations in for example the Serengeti: DM = 4-6 kg/ha/mm (Braun, 1973), or Athi Plains: DM = 4-7 kg/ha/mm (Potter, 1990), the figures are not differing much. Therefore, it can be assumed, that the estimated PSC is reliable enough to be used in the model.

3.3 Results of the Rangelands Condition Estimations

The results of the analysis of the field-samples are compared with the results of the model.

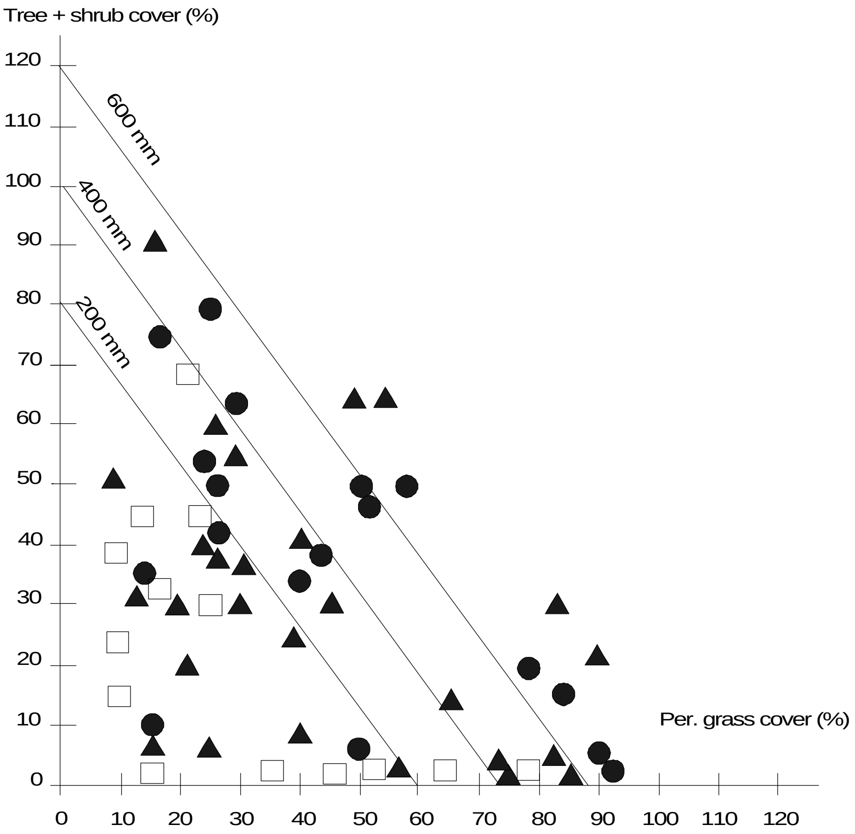

Figure 7. **Relation between cover of perennial grasses and cover by trees and shrubs. A [box] indicates samples with an average yearly rainfall of less than 200 mm, a [delta] between 200 and 400 mm and a [circle] between 400 and 600 mm or above 600 mm rainfall per year. The lines indicate the maximum perennial grass cover per rainfall zone.**

If the perennial grass cover, estimated in the field-samples, is not differing more than 5% of the "maximum" to be expected perennial grass cover, according to figure 6.2, the rangelands condition is considered to be in good condition. When the perennial grass cover of the field-samples is differing more then 5 percent, but not more then 25 percent (range -5% till -25%), the situation is considered to be overgrazed and when differing more than 25 percent, the rangelands are considered to be in very bad condition (unless specific biophysical conditions indicate different).

Figure 8. Serious degradation of the rangelands in the Amboseli Biosphere Reserve (sample number 6), due to overgrazing.

Figure 9. Severe destruction of the rangelands, like gully erosion, in the Amboseli ecosystem (sample number 56).

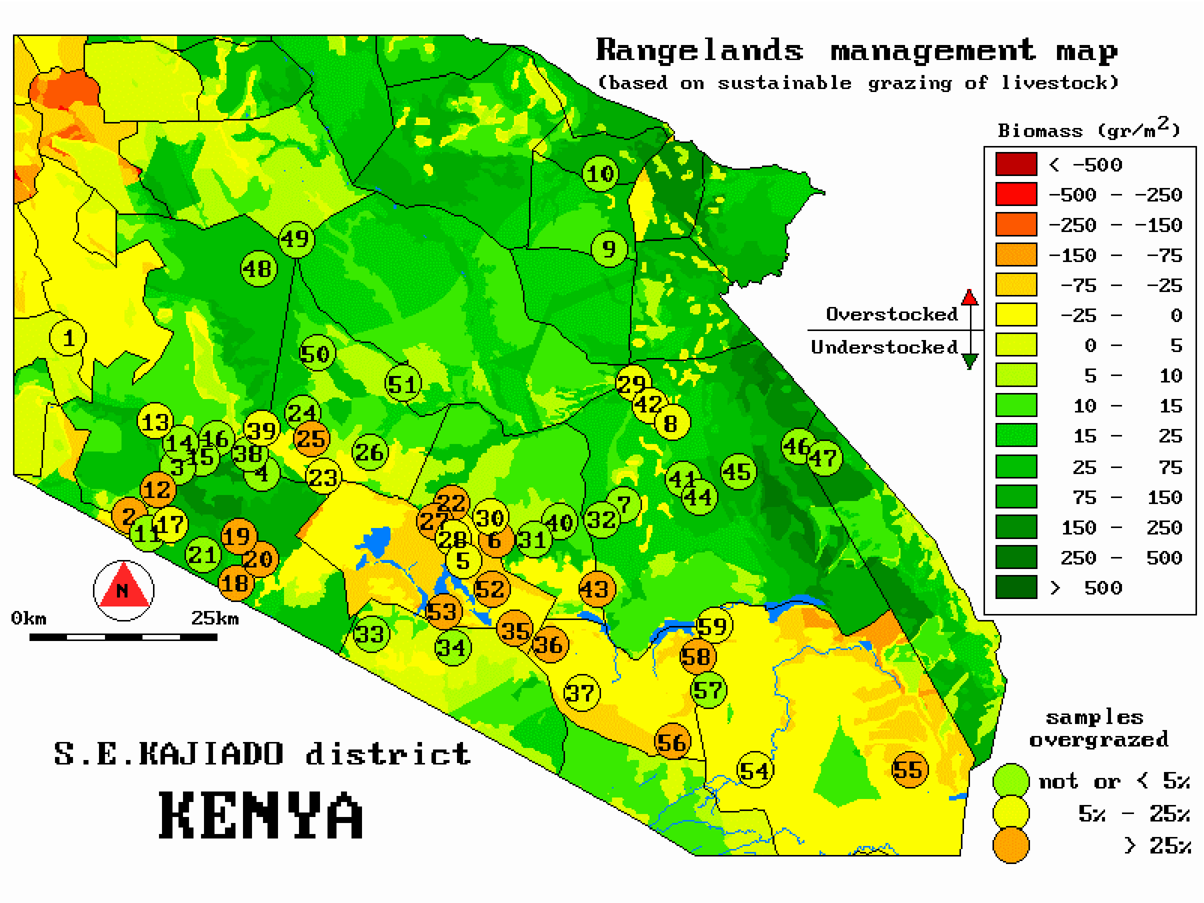

Figure 10. **The model result of expected rangelands to be over- or under stocked (see chapter 5) and the location of the cover estimation samples, taken at the end of the long dry season. Samples in green are representing good rangelands conditions, while samples in yellow and orange indicate respectively less or more degradation of the rangelands.**

Only 4 of the 59 samples, taken in the field, differ substantially from the calculated results by the model, concerning the rangelands situation at the end of the long dry season (over- or understocked).

Sample 12 is taken near rock outcrops, with 70 percent bare soil and stones, which is probably the reason of the low grass cover. This sample is not representative for normal rangelands. Sample 19 is taken on a salty floodplain with mainly herbs and about 45 percent bare soil. The salty soils probably hinder the growth of the perennial grasses. Sample 30 is a typical rangelands sample which is overgrazed, while the model calculates little understocked. This difference is probably due to the fact, that the sample is located very close to the national park boundary and wildlife can be expected to range in these areas as well, especially when biomass in the N.P. becomes limited. Sample 57 is taken in very dense bushed woodland in a dry riverbed/floodplain, where livestock grazing is hardly possible. This might be the reason, that the model is calculating a lower perennial grass cover as in the field sample. Another 4 field-samples (2, 5, 18 and 43) differ at least 10 percent or more of the model calculation, e.g., are considered to suffer from little degradation, while the model calculates much degradation (or the other way round), while the rangelands condition of the other 51 field-samples are in correspondence with the by the model calculated rangelands condition.

By comparing the estimated rangelands condition of the 59 field-samples with the by the model calculated rangelands condition, the figures are again not differing much. Therefore, it will be assumed, that the result of the model (the expected rangelands condition at the end of the long dry season), together with the results of the comparisment of the estimated PSC of the 7 field-samples with the calculated PSC by the model, is reliable enough to be used in the model and for simulation purposes.

4. Sensivity of the Parameters

The sensivity analysis performs several functions in the validation process. It helps to identify parameters that strongly affect model output and that, therefore, must be estimated with great care. Most sensivity analysis of complex biophysical models involve changing one parameter at a time. The sensivity analysis indicates a "robust" model when small changes in input parameters result in small changes in model output (Swartzman and Kaluzny, 1987).

4.1 Sensivity of the Prameters used for the Amboseli Biosphere Reserve

A sensitivity analysis has been conducted by changing each parameter value with +/- 10% and +/- 50%. The sensivity of the model results (the total amount of forage available for livestock in the Amboseli Biosphere Reserve) for the in the model used parameters, are classified.

Table 6. Classification of the sensivity of the parameter changes for the result (impact) of Amboseli rangelands management model

Parameter changes of +/-10 % and +/-50 % in their values		
+/-10 % change result change (%)	**+/-50% change result change (%)**	**Sensivity of the model**
0 - 1.0	0 - 5.0	extreme little
1.0 - 2.5	5.0 - 12.5	very little
2.5 - 5.0	12.5 - 25.0	little
5.0 - 10.0	25.0 - 50.0	moderate
10.0 - 25.0	50.0 - 125.0	much
25.0 - 50.0	125.0 - 250.0	very much
50.0 - 100.0	250.0 - 500.0	severe

The research priority for the parameters used is based both on the effect of a certain parameter on the model result, in combination with existing data (research) to establish the parameter in question. If the effect of a parameter is low, research priority is low as well, if the effect of a parameter is high, research priority is high unless detailed research data concerning that parameter is already available.

The parameters, used in the Amboseli rangelands model, are based on existing literature and/or research in the field. A sensitivity analyses has been conducted and the sensivity of the model result (the amount of forage available for livestock) for the in the model used parameters are classified.

Table 7. Results of the sensivity test of the used parameters for the Amboseli rangelands management model.

Parameters used:	% change impact		sensivity of the model
	+/-10%	+/-50%	
AVAILABILITY			
Rain-affectivity	24.6	162.4	much to very much
Proper use factor	32.5	111.0	much to very much
Grass cover	28.0	148.2	very much
DEMAND			
Dry matter intake	22.3	109.6	much
Nr. dry months	22.3	109.6	much
ACCESSIBILITY			
distance to water	13.6	81.1	much
Slope hindrance	2.9	16.6	little
Shrub hindrance	3.2	19.7	little
Stoniness	3.0	17.6	little

The basis (amount of available data) on which the parameter value has been established and the priority for further research on that specific parameter.

Table 8. Results of the sensivity test of the used parameters for the Amboseli rangelands management model and the research priorities are indicated

Parameters used	Effect on the model output	Avail. Data	Research priority
AVAILABILITY			
Rain-affectivity	much to very much	+	+ +
Proper use factor	much to very much	+	+ +
Grass cover	very much	++	+
DEMAND			
Dry matter intake	Much	+	+/-
Nr. dry months	Much	++	+/-
ACCESSIBILITY			
distance to water	much	+	+
Slope hindrance	little	+	-
Shrub hindrance	little	+	-
Stoniness	little	+	-

According to the results of the tests to estimate the effect of the used parameters on the sensivity for the model output it appears that most parameters are very sensitive parameters. Nevertheless, most of them are a result of extensive literature studies (e.g., rain-affectivity, proper use factor, dry matter intake values) or field surveys (e.g. Perennial grass cover, number of long dry months, limiting distance to water). The slope steepness-, shrub density- and surface stoniness hindrance parameters have only little influence on the final model output and are a result of literature studies.

The most sensitive parameters, used in the Amboseli rangelands management model, are studied intensively, while the other parameters are influencing the model output much less to hardly any influence and although the bases of the establishment of their values might be less fundamental as the other parameters, because of their very little influence the research priority is also little. Although the most sensitive parameters are studied intensively, it is of uppermost importance that these parameter values are regularly surveyed and if necessary updated. The output of the model is very much depending on the reliability of these parameters.

5. Simulations of Management Options in the Amboseli Biosphere Reserve

5.1 Simulation Possibilities

The other option with the rangelands management model is the possibility of running simulations concerning the management of the Amboseli Biosphere Reserve. It is up to the user, what management option to increase (or reduce) the range conditions of the Amboseli ecosystem he likes to try out by running that simulation. It is possible to use other data by changing, for example, the input maps, to change data in existing tables and to change the values of the factors used, and it is possible to run simulations for any desired year. An overview of the possible options to change is given below:

The procedure to change maps, tables or factors, needed for running a desired simulation is basically the same as for updating the model. When a certain change has been carried out (to know the expected result of the implementation of a certain management activity), the user can run that simulation for **any year** and when the new calculations are finished, the rangelands management model will show the expected result of that specific simulation. An overview of the possible options to change in the model is given below:

- AVAILABILITY:
  - Maps: Vegetation (perennial grass cover)
  - Tables: Rainfall data
  - Factors: Runoff
    . Grass cover
- DEMAND:
  - Maps: Group ranches
  - Tables: Population statistics
    . Livestock per group ranch
  - Factors: Population growth
    . DM intake (kg/day/animal species)
    . Long dry months
- ACCESSIBILITY:
  - Maps: Fencing
    . Stoniness
    . Shrub cover
    . Artificial watering points
  - Factors: Slope steepness
    . Water distance

5.2 Management Decisions (Simulations) and the Expected Rresponse

During the regional workshop on "Geo-Information systems for Natural Resource Management of Biosphere Reserves", d.d.: 29 - 31 October, 1993 in Nairobi, Kenya, the participants analyzed the problems still occurring in the Amboseli Biosphere Reserve and discussed the possible management options, to solve these problems. By making use of the developed modelling system several simulations can be done and the results are discussed below.

5.2.1 The Model

The Amboseli Rangelands Management model is based on the actual situation at the end of the wet season in 1992 and the management problems are in principle "how to survive the coming dry season", without degradation of the environment. Therefore, the results of the model (figure 12) have to be analyzed first to be able to propose applicable and useful management options for a better management. When the user wants to analyze the situation for an other year, for instance 1996, the user has to update the model first with the actual rainfall data at the end of the wet season of 1996 and with the most recent statistical data (e.g., animal census, population census). Even more, if some changes took place like rangelands degradation, expansion of agricultural plots, fencing of certain areas etc., these changes should be included as well.

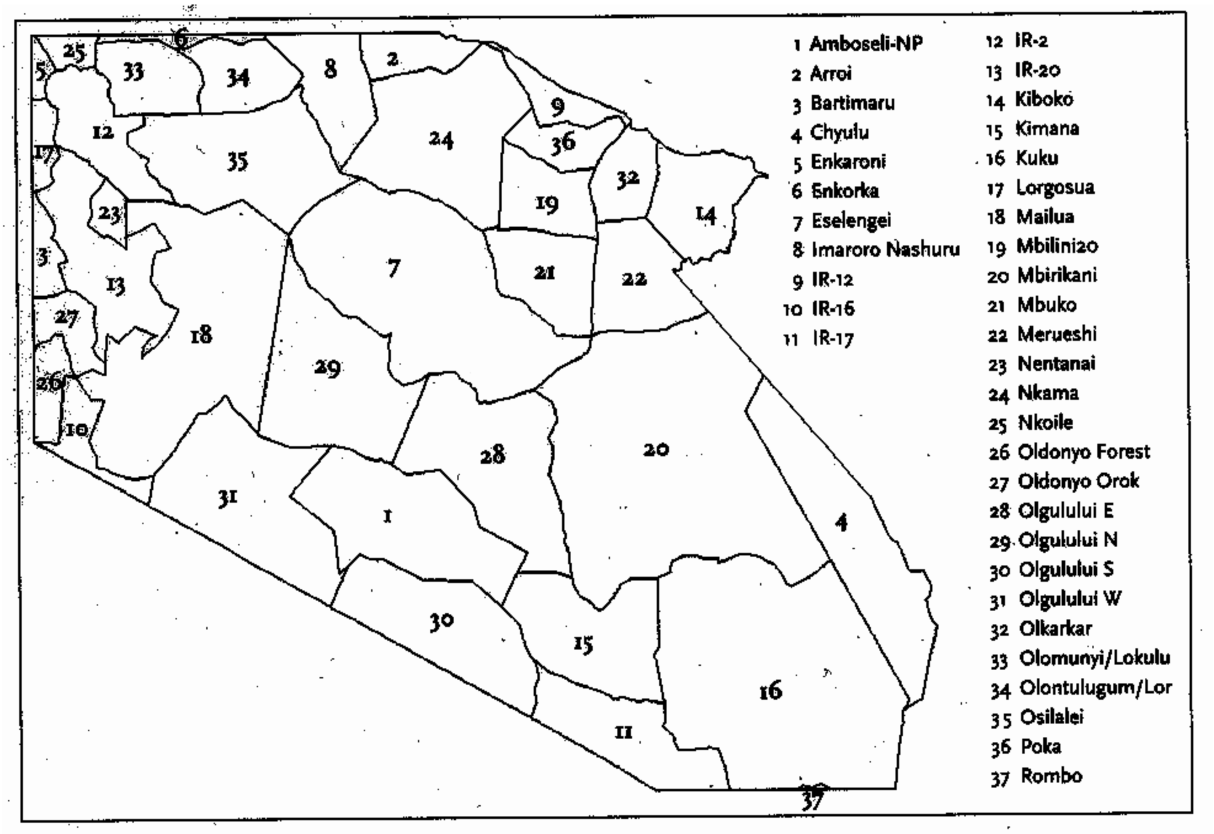

Figure 11. The location of the Amboseli National Park and the group ranches in the Amboseli ecosystem, south-east Kajiado district.

According to the situation in 1992, most group ranches (37 in the south eastern part of the Kajiado district) are not suffering from overgrazing of the rangelands, but still 12 group ranches do, especially in the south eastern part (Kimana, Kuku and Rombo), the western part (IR-2, IR-16, IR-20, Bartimaru, Nentanai, Lorgosua, Nkoile, Enkaroni) and east (Olkarkar). Also Amboseli National Park is overstocked during the dry season. Analysis of the statistical data can indicate in what extend the group ranches are expected to be overgrazed and why, while the output map indicates what areas within each group ranch are expected to be overgrazed or not.

For instance, the group ranch Kuku in the south east, which is, according to the map especially in the north east severe overgrazed, while in the centre still a considerable amount of forage is left. Statistically, there is a shortage of 15,731 tons of forage, but the amount of forage not utilized is 14,705 tons. When looking at the other result output of the model, the accessibility map (figure 13), it is clear, that this is partly due to inaccessibility because of lack of drinking water for livestock (770 tons forage).

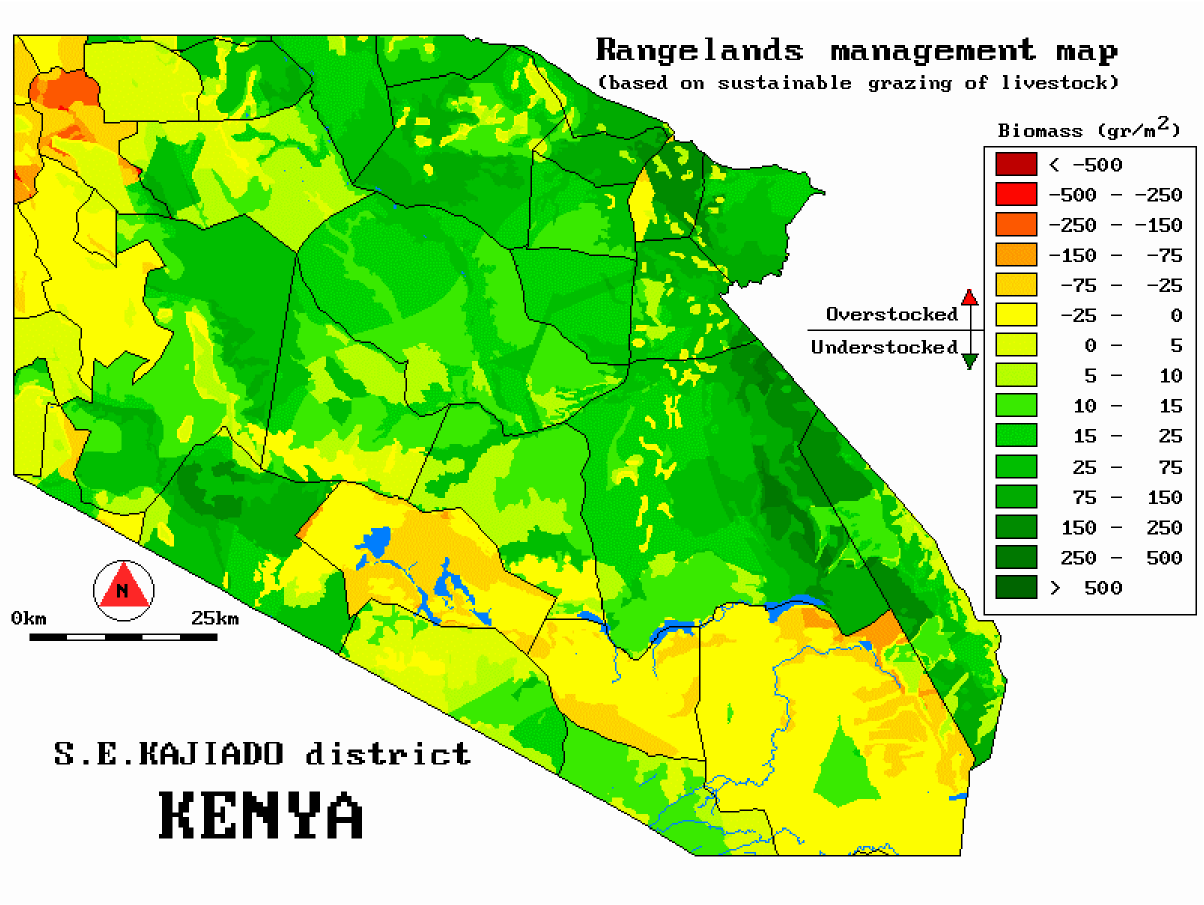

Figure 12. **The spatial result of the model, calculated for the situation (condition of the rangelands) to be expected at the end of the dry season in 1992.**

The other overstocked group ranch in the south east is Kimana (shortage of 7,694 tons forage, 2,400 tons is lost because of suitability, but not because of inaccessibility due to lack of drinking water for livestock). Therefore, it may be concluded that the to be expected forage shortage is mainly due to overstocking (current number of livestock 34644, while recommended 15816).

When looking at group ranch Olkarkar in the north east, the shortage is 378 tons of forage, so little compared to the group ranch Kuku, the amount of forage lost due to accessibility (lack of water) is 11,357 tons and 2,765 tons of forage, due to suitability. For the individual ranch IR-16 in the south west the shortage of forage is 763 tons of forage, while 558 tons is lost due to lack of water and 1,453 tons is not utilized because of not suitable for grazing.

Table 9. **An overview of the group ranches which have a to be expected forage shortage (tons/ranch) for the coming long dry season of 1992. Also the amount of forage loss, due to lack of drinking water (inaccessible) or other biophysical factors like slope-steepness, shrub-density and/or surface stoniness (unsuitable) are indicated**

Group ranch	Shortage (tons)	Inaccessible (tons)	Unsuitable (tons)
South-east			
Amboseli NP	13,822	0	574
Kuku	15,731	770	14,705
Kimana	7,694	0	2,400
North-east			
Olkarkar	378	11,336	2,765
South-west			
IR-16	763	558	1,453
North-west			
Bartimaru	109	0	612
Enkaroni	350	0	117
IR-2	11,718	805	2,861
IR-20	1,487	3	5,101
Lorgosua	2,788	0	762
Nentanai	561	0.4	665
Nkoile	157	0	341

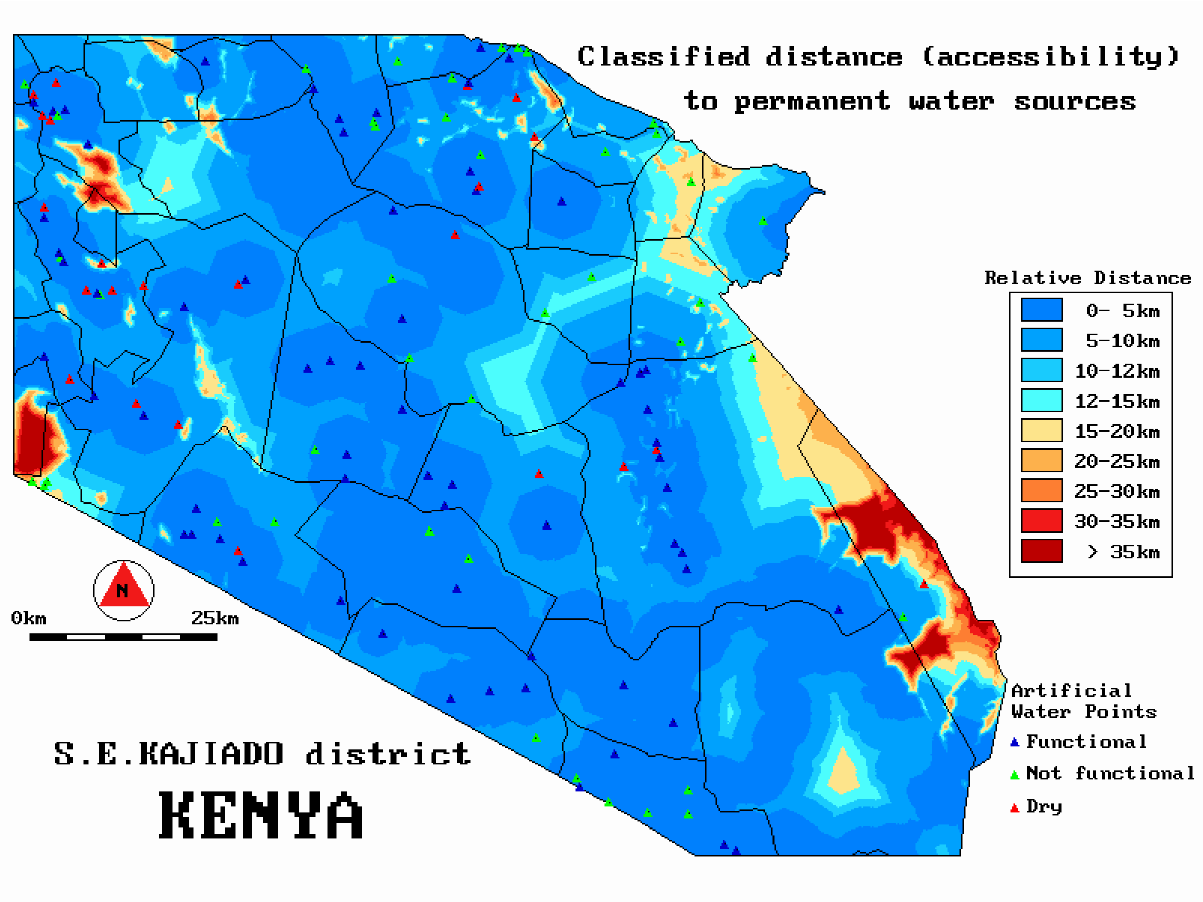

Figure 13. Accessibility of the rangelands for livestock in the south eastern Kajiado district. The accessibility is a combination of hindrance due to slope steepness, shrub density and surface stoniness, together with the distance of the rangelands to watering points like artificial ones e.g., boreholes, booster water (indicated with a triangle) or natural perennial water bodies (not indicated).

In the north western part the situation is a little bit different. Most of the group ranches are expected to suffer from overgrazing of the rangelands, eg., IR-2, Lorgosua, Enkaroni, Nkoile, Bartimaru, IR-20 and Nentania, not because of lack of drinking water in the area, but just too large livestock numbers (cattle, shoat and donkey) per group ranch (IR-2: current livestock number 41439, while recommended 11559, Lorgusua: current 7731, recommended 2572, Enkaroni: current 5122, recommended 4130 and Nkoile: current 5286, recommended 4816).
Amboseli National Park is also a different situation. The expected forage shortage is not depending at all of the availability of drinking water or rangelands loss due to suitability (only 574 tons forage). The total wildlife population is expected to consume 24,009 tons of forage during the dry season, while the expected peak standing crop (PSC) is about 24,456 tons, of which 11,005 tons will be available for grazing on a sustainable base, or only 46 percent of the total demand. According to the outcome of the model, the national park is likely to be severely overgrazed during the long dry season.

If Amboseli National Park would have been fenced all around its boundary, the number of wildlife able to live in the park on a sustainable base, would have to be reduced with about 50 percent! This is in correspondence with the calculation by Western (1982), in which he estimates a decline of 40-50 percent of the large herbivore population.

Although wildlife grazing is assumed not to be directly manageable (see chapter 5), it is very likely, that wildlife will utilize a considerable amount of forage from the neighbouring group ranches as well. Fortunately, most neighbouring group ranches, except Kimana (see above), still have a surplus, e.g., Olgulului-east 7,403 tons, Olgulului-north 9,412 tons, Olgulului-south 2,625 tons and Olgulului-west 20,284 tons and no lack of drinking water or unsuitable rangelands for grazing. Satisfying agreements should be made by KWS with the neighbouring group ranches to avoid conflicts, often resulting in harassment of wildlife.

5.2.2 Simulation 1

Normally the long dry season is about six months long, according to the rainfall data on a long term base. The amount of forage (PSC), at the end of the wet season, determines the carrying capacity of the rangelands for wildlife and livestock and the number of recommended livestock is based on the forage intake during the long dry season of six months. Unfortunately, the start of the rainy season is fluctuating quite often and for developing sustainable rangelands management, it is wise to be on the safe side, although six months of long dry season (used in the model) is already quite on the safe side. The next simulation will demonstrate the influence of possible fluctuations in the starting date of the next rainy season on the rangelands. Figure 14 shows the situation of the rangelands, when the rains starts, for instance, one month earlier, in the beginning of October.

The amount of forage intake (consumption) by both wildlife and livestock will be reduced by about 17 percent (from 325,428 tons to 271,190 tons forage consumption), so the total forage of the rangelands left at the end of the dry season will be more. When looking at figure 14 still eight group ranches will suffer from overgrazing like Kuku (shortage of 7,778 tons) and Kimana (shortage of 4,879 tons), IR-16 (shortage of 544 tons), Enkaroni (shortage of 49 tons), IR-2 (shortage of 9,005 tons), IR-20 (shortage of 27 tons), Lorgosua (shortage of 2,092 tons) and Nentanai (shortage of 366 tons). Only Bartimaru, Nkoile and Olkarkar are not suffering of forage shortage any more.

This means that even in "good years", when the dry season is relatively short, many group ranches still suffer by overgrazing. Therefore, for a sustainable management of the rangelands, the livestock owners can not rely on better "climatological circumstances" only, but do have to take some management decisions to improve the situation.

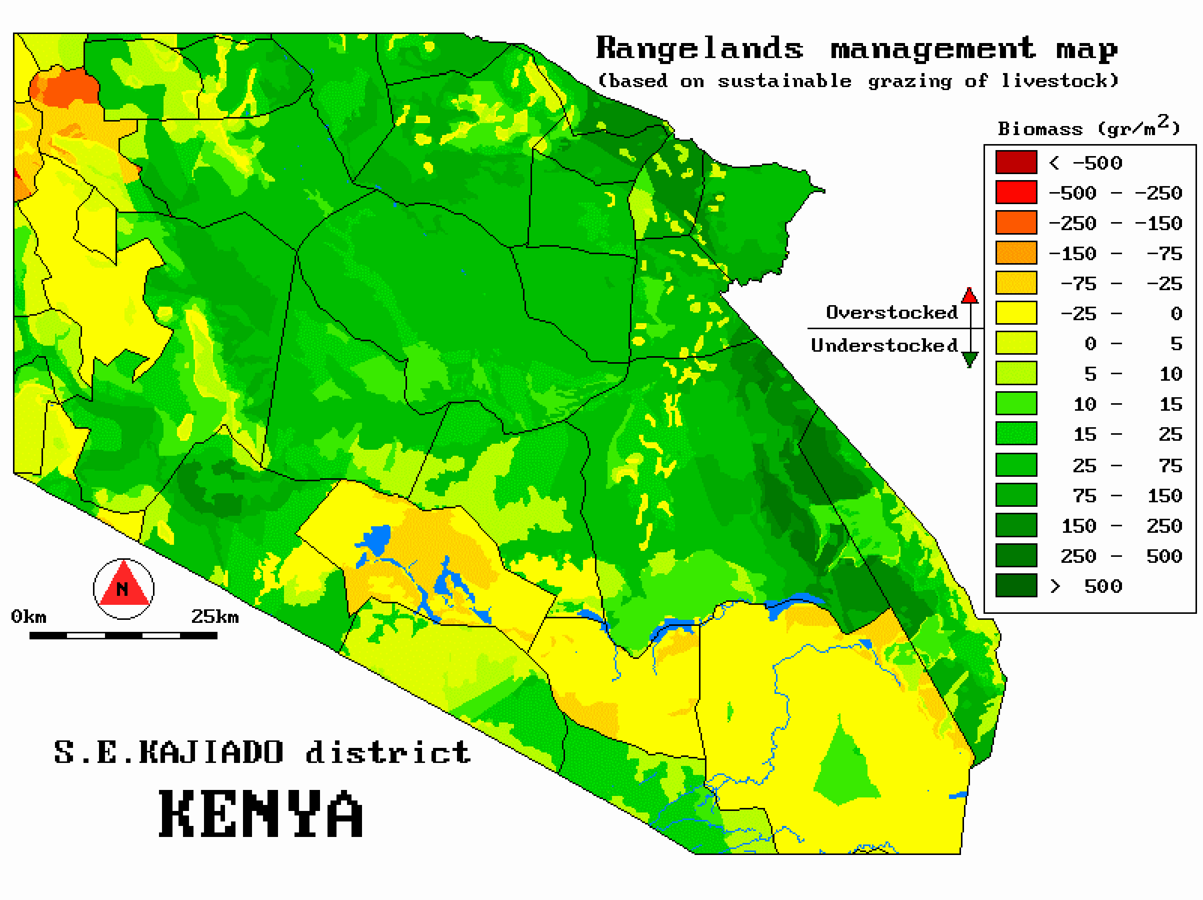

Figure 14. The spatial result of simulation 1, when the expected rains are one month earlier (October) as normal (based on long term rainfall data).

5.2.3 Simulation 2

The next simulation shows the situation, when the rains are too late, so when they start in December.

It is clear from figure 15, that if the expected rains are too late, at least twelve group ranches will suffer now from more or less severe overgrazing, especially the group ranches Kuku, Kimana and the group ranches in the north-western part. Still, most of the livestock will survive, because the model is calculating the carrying capacity on a sustainable base, so in fact the real amount of forage available is 45 percent more than used. But, by using the extra 45 percent of forage as well, this will lead to degradation of the rangelands, resulting in a lowering of the carrying capacity of the rangelands for livestock in the next coming years.

Therefore, to be on the safe side, each group ranch should take care of not having too much livestock, to be sure to be able to survive on a sustainable base, even when the rainy season is too late.

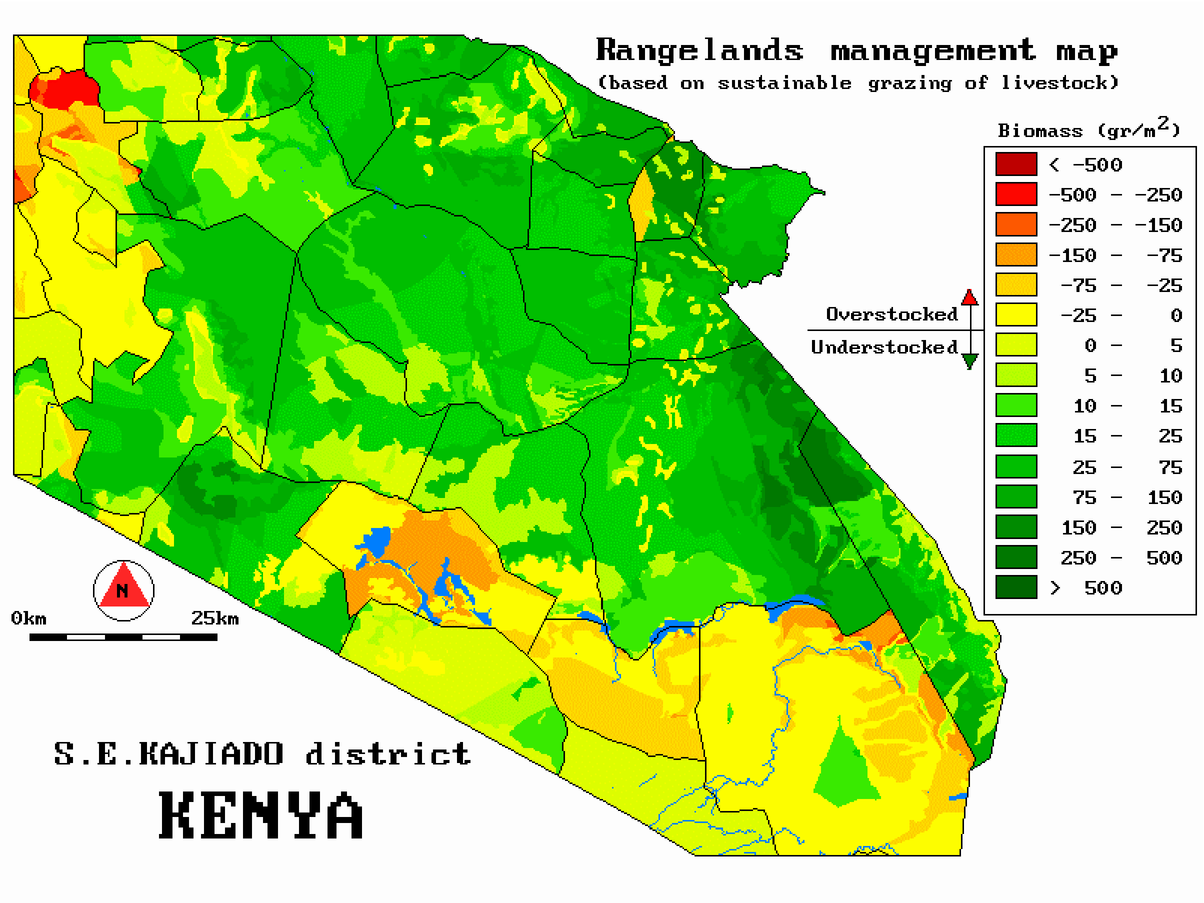

Figure 15. The spatial result of simulation 2, when the expected rains are one month later (7 months of dry season) than expected.

5.2.4 Simulation 3

The amount of rainfall is very unpredictable and quite often the area is suffering from a period of severe drought like in 1960-1961 (about 70% of cattle died), 1973-1976 (about 50% of cattle died) and 1983-1984 (about 65% of cattle died) (Bekure et al, 1991, Western and Grimsdell, 1979). The impact of the drought on the cattle population is often the most serious in the plains, where cattle losses up to 90% were estimated during the drought of 1973-1974. The amount of rainfall during these drought-periods were on the average about 50% less than normal in the plains and about 30% less than normal in the other areas (Altman et al., 1992, Irungu, 1992, Min. of Water Development, 1990), which might explain the higher mortality of the cattle population in the plains. Nevertheless other factors like the outbreak of severe diseases may have played an important role in the high mortality rate as well (Western and Grimsdell, 1979).

According to simulation 3 (figure 16), where the amount of rainfall during the wet period has been simulated to be 60% of the normal (average) rainfall for that period, the Amboseli ecosystem as a whole will have a severe shortage of forage (15,000 tons) for livestock at the end of the dry season. In this simulation it is assumed, that the next wet season will start in November again, as usual. In fact, as soon as the forage availability becomes **zero**, animals start to die.

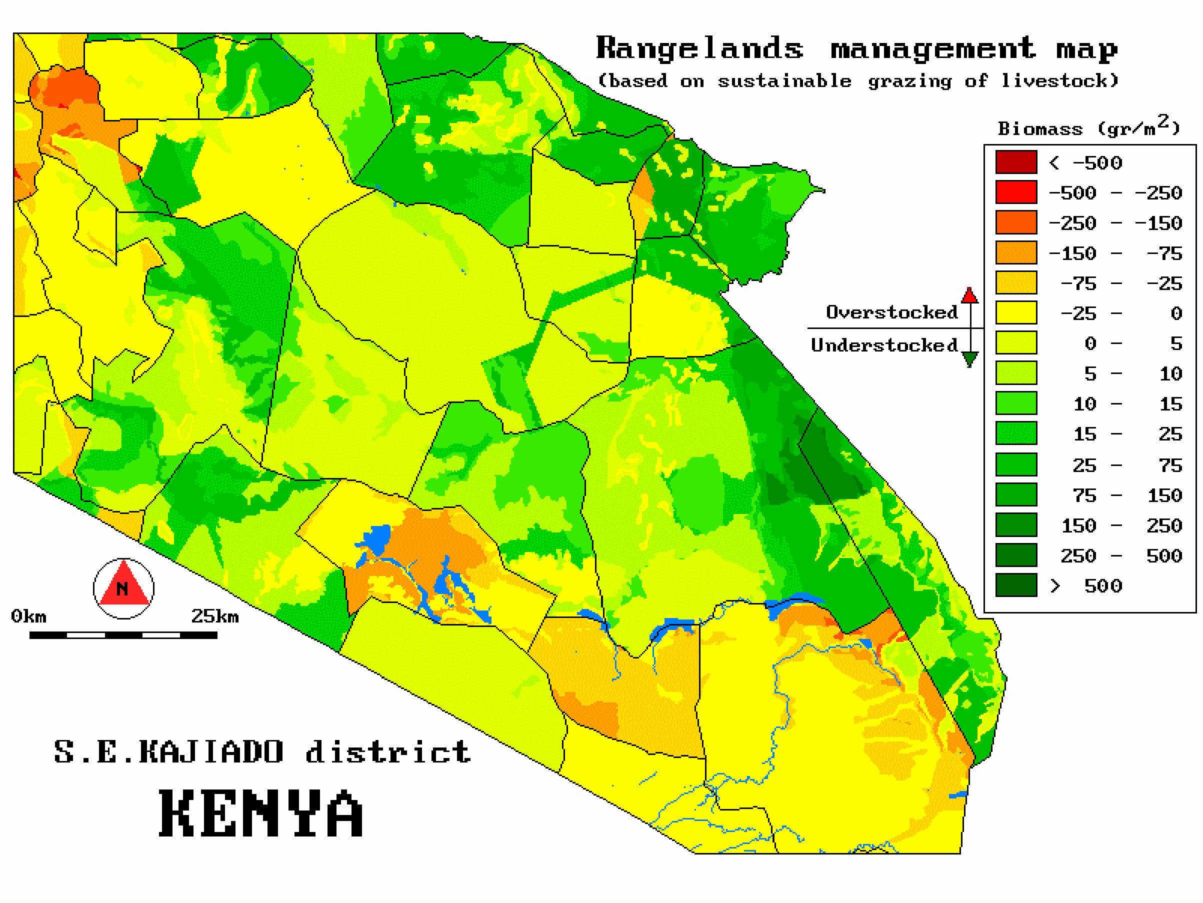

Figure 16. **The result of simulation 3, when the amount of rainfall during the wet season is only 60% of the normal (average) rainfall for that period.**

According to the actual livestock numbers, at least about 27000 head of cattle should be slaughtered (or evacuated) to end up with zero forage available at the end of the dry season. It is understandable that, if this is not the case, in reality much and much more cattle will die because of starvation. Furthermore, what is not included in the simulation, is the shortage of drinking water during these drought spells. Livestock has to walk for longer distances which will weaken them even more and make them more vulnerable for diseases, resulting in an even more higher mortality rate under livestock as predicted only on base of shortage or lack of forage.

Finally, most drought spells are not for only one season, but continue over more seasons, like in 1973-1976. In this case the rangelands will not be able to recover and severe degradation of the rangelands will be the result. If this is the case, the forage availability for livestock will become even worse in the next season, resulting in a probably even much higher mortality rate as during the previous season.

5.2.5 Simulation 4

If assuming, that the rains will start when expected, so according to the long term rainfall data, still some group ranches have severe overstocking problems to deal with. To solve the problem in Kuku the most easy way is to utilize a certain part of the rangelands of the neighbouring group ranch Mbirikani for livestock grazing, which has a surplus of 48,384 tons forage, or partly in the Chyulu's, with a surplus of 11,477 tons forage and partly in IR-17, with a surplus of only 2,210 tons. But grazing livestock in another group ranch has to be compensated, in cash or in kind.

Another possibility is to drill a new borehole in the centre of the group ranch itself. Then the previously not utilized rangelands of Kuku will compensate the extra forage needs for livestock a little.

A comparable situation exists for Olkarkar and IR-16, but here the not utilized rangelands will easily compensate the extra forage needs for livestock in Olkarkar and for about 60 percent in IR-16. When looking at the accessibility map, both group ranches have boreholes at critical locations, but unfortunately not functional. For both group ranches is suggested to make the not functional boreholes operational again to solve the problem of overgrazing in their ranch.

In the north west the situation is really problematic. Almost all of the group ranches with a forage shortage can not improve the situation by adding new watering points, because all the rangelands are already accessible (except for a small part in IR-2, but will reduce about 5 percent only of the total shortage) (table 9).

To drill a new borehole in Osilalei, which has 3,676 tons of forage in inaccessible areas left, will also make the 805 tons forage in IR-2 accessible, so totally increase the forage with 4,481 tons, if these neighbouring group ranches can make a deal to cooperate together. Furthermore, Osilalei had already a surplus of 5,884 tons of forage. The result of simulation 4 is presented in figure 17 (accessibility map) and figure 18 (rangelands management map).

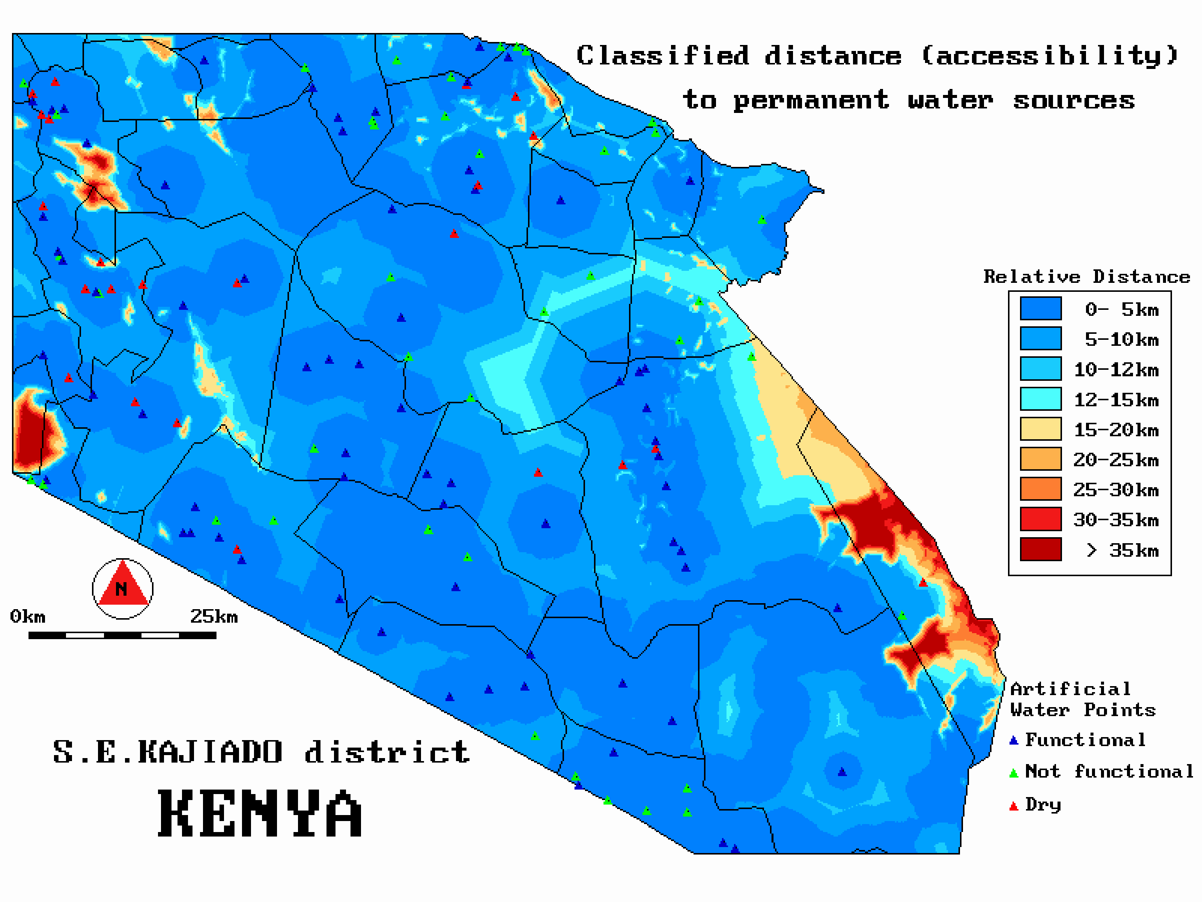

Figure 17. In this simulation 4 (for 1992) the accessibility to watering points has been changed. A new borehole has been drilled in the Kuku and Osilalei group ranch, while both in Olkarkar and IR-16 group ranch not functional boreholes have become operational again.

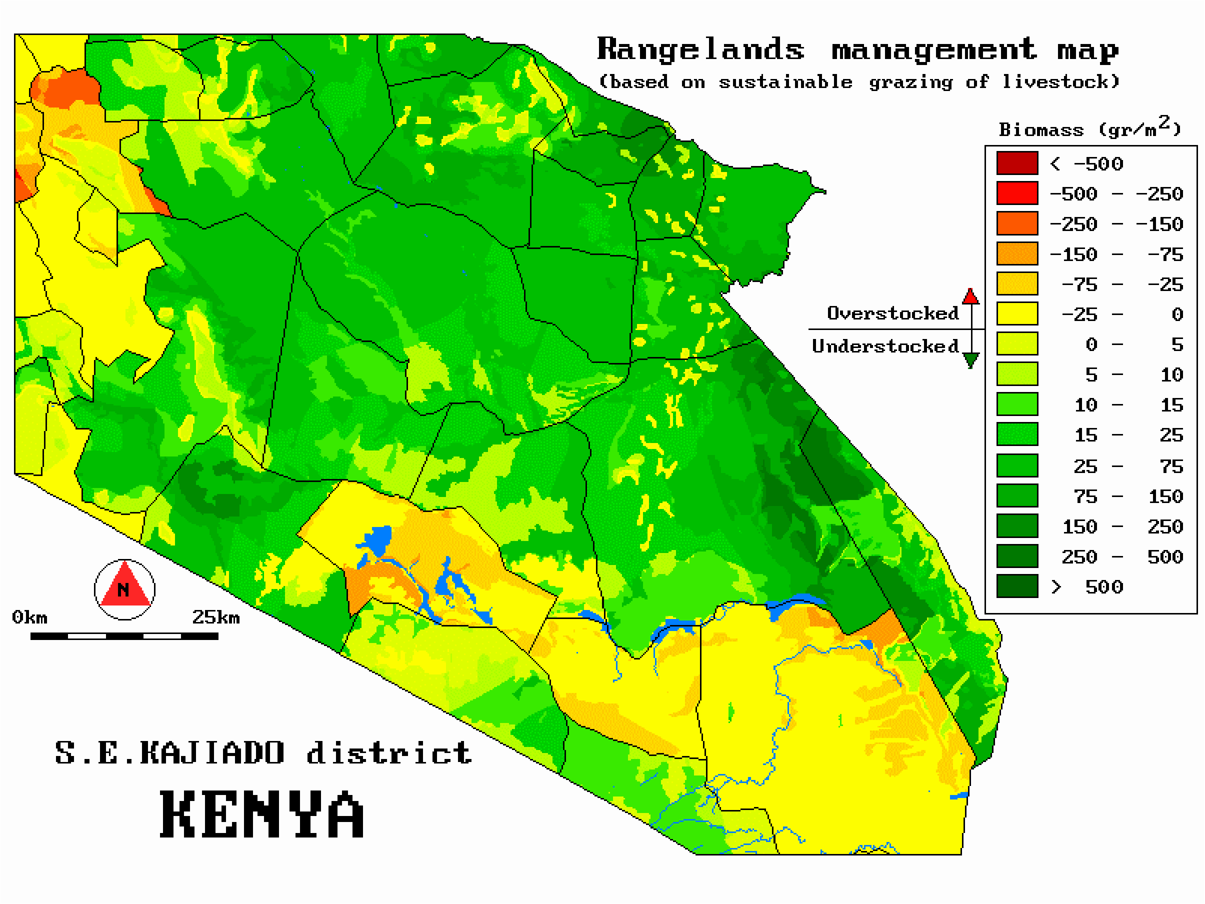

Figure 18. **The new rangelands situation after the simulation 4, where the accessibility to not utilized rangelands have been improved.**

The over all situation in Kuku is still not sustainable at all (shortage is still 15,202 tons), loss to inaccessibility is reduced to 241 tons, loss to unsuitability is still 14,705 tons. Suitability loss is mainly due to large areas with high shrub cover (see table 11). One of the management options in Kuku could be a better rangelands management to prevent shrub encroachment. Another possibility is to reduce livestock numbers to recommended, but this means a reduction of at least about 35 percent (from 101753 to 66880) of the actual livestock. It is also possible to move livestock to the neighbouring group ranch Mbirikani, which has a surplus of forage for about 110928 numbers of livestock or 48,384 tons forage.

The situation in Kimana group ranch still remained the same, because no management actions for Kimana were considered in this simulation. The problems in Olkarkar (north east) seem to be solved. Instead of being overstocked for the dry season (shortage of 378 tons forage), the group ranch is now "understocked" (surplus of 10,971 tons forage). No further management actions besides repairing the borehole seems to be needed.

When looking at IR-16 (south-west), this ranch is still overstocked (shortage of 223 tons forage, which means a reduction in overgrazing of about 70 percent), but the amount of forage loss due to inaccessibility is only 17 tons. A large part of the group ranch covers the slopes of the Namanga Hill, which is unsuitable for grazing because of slope steepness and surface stoniness. The best management option seems to be reducing the amount of livestock with 17 percent (from 2770 to 2301) or to graze some part of the livestock on rangelands belonging to the neighbouring group ranch Mailua (surplus of forage for about 75000 numbers of livestock).

The situation in the north western part is still problematic. In principle no areas are inaccessible any more due to lack of water. Some areas, especially in ranch IR-2, are not suitable for grazing because of slope steepness and / or surface stoniness, but those aspects are hardly manageable. The ranch IR-2 has still a shortage of 10,933 tons of forage, Nkoile 157 tons, Enkaroni 350 tons, Lorgosua 2,788 tons, IR-20 1,488 tons and Bartimaru 109 tons. Neighbouring ranches with a surplus are Oldonya Orok (surplus of 604 tons), again Mailua (surplus of 27,460 tons), Osilalei (surplus of 9,560 tons), Olontulugum / Lor (surplus of 5,804 tons) and Olomunyi / Lokulu (surplus of 1,571 tons). Overall is the shortage of these ranches around 16,000 tons and the surplus of the neighbouring ranches around 45,000 tons of forage.

When taking the distance for livestock in consideration, livestock belonging to the "shortage ranches" preferably range in the most nearby "surplus ranches". Nkoile and Enkaroni, together with a shortage of 507 tons, should be able to compensate it with grazing in Olomunyi / Lokulu, Osilalei and Olontulugum / Lor (surplus of 16,935 tons). The other group ranches with a total shortage of about 15,318 tons should be able to compensate their shortage by grazing livestock in Mailua (surplus of 27,460 tons).

Furthermore, it is always possible to reduce the livestock numbers to the recommended number of livestock, but of course most group ranches would not like this management action. First, to have large herds of livestock is traditionally a sign of wealth, so it is indicating the owners social position. On the other hand, the Maasai are realising already, that when lowering livestock numbers to a sustainable amount, the quality of livestock often will improve and so the marketing value. Furthermore, the rangelands will stay in an acceptable condition. Still for many Maasai is it difficult to accept or to understand that lowering livestock numbers might be an advantage. They still think traditionally "the more the better", and in cases of drought it is better to have as much livestock as possible (according to them), so at least some will survive. Only intensive extension service and good examples from neighbouring group ranches might convince them to reduce their livestock numbers to a sustainable level. After all, at the end the final profit probably will be even more.

5.2.6 Simulation 5

When looking at the surplus and shortage of forage of the different group ranches, the overall picture is, that, in total, the forage consumption is more or less in balance with the forage availability. So, when the group ranches, still suffering from overstocking (see simulation 4), can make a deal by herding parts of their livestock on rangelands of neighbouring group ranches, which are still having a surplus of forage at the end of the long dry season, the situation can become in balance according to sustainable grazing in the Amboseli ecosystem. In table 10 a herding strategy for several group ranches has been proposed to improve the situation of the rangelands, according to the previous simulation 3.

The new herding strategy is based on a proposed number of cattle of those group ranches, estimated to be overstocked, that is suggested to graze on neighbouring group ranges with still a surplus of forage, in order to reach the "recommended" number of livestock (see table 10). No changes in number of sheep and goats are suggested, because these animals are not seemly to walk for long distances without water. Furthermore, the number of donkey's are suggested to be the same as well, because donkey's are needed for domestic purposes of the Maasai themselves (e.g., transport of drinking water). Nevertheless, according to the livestock statistics, the number of shoat and donkey's do contribute significantly to the total forage consumption. Therefore, the number of "overstocked" shoat (consumption of 0.6 kg DM/day) and donkey's (consumption of 3.5 kg DM/day) has to be recalculated to the number of cattle (consumption of 3.1 kg DM/day). The result of this simulation is shown in figure 19.

Table 10. Forage shortage group ranches (-) with the actual (1992) number of livestock and the neighbouring forage surplus group ranches (+), and the number of cattle of "shortage" group ranches advised to graze on the neighbouring "surplus" group ranches

Group ranch	Actual			Recommended			To change Cattle
	cattle	shoat	donkey	cattle	shoat	donkey	
south-east:							
Kuku (-)	71974	29021	758	47307	19075	498	- 30000
Chyulu (+)	7323	6420	0	24675	21633	0	+ 10000
Mbirikani (+)	47171	19322	1067	124622	51047	2819	+ 20000
south-east:							
Kimana (-)	21926	12024	694	10010	5489	317	- 15000
Olgulului-S (+)	7665	3020	58	11944	4706	90	+ 2000
Olgulului-E (+)	4505	3320	104	15707	11582	363	+ 3000
Mbirikani (+)	47171	19322	1067	124622	51047	2819	+ 10000
south-west:							
IR-16 (-)	2215	554	1	1840	460	1	- 500
Mailua (+)	23575	19778	623	64309	53951	1699	+ 500
west:							
Bartimaru (-)	4052	4962	48	3898	4773	46	- 500
Lorgosua (-)	6997	467	267	2328	155	89	- 5000
IR-20 (-)	13446	7020	608	11163	5828	505	- 5000
Mailua (+)	23575	19778	623	64309	53951	1699	+ 10500
north-west:							
Enkaroni (-)	2267	2452	403	1828	1977	325	- 1000
Nkoile (-)	2508	2700	78	2285	2460	71	- 500
Osilalei (+)	23039	14004	741	37690	22909	1212	+ 1500
north-west:							
Nentanai (-)	1657	1828	50	862	951	26	- 1200
IR-2 (-)	24793	15870	776	8114	5194	254	- 20000
Osilalei (+)	23039	14004	741	37690	22909	1212	+ 500
Mailua (+)	23575	19778	623	64309	53951	1699	+ 20700

In principle, there is no overstocking any more in the ecosystem, when the group ranches apply herding strategies like above suggested. The total forage demand by both wildlife and livestock is still 325,425 tons for the average long dry season, resulting in an overall forage surplus of 224,506 tons in the whole ecosystem. Still the balance between overstocking and carrying capacity is very fragile. When the rainy season is only one month too late (see simulation 2), some group ranches (Kuku and Nkoile) will already suffer from overgrazing, despite their "herding strategy", and others are about their limits of the carrying capacity (Kimana and Enkaroni). In an even worse situation, when the rainy season starts at the end of December, at least about half of all the group ranches will suffer from severe overgrazing, especially in the south-east and in the north-western part of the ecosystem. The central and north-eastern part still have some surplus left, but the distance to move cattle to those areas is to far and even than, the surplus of forage in these rangelands is not sufficient to compensate the shortage.

Amboseli National Park is severely overstocked with a forage shortage of 13,641 tons, but the neighbouring group ranches Olgulului-W and Olgulului-N still have a surplus of respectively 10,971 tons and 9,491 tons of forage. Both Olgulului-W together with Olgulului-N can easily support the "extra" numbers of wildlife during the dry season and, therefore, it is very likely that during the dry season wildlife is going to make use of the rangelands of Olgulului-W and Olgulului-N, when the availability of forage in the park becomes limited. When maintaining the actual wildlife population of the Amboseli ecosystem, proper agreements should be made with these group ranches to avoid conflicts between KWS and the local Maasai of especially the neighbouring group ranches.

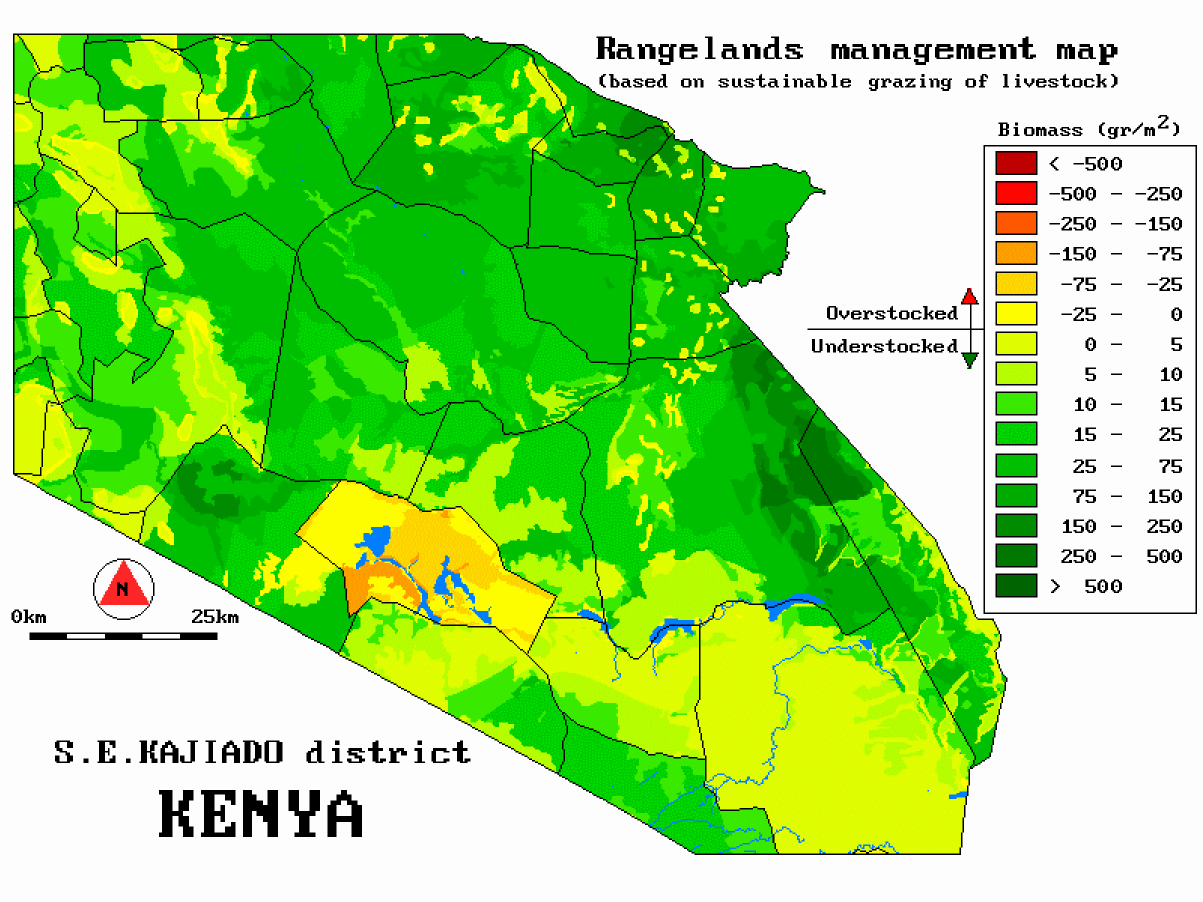

Figure 19. **The spatial result of simulation 5, where, together with the four additional boreholes, the group ranches with a shortage of forage adapt their herding strategy in such a way, that they graze parts of their livestock in neighbouring group ranches, which have a surplus of forage, to prevent overgrazing in their own group ranch, but in avoiding it in the neighbouring group ranches as well.**

Also the situation for wildlife in Amboseli National Park becomes critical, when the rains are too late. When one month too late, the shortage (about 18,000 tons forage) still can be compensated by the neighbouring group ranches (about 28,000 tons forage surplus), but when the rains start at the end of December, the to be compensated demand of wildlife (about 50,000 tons) exceeds the (still) surplus of Olgulului-W and Olgulului-N (about 20,000 tons).

All together it is obvious, that at present, the management of the rangelands on a sustainable level is possible, when applying proper herding strategies and appropriate agreements, but as soon as the (unpredictable) rainy season starts later than usual, many group ranches will be confronted with severe overgrazing problems resulting in rangelands degradation. Therefore, it is advisable to improve the situation by looking at other rangelands management options, which will improve the situation on a more long term point of view.

5.2.7 Simulation 6

One of the simulations on "long term base" is for instance to reduce bush encroachment. In the south-eastern group ranches forage loss because of not suitable areas for grazing seems mainly due to large areas with high shrub cover, like in Kuku, about 75% of the total rangelands, for Kimana 72%, Olgulului-South about 92% and for the whole area of IR-17. The same is applicable for other group ranches in the north-west, like Lorgosua, Bartimaru, Nentanai and IR-20. Very large areas suffer from bush encroachment (see table 11) with shrub cover densities up to 60 percent or more (in Lorgosua about 73%, in Bartimaru about 59%, in Nentanai about 76% and in IR-20 about 84% of their total rangelands).

One of the management options in these rangelands could be an improved rangelands management to reduce bush encroachment. In this simulation areas with a shrub cover from 20 percent up to 60 percent are improved, resulting in a shrub cover off less than 20 percent to reduce shrub hindrance for livestock in these areas. Areas with shrub cover above 60 percent are considered as being part of the ecosystem and to be left as they are. In table 11 a comparisment has been made of the change in forage available for livestock (carrying capacity) before and after the rangelands improvement.

Table 11. The group ranches with the percentage of their total rangelands covered by shrubs with a density higher of 20 percent and the effect of available forage after the rangelands improvement, in relation to the actual situation (model result)

group ranch (ha)	total area (ha)	Dense shrubs	% of total	C.capacity (tons-model)	C.capacity (tons-impr.)	% Improve-ment
Arroi	8596	1484	17	7,250	7,364	1.6
Bartimaru	5084	2984	59	2,756	3,247	17.8
Chyulu	39844	0	0	16,320	16,320	0
Enkaroni	2100	352	17	1,458	1,489	2.1
Enkorka	2456	352	14	1,156	1,184	2.4
Eselengei	73900	5828	8	39,419	39,881	1.2
Imaroro	16620	1428	9	12,316	12,629	2.5
IR-12	7344	1356	18	10,268	10,410	1.4
IR-16	8064	5068	63	550	701	27.5
IR-17	24188	24188	100	10,992	13,505	22.9
IR-2	17196	8204	48	4,533	5,183	14.3
IR-20	27060	22864	84	7,272	9,895	36.1
Kiboko	18332	3364	18	11.048	11,621	5.2
Kimana	29988	21692	72	6,463	7,554	16.9
Kuku	99492	74644	75	28,626	31,286	9.3
Lorgosua	4348	3176	73	1,390	1,816	30.6
Mailua	72660	29532	41	43,085	44,963	4.4
Mbilini	14220	172	1	9,305	9,308	0.1
Mbirikani	112068	28136	25	77,852	79,888	2.6
Mbuko	18272	0	0	8,342	8,342	0
Merueshi	20004	2064	10	7,342	7,629	3.9
Nentanai	3644	2760	76	608	836	37.5
Nkama	42672	11696	27	32,830	34,165	4.1
Nkoile	3356	1792	53	1,606	1,717	6.9
Oldonyo Forest	6624	1096	17	496	576	16.1
Oldonyo Orok	7884	4728	60	3,624	4,238	16.9
Olgulului E	41536	5184	12	10,380	10,870	4.7
Olgulului N	41300	740	2	16,504	16,583	0.5
Olgulului S	33476	30888	92	7,326	9,236	26.1
Olgulului W	43884	7848	18	22,337	22,892	2.5
Olkarkar	10452	3632	35	2,826	2,840	0.5
Olomunyi	13948	5956	43	5,924	6,422	8.4
Olontulugum	13524	1920	14	7,852	8,031	2.3
Osilalei	39168	8660	22	20,916	21,512	2.8
Poka	8948	740	8	13,617	13,686	0.5

Although for many group ranches improvement of the rangelands by reducing shrub hindrance for livestock resulted in a considerable increase of the carrying capacity of their rangelands (e.g., Olgulului-S 26.1%, IR-16 27.5%, IR-17 22.9%, IR-20 36.1%, Lorgosua 30.6%, Nentanai 37.5%), the total increase of the carrying capacity for livestock was not more than 5.3 percent (441,040 tons -> 464,434 tons forage available). This is mainly due to the fact that most group ranches, with a high percentage of increase of the carrying capacity, are relatively small areas (like Lorgosua, Nentanai, IR-16) and their rangelands improvement is not contributing much to the total ecosystem. Furthermore, in many (large) group ranches, when the shrub cover is high, the grass cover is still low and/or difficult accessible (like Kuku, Kimana), so the increase of forage for livestock is still little.

But in those areas where high shrub cover (and in most cases with a low grass cover) has been reduced to less than 20 percent, the grass cover should increase as a logic consequence of proper rangelands management. In this simulation, besides the two new boreholes and the other two repaired boreholes which are still applicable as in simulation 4, areas with shrub cover above 20 percent are improved resulting in a shrub cover of less than 20 percent and the grass cover of these areas, where the shrub cover has been reduced, has been improved to at least 60 percent cover.

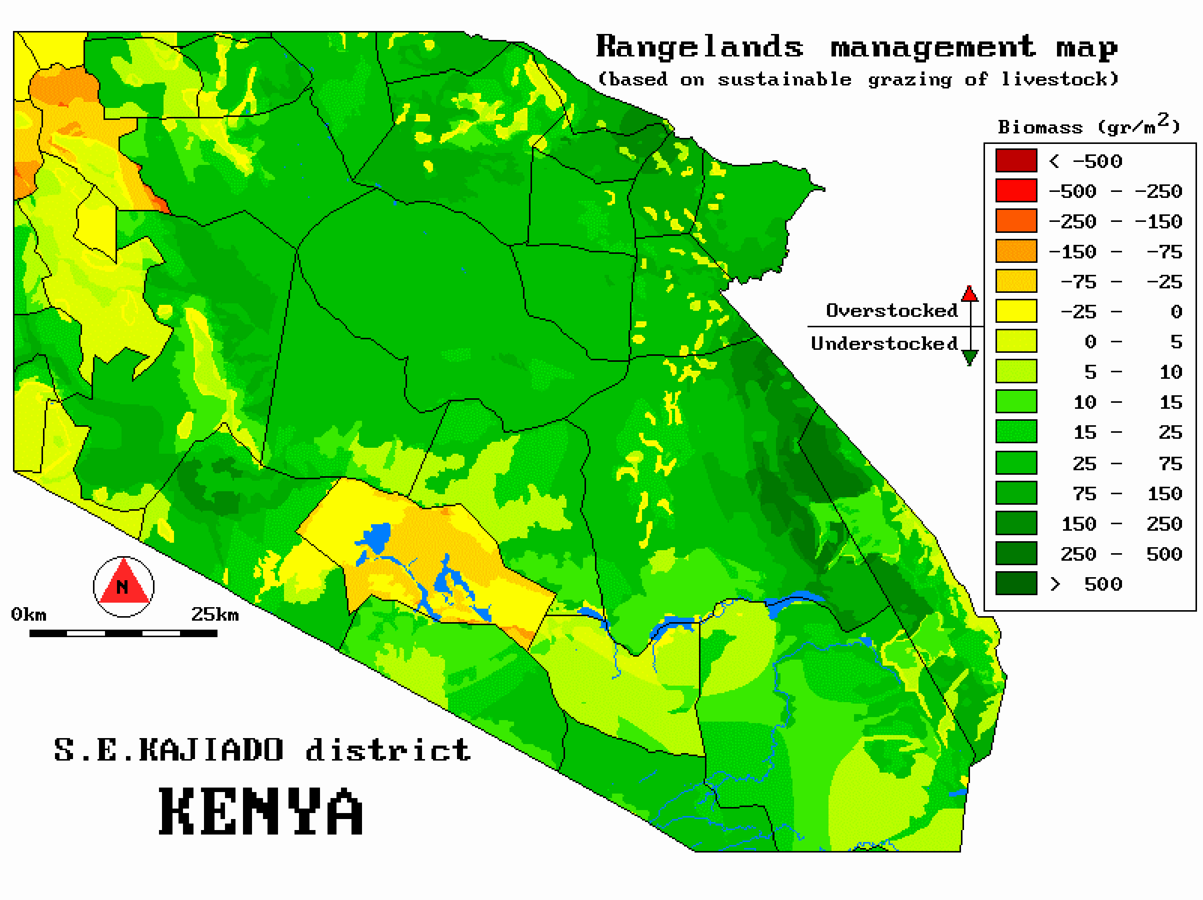

Figure 20. The spatial result of simulation 6, where besides the 2 additional and the 2 now working boreholes, bush encroachment has been reduced to less than 20 percent shrub density and the grass cover in those areas has been improved to 60 percent as well .

When looking at table 12, most of the group ranches with previously small areas with dense shrub cover showed hardly any improvements (like Olgulului-w 2.7%, Mbirikani 6.7%, Nkama 4.1%, Imaroro, 2.5%, IR-12 1.4% Mbilini 0.1%, etc), while in other comparable group ranches the carrying capacity increased much more, due to the previously very low grass cover in those areas (like Eselengei 15.6%, Kiboko 42.6%, Merueshi 51.9%, Oldonyo Forest 77.4%, Olgulului-N 30.1%, Osilalei 22.5% and Olkarkar 401.6%). The carrying capacity of the group ranches, with large areas of previously dense shrub cover, generally increased considerably (like Kimana 152.9%, Kuku 117.4%, IR-16 170.2%), while in other comparable group ranches the carrying capacity increased much less, due to a previously already quite high grass cover (like Bartimaru 27.8%, IR-20 36.1%, Lorgosua 30.6%, Nkoile 6.9%). Overall the total carrying capacity of the ecosystem increased from 441,040 tons to 557,017 tons, which is considerably (26%) compared to the actual situation (model-result).

Table 12 The group ranches and the effect of available forage for livestock (carrying capacity) before and after the rangelands improvement as in simulation 6.

group ranch	C.Capacity (tons-model)	C.Capacity (tons-impr.)	% improvement
Arroi	7,250	7,364	1.6
Bartimaru	2,756	3,521	27.8
Chyulu	16,320	16,320	0
Enkaroni	1,458	1,489	2.1
Enkorka	1,156	1,184	2.4
Eselengei	39,420	45,575	15.6
Imaroro	12,316	12,629	2.5
IR-12	10,269	10,414	1.4
IR-16	550	1,486	170.2
IR-17	10,991	16,334	48.6
IR-2	4,533	6,022	32.8
IR-20	7,272	9,895	36.1
Kiboko	11,048	15,450	42.6
Kimana	6,463	16,344	152.9
Kuku	28,626	62,234	117.4
Lorgosua	1,390	1,816	30.6
Mailua	43,085	50,712	17.7
Mbilini	9,305	9,308	0.1
Mbirikani	77,852	83,084	6.7
Mbuko	8,342	8,342	0
Merueshi	7,342	11,154	51.9
Nentanai	608	836	37.5
Nkama	32,830	34,165	4.1
Nkoile	1,606	1,717	6.9
Oldonyo F	496	880	77.4
Oldonyo O	3,624	5,977	64.9
Olgulului E	10,380	11,940	15.0
Olgulului N	16,504	21,477	30.1
Olgulului S	7,326	10,173	38.9
Olgulului W	22,337	22,942	2.7
Olkarkar	2,826	14,174	401.6
Olomunyi	5,924	6,422	8.4
Olontulugum	7,852	8,031	2.3
Osilalei	20,916	25,632	22.5
Poka	13,619	14,442	6.0

Still 5 group ranches are overstocked (Enkaroni, IR-2, Lorgosua, Nentanai and Nkoile), of which IR-2 has still a shortage of 10,229 tons of forage, while the stocking rate of the other group ranches are just above their carrying capacity. Furthermore the location of all these overstocked group ranches is in the north-western part of the ecosystem, while the rest of the ecosystem seems to be in balance now with the carrying capacity and the number of livestock. The overall result indicates that, after the simulated improvements of the rangelands, there is a surplus of about 292,740 tons of forage in the whole ecosystem. Even in the north-western part the main contributing group ranches to supply forage for livestock (Osilalei and Mailua) have a considerable surplus of forage (resp. 10,599 tons and 34,820 tons).

So, it is very well possible to adapt a herding strategy for those overstocked group ranches to prevent overgrazing in their own group ranch by herding parts of their cattle in the above mentioned group ranches with an expected surplus (see table 13). Nevertheless, especially ranch IR-2 should realize, that their carrying capacity is far below the actual stocking rate, in fact the actual stocking rate is about 170% above the carrying capacity, even after the simulated rangelands improvement. Or they have to range at least 80% of their cattle in neighbouring group ranches, or they have to buy additional forage, but is seems absolutely impossible to maintain the actual stocking rate just by utilizing their rangelands only.

Table 13. Forage shortage group ranches (-) with the actual (1992) number of livestock and the neighbouring forage surplus group ranches (+), and the number of cattle of "shortage" group ranches advised to graze on the neighbouring "surplus" group ranches, still after the rangelands improvement (simulation 6)

Group ranch	Actual			Recommended			To change Cattle
	Cattle	shoat	donkey	cattle	shoat	donkey	
West:							
Lorgosua (-)	6997	467	267	3041	203	116	- 4500
Mailua (+)	23575	19778	623	75227	63111	1988	+ 4500
north-west:							
Enkaroni (-)	2267	2452	403	1867	2020	332	- 600
Nkoile (-)	2508	2700	78	2442	2629	76	- 100
Osilalei (+)	23039	14004	741	39282	23877	1263	+ 700
north-west:							
Nentanai (-)	1657	1828	50	1185	1307	36	- 600
IR-2 (-)	24793	15870	776	9187	5881	288	- 20000
Osilalei (+)	23039	14004	741	39282	23877	1263	+ 600
Mailua (+)	23575	19778	623	75227	63111	1988	+ 20000

Even, when the rains comes one month too late, the rangelands of a few additional group ranches will suffer by overgrazing e.g., Kimana, IR-16 and IR -20, but their shortage is still limited (55 tons, 53 tons and 428 tons respectively), which can easily be compensated by additional grazing in neighbouring surplus group ranges. The overall situation of the ecosystem is still sustainable with a surplus of 237,417 tons of forage.

In conclusion it seems very advisable to reduce bush encroachment in the ecosystem, to improve the condition of the rangelands, especially in the south-eastern part of the ecosystem. It is also advisable to drill and repair the proposed boreholes and maintain the existing ones to be sure that the improved rangelands are accessible for livestock.

5.3 Competition between Wildlife and Livestock

Another output is the group ranch map with an indication of the forage consumption by both wildlife and livestock during the dry season (see figure 21). The length of the vertical bars indicates the amount of forage consumed by wildlife (left green bar) and livestock (right red bar) in kg per group ranch. Furthermore, the output gives statistical values about the forage consumption and the ratio between the forage consumption between wildlife and livestock per group ranch as well.

This output can be a very handy tool during discussions concerning compensation for forage loss in group ranches, due to wildlife grazing. As can be seen from the map, not all the group ranches surrounding the Amboseli National Park (Kimana, Olgulului-N, Olgulului-E, Olgulului-S and Olgulului-W) suffer most from wildlife grazing. Especially the group ranches more east and south-east (Mbirikani and Kuku) have a much higher forage intake by wildlife. In less extent even northern ranches (Eselengei and Merueshi) have an almost comparable forage intake to be expected due to wildlife grazing as the group ranches directly surrounding the Amboseli National Park (see also table 14). For the other group ranches, the forage consumption due to wildlife grazing during the dry season is little (in general less than 1,000 tons forage).

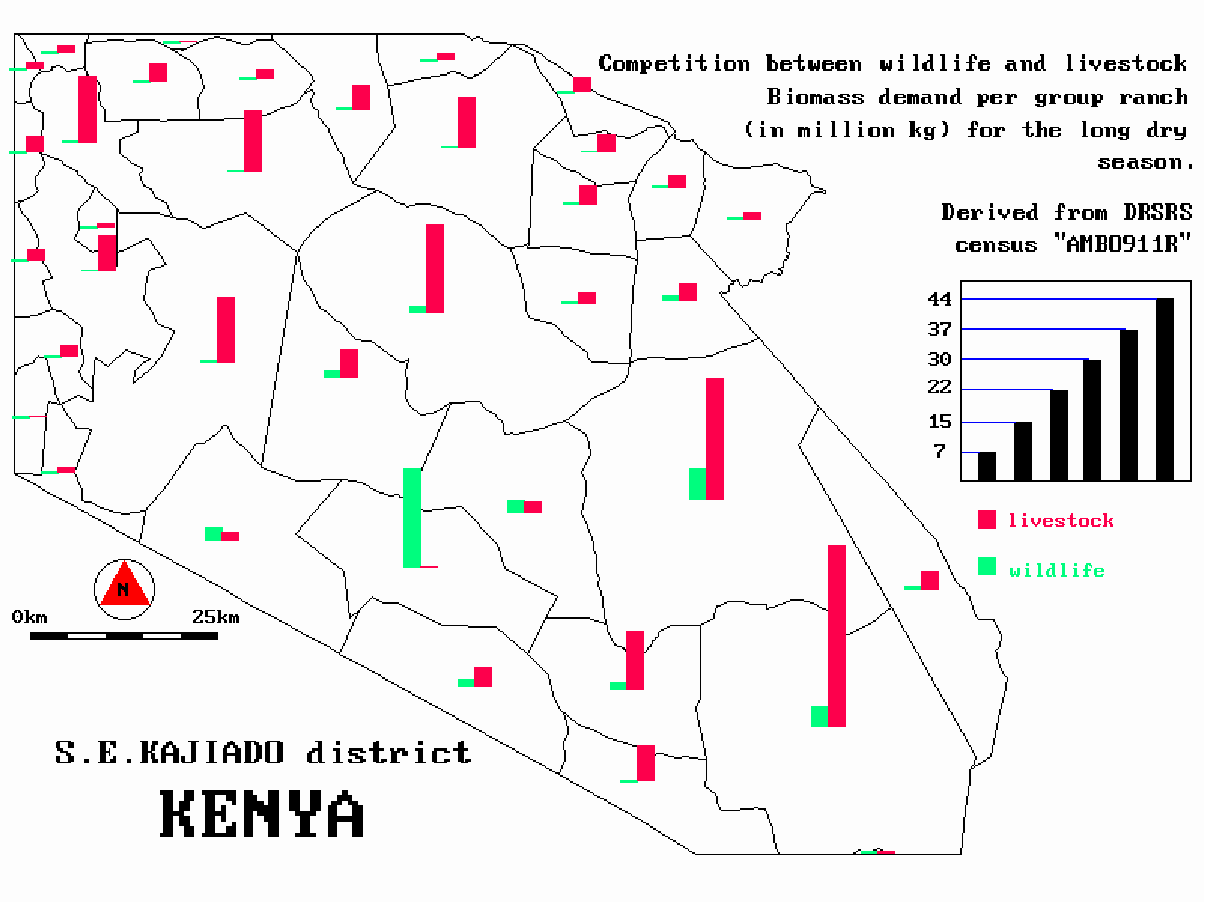

Figure 21. **The forage consumption by both wildlife and livestock during the long dry season per group ranch and the ratio between wildlife and livestock of the total forage consumption per group ranch.**

Although Mbirikani and Kuku have the highest (absolute) forage consumption by wildlife, compared to the total forage consumption by the large herbivores (wildlife and livestock) the consumption by wildlife is only 20% and 11 % respectively of the total forage consumption in their group ranch. Relatively the group ranches Olgulului-E and Olgulului-W with respectively a forage consumption by wildlife of 53% and 61% of the total forage consumption will have the highest forage loss due to wildlife grazing. In one way or the other, these figures and statistical data can serve as an indication to estimate the hight of possible compensation (revenue) for group ranches, suffering from losses due to the presence of wildlife on their rangelands.

Table 14. The forage consumption (tons) by both wildlife and livestock during the long dry season per group ranch and the ratio (%) between wildlife and livestock of the total forage consumption per group ranch.

Group ranch	forage intake wildlife (tons)	forage intake livestock (tons)	intake wildlife (%)	intake livestock (%)
Amboseli N.P.	24,009	245	99	1
Surrounding:				
Kimana	1,945	14,157	12	88
Olgulului-N	1,965	7,091	22	78
Olgulului-E	3,314	2,977	53	47
Olgulului-S	1,928	4,072	29	71
Olgulului-W	3,267	2,053	61	39
south-east:				
Mbirikani	7,560	29,468	20	80
Kuku	5,217	44,357	11	89
north-east:				
Eselengei	1,881	21,382	8	92
Merueshi	1,348	4,365	24	76

5.4 The Human Aspect

The model is calculating the required number of livestock according to the needs of the Maasai population per group ranch as well, which is based on the metabolic intake of the Maasai. For the actual situation (model results) the current "overall" situation indicates a shortage for both cattle and shoat (18 of the 37 group ranches have livestock numbers below the required number of livestock (see table 15).

Table 15. A comparison is made between the required number of livestock according to the needs of the Maasai population in 1992, based on their metabolic intake, the actual livestock numbers and the recommended livestock numbers, based on the sustainable carrying capacity of the rangelands, in the Amboseli ecosystem

	number of cattle	number of shoat
required:	545184	511050
actual:	399509	288665
shortage:	145675	222385
recommended:	663141	607008
actual:	399509	288665
additional:	263632	318343

Although according to the recommended number of livestock, based on the carrying capacity of the Amboseli ecosystem, the ecosystem can in principle support the required number of livestock for human need. Still about 12 ranches have, according to the human need, a shortage in number of livestock. This can indicate, that the Maasai have changed their traditional way of feeding and instead of depending mainly on livestock that they have other food additional on their diet (like products from agriculture crops or bought in the city), as there were no signs of malnutrition in the field.

Nevertheless, with an estimated population growth rate of 4.7% it is obvious, that the Maasai have to change their feeding habits to other (agricultural) products, as the number of livestock can not grow much more to fulfil their metabolic requirements only based on livestock, without high risk of overgrazing of the rangelands when some (natural) changes take place. For example when the dry season is 7 months instead of normally 6 (see simulation 2), the recommended livestock numbers are almost equal with the for the Maasai required livestock numbers (see table 16). In an even worse situation as in simulation 3, when the amount of rainfall is only 60% of the average rainfall, the recommended number of livestock can become even below the by the Maasai required number of livestock. In these situations the total number of livestock is needed just for the survival of the local Maasai population. As soon as, for example, livestock diseases occur, the Maasai population will suffer of malnutrition or worse as well.

Table 16. A comparison between the required number of livestock according to the needs of the Maasai population, based on their metabolic intake, the actual livestock numbers and the recommended numbers during a 7 month long dry season and a wet season with very low rainfall, based on the sustainable carrying capacity of the rangelands

	number of cattle	number of shoat
Normal situation:		
Required:	545184	511050
Actual:	399509	288665
Shortage:	145675	222385
long dry season 7 month:		
Recommended:	562950	514533
Actual:	399509	288665
Surplus for:	163441	225868
60% of average rainfall:		
Recommended:	390773	350028
Actual:	399509	288665
over/understocked by:	-8736	61363

All together it is clear from above and the simulations, that the balance between livestock numbers, the rangelands condition and the livestock numbers required by the Maasai is very fragile and easily being disturbed with the to be expected consequences as result.

5.5 Simulation in the Amboseli Biosphere Reserve in Practice

Summarizing, the use of the Amboseli "rangelands management model" can provide the managers and other decision makers with information, which might lead to taking decisions, which are based on the forage availability during the dry season and the demand for forage during this period. A summary of the simulations with their effect on the overall situation of the Amboseli ecosystem is given in table 17.

Table 17. A summary of the simulations carried out and the effect on the forage availability, forage demand and the overall improvement of the rangelands of the Amboseli ecosystem. Also the number of group ranches with an estimated forage shortage is given

Management Actions	forage avail. (tons)	tot. forage demand (tons)	inaccessible forage (tons)	forage available (tons)	impr. (%)	neg. ranch
model:						
actual situation	**732,284**	**325,428**	**230,094**	**+176,762**	n.a.	12
Simulation 1:						
dry season 5 months	732,284	271,190	232,629	+228,466	+29%	8
Simulation 2:						
dry season 7 months	732,284	379,666	228,987	+123,632	- 30%	12
Simulation 3:						
60% of av. rainfall	423,888	325,428	113,895	-15,435	-109%	16
Simulation 4:						
4 add. boreholes	732,284	325,428	205,696	+201,161	+14%	11
simulation 5:						
4 add. boreholes and change herding practic	732,284	325,428	182,353	+224,506	+27%	1
simulation 6:						
4 add. boreholes and red. bush encroachme	813,553	325,428	195,386	+292,740	+66%	5

The examples shown are simulations, based on average rainfall or possible fluctuations in the average rainfall during the wet (growing) season to demonstrate the possible consequences for the rangelands under the actual wildlife - and livestock numbers and distribution. The simulations show as well the possibilities to change livestock numbers and adapt grazing patterns to give an indication of how to maintain or improve the condition of the rangelands as much as possible.

Furthermore, with the actual population growth rate, the change in the traditional lifestyle to start cultivating agricultural crops for providing additional food seems to be necessary, unless the population growth rate can be reduced. Nevertheless, the introduction of agriculture in a semi arid ecosystem should be done very carefully and well considered to be sure not to disturb wildlife migratory routes or prevent livestock movements when necessary.

The results of the simulations will give the user a good impression of those management options, which will likely influence the development in the ecosystem in a desired or not desired direction and the results will also indicate what management option will have a strong or just little influence on the condition of the rangelands for each group ranch or the development of the Amboseli ecosystem in general. Therefore, the results from the Amboseli rangelands management model will serve as a guideline for decision makers, to emphasize on those management options that will lead to a desired situation.

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