A System for Integrated Management and Assessment of East African Pastoral Lands

Balancing Food Security, Wildlife Conservation, and Ecosystem Integrity

Edited by:

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Final Report to the Global Livestock Collaborative Research Support Program

Natural Resource Ecology Laboratory

Colorado State University

IMAS Project

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A System for Integrated Management and Assessment of East African Pastoral Lands: Balancing Food Security, Wildlife Conservation, and Ecosystem Integrity

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EXECUTIVE SUMMARY

The African continent is a place of great contradictions, with a cultural diversity that is unmatched, world-renowned wildlife populations, the promise of economic development, and abundant natural resources. Africa is also a place of war, famine, and disease, including an AIDS epidemic. Two-thirds of the African continent is either arid or semi-arid, where agriculture is problematic or incompatible. In these areas, livestock production and wildlife conservation are the most common forms of land use. In Kenya, for example, rangelands support over 25% of the human population of that country, and over half of the livestock population. About 80% of Kenyan large wildlife are also found in these areas, and income from tourism has become an important source of revenue. For thousands of years the pastoral people of East Africa were able to persist, and even flourish, in spite of periods of droughts and disease, and to coexist with large herbivores. Today that long-standing pattern of success appears to be disrupted. Pastoralists' well being, livestock, and wildlife populations, and the diversity of ecosystems are declining. The program supporting our work, the Global Livestock Collaborative Research Support Program (GL-CRSP) of the US Agency for International Development, has among its strategic objectives to assist developing countries to identify and remedy problems in livestock production, to enhance the nutritional status and incomes of livestock producers, and to do so "while monitoring the effects of production on the environment and exploring the integration of production systems with the rational use of natural resources, such as wildlife." These objectives led us to propose the Integrated Management and Assessment System (IMAS) project to help managers and stakeholders balance food security, wildlife conservation, and ecosystem integrity.

In IMAS we focused upon two semi-arid areas in East Africa, Ngorongoro Conservation Area in northern Tanzania, and Kajiado District, southwestern Kenya. The sites are both locations of great experiments in balancing human well being, pastoral land use, and conservation. Ngorongoro Conservation Area (NCA) is a world-renowned wildlife conservation area that is also inhabited by more than 50,000 Maasai and their livestock. The managers of the area have a mandate to balance the needs of humans and wildlife in NCA, while drawing income from tourists visiting sites such as Ngorongoro Crater. Livestock populations in NCA have been relatively stable, but human populations have increased dramatically. This has led to a dramatic decrease in the number of livestock per person, a measure of the wealth and well being of pastoralists. This reduction in relative numbers of livestock has been offset somewhat by cultivation; Maasai in NCA may cultivate small plots of land. The main limitation on livestock production in NCA is the annual migration of wildebeest from Serengeti National Park. Wildebeest are the most numerous large herbivores on NCA during the wet season, then move into the Serengeti at other times of the year. Maasai graze their cattle on the short grass plains until the early wet season (January), but must move their animals to the midlands and highlands because wildebeest calves carry a virus causing malignant catarrhal fever in cattle. Cattle are therefore concentrated in the high elevation areas during the wet season. High elevation areas have the most ticks in NCA, and their populations are highest in the wet season, and so many Maasai livestock are lost to tick borne diseases such as East Coast Fever. Livestock concentrated in the midlands and highlands also leads to range degradation. In general, livestock and wildlife continue to be viewed as competitors for forage, and as posing risks to each other for disease transmission.

The other major study site, Kajiado District, contains Amboseli National Park, and the northern slopes of Mount Kilimanjaro. Wildlife of Amboseli expand their ranges during the wet season to graze across the entire basin, then in the dry season their ranges collapse to include Amboseli National Park and the surrounding areas that have permanent water sources. Some of those water sources are large swamps fed by springs draining the slopes of Mount Kilimanjaro. In southern Kajiado, some key swamps have been fenced to protect drinking water and water for irrigation, and have been surrounded by cultivation. These barriers limit the access of wildlife to the swamps. Another ongoing change that makes Kajiado unique is the formation of group and individual ranches. In the 1960s, large blocks of land called Maasai sections were divided into smaller group ranches, to be managed jointly by ranch members. The ranches were put in-place to improve livestock production, promote the development of common resources, and encourage the long-term ownership of the lands by the Maasai. In practice, group ranches have generally not been managed jointly, and fragmentation of the district continues. The movements of Maasai within the district are now limited by ranch boundaries, reducing the options available to them during times of drought, for example. Fencing associated with group ranches limits the movements of wildlife as well. In general, wildlife populations in the greater Amboseli ecosystem are declining precipitously, while human populations are expanding and economic activities are intensifying.

These threats and others highlight the need for a system that allows managers and stakeholders a means of assessing ecosystem effects as a whole. Further, governmental and non-governmental groups in East Africa fully support integrated approaches to management. The Kenya Agricultural Research Institute and the International Livestock Research Institute, and private groups such as the Inuyat e-Maa, a non-governmental organization representing Maasai interests, are working together to benefit East African pastoralists and livestock development. In Tanzania, Wildlife Management Areas are being formed, which will bring together competing interest groups to manage for sustainable wildlife populations while assisting area residents. Tools and assistance that would enable these groups to make decisions based upon the integration of available information are needed; that was the goal of the GL-CRSP IMAS project.

A team of 52 scientists, administrators, and students cooperated to attain the GL-CRSP IMAS goals. In the most general sense, the subprojects performed under GL-CRSP IMAS were designed to support the development of a tool to conduct integrated assessments of alternative policies, with the SAVANNA modeling system at its center. Field and GIS work gathered data for use in setting-up the ecosystem model and disease models and a socio-economic model were created to broaden the applicability of SAVANNA. However, the interests and expertise of IMAS scientists, leveraged funding, and other opportunities that presented themselves, allowed us to extend our assessment beyond model support. In practice, subprojects were put in-place under GL-CRSP IMAS, and each of these is summarized below.

Forage yield and chemical composition was assessed at three sites in the NCA, Ngorongoro Crater, Esilwa, and Malanja, using established methods. Forage yield was higher in Ngorongoro Crater than for other areas tested. Conversely, crude protein and ash values were higher for Esilwa, an area outside the crater. In general, the wooded Esilwa site supported higher quality forage, but in lower quantities. Range condition ratings for the three assessed sites in NCA were: ‘good’ for the crater and Malanja and ‘fair’ for Esilwa. On a comparative basis, Malanja was far less utilized than the other two sites, although it had the greatest amount of forage yield. Erosion and overgrazing were prevalent in Esilwa, and was the most heavily used of the three areas (30% use). Soil organic matter content was low. Forage yields between the dry and wet seasons were 896 and 1,552 kg dm/ha respectively. Although Esilwa was in ‘fair’ condition, its forage chemical composition was higher in both seasons when compared with Malanja and the Crater. The average forage yield for Ngorogoro Crater was 2,547 and 2,608 kg DM/ha for the dry and wet seasons, respectively. The crater had twice the number of wild herbivores in the wet season compared to the dry season. For four sites assessed, forage use in the crater was between 10% and 18%. In general, forage yield, protein content, and crude fiber increased with annual precipitation. These factors correlated with increased numbers of migratory wild herbivores during the wet seasons. Climate or seasonal variations were the key factors that brought about changes in wild herbivore numbers in the wet and dry seasons respectively. In a related study, the body condition and forage selection of livestock in NCA was assessed using fecal analyses. Forage dry mass was between 2,300 kg/ha and 2,780 kg/ha, on average, with the highest yield being 4,500 kg/ha. The average dry mass values ranged from 91.2% to 95.3% for *Aspillia mosambicensis* and “Arang’awa” respectively. The average crude protein ranged from 4.5% to 17.7% for *Pennisetum schimperi* and *Trifolium subrotundum*, with a mean of 10.2%. Livestock Body Condition Scores during May were M+ for cattle and F for goats. This implied that during this time livestock were in good condition.

In correlational analyses at Kiboko Range Research Station, Kenya, distance to water was strongly correlated to altitude because most water sources are along the Kiboko River and the adjacent plains, which are at low altitudes. Erosion was not strongly correlated to rainfall indicating that factors that contribute to erosion in the area were a result of land use practices. Soil nitrogen and phosphorous positively correlated to grazing intensity. Grazing intensity is negatively correlated with soil moisture at all levels; this is probably due to the effects of livestock trampling on soil physical characteristics and the grazing effects on cover and biomass. Ordination analyses conclude that herbaceous standing crop in the prolonged dry season in the study area was generally determined by soil moisture at 5 cm depth, distance to watering points and the level of erosion. Small-scale ranches were associated with erosion and high weed biomass. Kiboko group ranch, in which the pastoralists are largely sedentary, was also associated with erosion and low soil moisture. Ordination of sites in respect to cover produced relatively distinct grouping of sites under similar management. Small scale ranches of Olkarkar and Meruseshi were associated with high soil nitrogen, high livestock density and dominated by *Pennisteum mezianum*. Sites in the conservation areas of Chyulu reserve and Kiboko station were associated with low stocking density and great distance to water. Sites in Kiboko group ranch and small scale mixed farms were associated with high nitrogen, low soil moisture and high percentage of bare ground.

We compiled spatial data to supported spatial analyses, as well as ecosystem modeling using the SAVANNA model, socioeconomic modeling, and wildlife and livestock disease description and modeling. Landsat Thematic Mapper data was acquired for the Serengeti Ecosystem and Kajiado District, and used to make vegetation maps of the study sites. Normalized difference vegetation indices calculated from weather satellite images were merged into a spatial database, and used in analyses. Other regional spatial layers gathered included political boundaries, game reserves and conservation areas, demographic data, agricultural statistics, topographic information, soils information, climatic data, and land cover.

Detailed spatial layers have been compiled for NCA and Kajiado District. Land cover maps were made for NCA and Kajiado District, which were used in ecosystem modeling and in analyses of vegetation change in both areas. Water sources were compiled or acquired for the sites, and distance to water maps were calculated for use in modeling. Detailed soils maps were acquired for the areas, and we created maps showing the relative densities of livestock and wildlife species in each site. A spatial layer showing the distribution of bomas in NCA and Loliondo was acquired, for use in modeling. In Kajiado, a relatively recent atlas was available, so those layers were digitized, such as roads, ecozones, and group ranches. Aerial surveys of wildlife by the Kenyan Department of Resource Surveys and Remote Sensing were made available to us, and simplified versions merged into our spatial databased.

Spatial analyses conducted addressed vegetation change in Ngorongoro Crater and Amboseli Basin; in Amboseli, a large portion of the study area has been converted to small-scale agriculture and some degraded in terms of vegetation resources as a result of overgrazing failing to take into consideration the vulnerability of the range ecosystem. In sum, declining vegetation cover, formation of erosional sites, abandonment of cropping fields, declining water availability, and wildlife reduction in number and species diversity can be seen to be the outcomes of recent land use changes, settlement, expanding cultivation and changing climatic conditions within the study area. A spatial analysis focused on the impacts of water development on the distribution and diversity of wildlife, comparing the semi-arid savanna in Kajiado to arid savannas in northern Kenya. In the arid savannas, human presence and livestock foraging excludes wildlife from within 5-10 km of water points. In Kajiado, where forage is more abundant, wildlife and livestock strongly intermix, with no exclusion of wildlife by livestock and people. Analyses were also conducted for all of Africa, mapping the large mammal diversity expected in conservation areas, and comparing that to expected increases in human population. The analyses indicate that East Africa will be the area with both high species richness in conservation areas and large stresses on those areas from expanding human populations.

We adapted the SAVANNA modeling system to NCA, creating an integrated management and assessement system that allows users to conduct sixteen experiments reflecting potential management questions. The model was parameterized for NCA, and a control was run for use in comparisons with experimental results. The experiments addressed changes in rainfall, livestock populations, veterinary practices, grazing lands available, water sources, and human population growth and cultivation. When rainfall was reduced to represent a two-year drought, changes one might expect were simulated by the IMAS tools, including a reduction in vegetation, with shrub biomass declining from 150 g/m^2 to 100 g/m^2 and green leaf biomass declined by one-third during the dry season. In an experiment, we modified observed rainfall, removing 1% of rainfall from the five wettest months and adding 1% of rainfall to the five driest months. When simulated, there was a large increase in dry-season green biomass, for example. Some wildlife populations increased markedly, whereas cattle populations declined.

We used the IMAS tools to assess potential ecological effects of increasing the number of livestock on NCA. Livestock populations were increased by 50%. When simulated, livestock populations remained relatively stable until a dry period in the 1980s, then cattle populations declined sharply. We repeated these analyses, keeping the livestock populations high and constant. Standing biomass for palatable grass leaves declined steadily during the 15 year simulation, from a peak of 44 g/m^2 in the last year to 35 g/m^2. In contrast, unpalatable herbaceous leaf biomass increased over time. Some wildlife populations declined under increased livestock density, whereas others did not decrease because of spatial or dietary separation from livestock.

We used IMAS tools to quantify the benefits that can be expected from improving veterinary care. We increased juvenile livestock survival by 7%, and when simulated, every few years there were up to 4,500 additional cattle that could be sold or slaughtered, and up to 5,000 additional goats and sheep almost every year. In another experiment, we increased birth rates for livestock by 5%, and results show that increased birth rates may lead to relatively few additional animals being available for the Maasai to sell or slaughter. When we increased overall adult livestock survival by 5% for each group, simulation results suggested that the expected results would be dramatic. Finally, we reduced mortality due to tick-borne diseases by half. The results of the simulation suggest that tick-borne diseases are an important source of mortality, and reducing that mortality adds thousands of additional animals that may be culled.

In a simulation, we allowed livestock to graze in Ngorongoro Crater, which is now illegal. Livestock used the crater, but populations did not change markedly, in-part because of the relatively small grazing areas added by allowing animals to use the craters. In another experiment, we increased the likelihood that cattle would use grazing areas in southwestern NCA, which they now avoid because of the high risk of livestock rustling. Simulation results suggest that a few hundred goats and about 3,000 additional cattle could be supported on NCA if security in the southwest was improved. However, resident zebra populations decreased by 14%, and elephant populations decreased by 18%.

In an experiment we restored 20 water systems that has failed in the past. Our simulation results suggested that restoring the water systems of NCA that had failed would redistribute animals across the area, with most of the changes occurring near the center of the study area, near Olduvai Gorge. To assess potential impacts of water use by the occupants of lodges, we removed water sources that were within 1 km of lodges. When modeled, the change in herbivore distributions was minor. Populations of animals that inhabited Ngorongoro Crater did decline, such as browsing antelope.

Maasai pastoralists in the region generally have an annual population growth rate of about 3% per year, and up to 6% when immigration is high. We used the IMAS tools to assess the potential effects of a 3% population growth. The simulation results include households increasing over a 15 year simulation from 5,000 to 7,702 households, and cultivation increasing from 4,727 ha to 7,293 ha. Overall, there were few changes in the populations of wildlife or livestock. We conducted a series of analyses, varying cultivation from 0.5% of the area to 5% of the area. Results from NCA-SAVANNA simulations suggest that changes in wildlife and livestock populations in response to up to 5% of the area in cultivation would be relatively small, except for elephant populations.

We conducted three sets of experiments using the SAVANNA application adapted to southern Kajiado. An important concern with the sub-division of Kajiado into group ranches has been the fragmentation of grazing resources. We selected four sites for closer analysis. These include a cluster of group ranches collectively known as Dalalakutuk, Mbirikani Group Ranch, Orkarkar Group Ranch, and an area of Mailua Group Ranch of the same size and shape of Orkarkar, for comparisons. We contrasted two scenarios: 1) the relative number of livestock that could be supported on each of the areas when livestock were allowed to move about the entire study area (10,732 km^2), and 2) the number of livestock that could be supported when they were restricted to the given area or group ranch. The Dalalakutuk region is a relatively arid portion of Kajiado. In the Kaj-SAVANNA control model, livestock remained fairly stable in Dalalakutuk. When livestock were restricted to Dalalakutuk region throughout a simulation, their populations declined. The Mbirikani Group Ranch is larger and more productive than the Dalalakutuk region. In Mbirikani, a dramatic influx of animals into the area occurred during a drought, moving in from drier portions of Kajiado. Kaj-SAVANNA simulations showed a similar but more dramatic response in the small Orkarkar Group Ranch to Mbirikani. When livestock were forced to select habitats from within the portion of Mailua Ranch select, rather than all of southern Kajiado, the populations declined to near zero.

In another experiment, we made the swamps of Amboseli Basin entirely unavailable to wildlife and livestock, representing encroachment by cultivation and draining for irrigation. Results from the simulation varied by animal group in a complex way, but in general the changes were in the direction we would predict. Grazing wildlife most common in the Amboseli region declined when swamps were unavailable, with buffalo declining by 17%. We used the IMAS modeling tools to assess what the effects of fencing Amboseli would be on some of the wildlife populations within the park. Our methods were similar to those used in studying ownership patterns. When wildlife populations were as in the control model but restricted to Amboseli and a simulation run, populations of wildebeest, zebra, and buffalo declined precipitously. As may be predicted, our simulation suggests that southern Kajiado District would support only a fraction of its current wildlife population if the animals were confined to Amboseli National Park.

The economic difficulties of the Maasai pastoralists in Ngorongoro Conservation Area are well known. One objective of our study was to determine whether these difficulties are endemic to Maasai pastoralists throughout northern Tanzania, or if they are specific to NCA Maasai. We compared NCA Maasai ecology and economy with their Maasai neighbors in the adjacent Loliondo Game Controlled Area. Interview data showed that households in Loliondo possess about three times the livestock holdings compared to NCA households. Furthermore, Loliondo Maasai have considerably larger agricultural acreage per person than in NCA, where plot size is limited by conservation policy. Households in the NCA are significantly larger on average, with a mean of 22 people, while for Loliondo the mean is 15. Livestock sales were higher in the NCA than in Loliondo. The mean number of cattle sold in Loliondo as a percentage of the total herd size was 3.7%; in the NCA it was 8.2%. There was tremendous variability in agricultural yields, but yields per person were generally about twice as high in Loliondo as those in the NCA. In general, the research demonstrated that Ngorongoro Maasai are indeed economically worse off than their counterparts in the adjacent Loliondo.

We also explored how major variations in landscape and vegetation influenced human activities and the pastoral economy. NCA and Loliondo Maasai classify their ecosystems into lowlands, midlands and highlands. In general, ‘lowlands’ refers to the short grass plain and to adjacent woodlands and savannas at lower elevations; ‘midlands’ are the mid-grasses, savannas and woodlands occurring on slopes and hills above the plains, and ‘highlands’ include the highland forests and high elevation grasslands. We found no significant relationships between these ecological zones and livestock holdings, either in terms of herd sizes or human:livestock ratios. However, there were significant differences among eco-zones in extent of cultivation. Ecozone also influences pastoral movement distances. Households inhabiting lowlands traveled the longest total distance during the year, households in the highlands the least.

Research in the Amboseli ecosystem, Kajiado, Kenya is examining pastoralist land use patterns in relation to the influence of development and economic diversification. A general settlement survey of all bomas within six study areas was carried out to identify Maasai land use patterns. The type and presence or absence of water resources was a deciding factor in the land use and economic decisions taken by pastoralists in Kajiado. Fully 80% of all settlements were engaged in some form of agriculture. A significant proportion of pastoral households across the Amboseli study zone are taking part in some form of employment and/or business activities. Business activities range from grain grinding, small shops, and cattle trading to buying and selling of vegetables and other commodities. Preliminary analyses indicate that up to 55% of all employment across the six study areas is linked with wildlife and/or tourism.

In Kajiado, wildlife density was inversely related to livestock density. Mbirikani group ranch is utilized almost entirely on a semi-nomadic mode with very few permanent settlements. These two factors probably also contributes to the low wildlife density. Bomas, livestock, and wildlife are all more common in open grasslands than brushy areas. There is higher density of bomas/households near permanent water sources, towns and roads. Wildlife was found furthest from water sources.

One component of our research set out to quantify the effect of human settlement patterns on the density, spatial distribution and biodiversity of wildlife of the Serengeti-Mara ecosystem, in Kenya, where livestock herds exist side by side with diverse wild herbivores herds. Intense ground surveys were conducted, and livestock were found to congregate near Maasai bomas (i.e., households) while wildlife clustered at intermediate distances from bomas during the wet season. Livestock and wildlife distributions were clearly complimentary during the wet season with livestock dominating the area within one km from bomas and wildlife concentrating at 2-3 km from bomas.

The effects of different land use patterns in relation to livestock holding was investigated in and around the Kiboko Range Research Station, Kenya. The settlements of Muuni and Kiboko are occupied by the Akamba tribe who are primarily agriculturists. Muuni and Kiboko settlement schemes have average land sizes of 7.9 and 6.3 acres respectively with both schemes allocating an average of 54% to farming. The stocking rates are 0.16ha/ TLU and 0.41ha/TLU for Kiboko and Muuni settlement schemes respectively (where 1TLU=250 kg live weight). In Kiboko group ranch the total number of cattle has declined by 32% since the last census of 1988, the number of sheep and goats has however increased by 23%, from 6,920 to 8,529. An important change in land use in the game reserve is the increase in cultivation with 96% of the households now practicing farming.

Interviews of Maasai were used to characterize their movements and land use in NCA. A severe drought occurred in 1997 and 1998 was an El Niño year. The drought of 1997 forced people to remain longer in the highlands than they would in a normal year. During the dry season some people and livestock were forced to move into the Northern Highland Forest and the Olmoti Crater. The use of forage resources in Olmoti and in the forest prevented major losses to starvation, and people seemed to have been able to cope with this drought without major problems. The mobility pattern of the people and livestock in the Endulen area changed little. The major problems were caused by a large number of people and livestock moving into the area from north of the NCA and from the Olbalbal area. People said that human nutrition was low because livestock were not giving much milk, crops had a very bad year, and the price for selling livestock had dropped dramatically. In contrast, people and livestock from the Olbalbal area drastically altered their normal mobility patterns in 1997, which was a dry year. The year 1998 was a very difficult year for people living in the NCA. Because of the unprecedented amount of rain, the crops in the area failed and there were major outbreaks of rarely seen livestock diseases and malaria. The forage resource was at an all time high, so livestock could recover condition as long as they were able to avoid disease.

Anthropometric measurements were taken on individuals in the Loliondo and in the NCA. Measurements of height, weight, upper arm circumference and tricep skinfolds were taken on individuals depending on their age. The results of comparing nutritional indices among NCA children in 1998 and 1999 showed that there was no effect of year on height of children, but weight differences were significant different (a mean of 25.9 kg for children in 1998 and 23.4 kg for children in 1999). In general, girls and boys in Loliondo tended to weigh more than their NCA counterparts; however, the differences were not significant. Among two- to five-year old boys, the difference in mean weight was on the order of 15%; among the six- to thirteen-year olds, the difference was 17% and among the adolescents, it was 4%.

PHEWS, the socioeconomic household model for Ngorongoro Conservation Area, has been completed and tested, and is fully integrated within the Savanna Modeling System. A set of scenarios was drawn up that PHEWS and Savanna together would be used to investigate, and were run and analyzed. PHEWS was also to be adapted for Kajiado in Kenya, a much more market-orientated production system. The general modeling approach taken was to use a small set of rules that govern the operation of the model, and then use the revealed characteristics of the model through simulations to adjust some of the key model parameters so that reasonable behavior of the model is obtained. We hypothesized that there is a quantity of livestock units per person that characterizes pastoral systems. We also hypothesized a hierarchy of goals at the household level. First, the household has to meet its food requirement. If there is a shortfall, then this is made up by recourse to various options, including the selling of an animal, if necessary. Second, the household is assumed to manage for livestock in terms of investment and disinvestment decisions — these types of livestock purchases and sales can be considered different to the meeting of household food requirements. Third, there is discretionary consumption; after the first two goals have been dealt with, with consequent impacts on the cash reserves (purchase of food, for example), there may be a certain amount of cash left over for spending on various items.

Based upon PHEWS simulations, pastoralist well being in NCA, even with small amounts of agriculture allowed, is not internally sustainable at current human population levels. If realistic population growth rates are imposed for the next 15 years, then the household food security situation would deteriorate markedly. The model suggests that the introduction of agriculture in 1992 in NCA occurred at a time to make a substantial improvement in householders' welfare. By the late 1990s, these welfare gains would have been overtaken by human population growth rates in excess of 6% per year. The model also shows that the NCA pastoralists are susceptible to drought; in the immediate term, household food security is severely compromised, but there is also the longer-term impact on livestock numbers where they have to be built up in the aftermath of drought. The model also indicates that various productivity-increasing interventions can have beneficial impacts on household welfare.

GL-CRSP IMAS research confirms that group ranches do not operate as economic organizations, but merely as commercial land units with a shared title deed by many individuals who carry on their livestock production activities individually. Without the sharing of acquired inputs, the group ranch implies merely joint ownership. The group ranches that have not been subdivided are generally those that have pending court cases concerning disputes over land ownership. There are also a few group ranches that have not been subdivided either because they are too dry or because there are some wildlife tourism benefits anticipated. Twenty-nine group ranches have been completely subdivided such that the owners have obtained individual title deeds. In total, these group ranches account for 51% of all group ranches and 35% of the group ranch area. However, when these are added to another eleven group ranches in the process of subdivision, the extent of group ranch privatization becomes clear.

Two surveys were carried out in Kajiado to generate data for the socioeconomic modeling effort. In the first survey of the wildlife, livestock and human interaction in Kajiado District focused on the case of the Amboseli National Park wildlife dispersal areas encompassing the Kimana and Mbirikani Group Ranches. The first survey found no evidence of severe competition for available resources between livestock and crop production in both Mbirikani and Kimana Group Ranches. Livestock and cropping enterprises give relatively high rates of return to capital, and most of the pastoralists and agro-pastoralists are able to derive their livelihood from the two enterprises. The second survey attempted to concentrate on the more highly commercial ranching operations found in the Kajiado District. While ranching was the main economic activity, 57% engaged in other economic activity in addition to ranching. All respondents control ticks and give veterinary drugs (commonly antibiotics) to their cattle. Preliminary analysis indicates a mean annual profit per ranch of some KSh 205,000 (US $2,600) for all respondents, but there are large variations depending on ranch size.

Diseases of wildlife and domestic animals in East Africa not only affect animal populations and but also have economic, social, and political implications. Therefore it is important to consider the impacts of disease in the generation of management alternatives for the ecosystem. Prior to developing disease submodules, we obtained information on the occurrence and distribution of important diseases within the affected animal populations. Participatory rapid appraisals (PRA) were used to determine the priority diseases of livestock, the animal health constraints to livestock productivity and the community perception to wildlife as a potential source of diseases of livestock. In 1998, the pastoralists identified East Coast fever, ormilo (turning sickness), malignant catarrhal fever, anaplasmosis, contagious bovine pleuropneumonia, blackquarter, lumpy skin disease and anthrax as the most important diseases affecting livestock. An average mortality rate of 52% for calves below the age of one year was reported. Tick-borne diseases, principally East Coast fever, were listed as responsible for the high calf mortality. In Kajiado, there were greater livestock disease control problems because of a drought, including foot and mouth disease, contagious bovine pleuropneumonia, and East Coast fever, due to lack of adequate tick control.

We used a mixture of long-term ecological data and computer models to examine epidemiology of malignant catarrhl fever in the NCA. The likelihood of cattle mixing with wildebeest to acquire malignant catarrhl fever was calculated based upon prevalence, proximity, exposure and infectiousness of the disease agent. These calculations were done in a spatial context, with the resulting model able to be merged with SAVANNA, with feedbacks between the two system. The submodel has been used by veterinarians in East Africa to explore the balance between the value of grazing and avoidance.

We sought to model the progression of rinderpest outbreaks in NCA herbivores. We required the model to model patterns realistically and to incorporate animal movements into disease risk and spread. We defined cattle movement frequencies between 16 blocks that comprised NCA, for 5 time periods during the year. In a simulation, SAVANNA provides a simulated population size for cattle for each block within the landscape. A subroutine estimates the proportion of a given population infected by disease, based upon a small suite of parameters. At each time step, and for each block, SEIR (Susceptible, Exposed, Infected, and Removed) equations are applied. Differential non-linear coupled equations are used to yield a state transition model describing the proportion of the population susceptible, exposed, infected, and removed during each time step. The model incorporates animal movements, modifying parameter values based upon animal movements and population sizes.

Finally, the GL-CRSP IMAS team had an extensive effort in gathering input from stakeholders, outreach to inform East Africans of the work, and training of regional scientists and managers. Workshops were held in East Africa early in the project to gather input in project direction, which brought together scientists, conservationists, and a representative of pastoralists. Participants shared their experiences with pastoral-wildlife systems, and specified the types of information that would be useful from their perspectives. A conceptual framework for the assessment system was developed, research sites were evaluated, and overarching goals, objectives, and assumptions were identified. Structured analysis methodology, a method of identifying stakeholder concerns, were used in a workshop that brought together scientists and managers to discuss transboundary issues in Kenya and Tanzania to the problem of livestock-wildlife interactions.

To inform stakeholders and managers of the region of the GL-CRSP IMAS project, we presented a series of talks at the workshop just mentioned, then presented a series of workshops throughout northern Tanzania. Additional presentations have been made to interested groups by East African team members. Results from GL-CRSP IMAS field work in NCA were reported back to the area's Maasai, an apparent rarity that was appreciated by the pastoralists. A web site was contructed that describes the GL-CRSP IMAS project. Finally, the GL-CRSP Integrated Management and Assessment System project and the SAVANNA modeling system were widely publicized in a report and press release from a promotional organization associated with the International Livestock Research Institute (ILRI), Nairobi.

A two-week GIS training course was developed and conducted at ILRI in April 1999. Nine participants attended, and the course was rated excellent by course participants. GL-CRSP IMAS, the SAVANNA modeling system, SavView, and our experiments were demonstrated to participants of two workshops, and in other presentations in 2000. Participants learned IMAS goals, the SAVANNA modeling system, and how to conduct experiments. Individuals were also trained in using IMAS tools during visits to CSU. The IMAS modeling system, including SAVANNA, is now installed in six locations throughout northern Tanzania and southwestern Kenya. At any of these installations, people may run their own experiments to assess potential effects of increased livestock populations, changes in rainfall, or changes in herbivore grazing patterns, as examples.

Our outreach and training efforts must be judged a success, with countless people informed of the utility of the GL-CRSP Integrated Management and Assessment System project through the media, more than one hundred East Africans informed first-hand of our efforts, and two dozen East Africans with in-depth training in the use of IMAS tools. Research results have been reported in more than 50 publications, reports, and presentations. The Conservator with the Ngorongoro Conservation Area Authority and others are very interested in using IMAS to extend our work to determine appropriate balances between wildlife and an increasing livestock population. We have also made the Tanzania National Parks Authority and Tanzania Wildife Research Institute aware of our products, and the Tanzania Ministry of Agriculture are quite interested in the GL-CRSP IMAS. All three of these organizations are influential in effecting policy in Tanzania. Kenyan organizations, including the Wildlife Service and the Agricultural Research Institute, are pursuing using IMAS assessments and tools in their work as well.

ACKNOWLEDGMENTS

An effort of the scope of the GL-CRSP Integrated Management and Assessment System project relies upon the input and assistance of many people. Our sincere thanks go to the members that made-up the GL-CRSP IMAS team (listed in *Appendix B*), especially to those not represented as authors in this report. Members of the GL-CRSP IMAS team produced outstanding results, often stretching limited resources and volunteering time. Our East African team members were particularly valuable; their scientific rigor, experience, and ease in cooperating with others helped us to attain our goals. East Africans seek to understand and manage lands where there are many challenges and an uncertain future. We are confident that those challenges will be met with enthusiasm, commitment, and insight.

We thank all the Maasai who welcomed us into their homes and from whom we learned so much. Without their input our work would have been much weaker – we hope that our respect for them as early and continuing stewards of the land and its wildlife has been evident. Our thanks also to the Kajiado Group Ranch committees for assisting us in our work, and to the late Dr. Said at the Waso Hospital at Ngorongoro, and Dr. Mgisu of Endulen Hospital. Their thoughts, insights, and help with logistics is appreciated.

Others who contributed to a successful project include: Cathy Wilson of the International Livestock Research Institute, who helped in many ways, including preparing and reporting on a major workshop in 1999 (see *Chapter 10*); Judy Rainy and Eoin Harris of Bush Homes of East Africa for their help with the same workshop and other assistance; Bjørn Figenschou of Tanzania Guides Limited and Pauli Sadiki of the University College of Lands and Architectural Studies, University of Dar es Salaam, for all their help in outreach and training efforts and logistics; Bush Homes of East Africa for providing assistance to students doing field work, and housing to students and other IMAS team members; Laurie Richards of the Natural Resource Ecology Laboratory for all of her editorial assistance in bringing together this final report and bearing all the other requests on her time with good humor; Karen Bradley of the Natural Resource Ecology Laboratory for her effort and skills in managing a very complex budget; and our thanks to the GL-CRSP group for their support of the IMAS effort and their guidance, with special thanks to Susan Johnson for all her assistance with report preparation – including helping to bring this report to print – and for help with budgets, travel, and providing countless other answers.

Chapter 1

East African Pastoralism and the Integrated Management and Assessment System Project

Kathleen A. Galvin and Randall B. Boone

INTRODUCTION

The African continent is a place of great contradictions, with a cultural diversity that is unmatched, world-renowned wildlife populations, the promise of economic development, and abundant natural resources. Africa is also a place of war, famine, and disease. Two-thirds of the African continent is either arid or semi-arid, where agriculture is problematic or incompatible. Further, in East Africa, rains falling in two distinct seasons and with spatial and temporal variability can make crop production a hazardous occupation in semi-arid zones (Pratt and Gwynne 1977, Ellis and Galvin 1994). In these areas, livestock production and wildlife conservation are the most common forms of land use which are also the areas where we have focused our work (Figure 1.1). In Kenya, for example, rangelands support over 25% of the human population and over half of the livestock population. The livestock sector produces 10% of the gross domestic product. About 80% of Kenyan large wildlife are also found in these areas. Income from associated tourism has grossed over $500 million per year, and has become an important and reliable source of revenue for the national government and local authorities (Ottichilo et al. 1997). According to one source, tourism is the primary source of foreign exchange, and wildlife-based tourism is 50% of the total (Byrne et al. no date, Grootenhuis et al. 1991).

The program supporting our work, the Global Livestock Collaborative Research Support Program (GL-CRSP) of the U.S. Agency for International Development, has among its strategic objectives to assist developing countries to identify and remedy problems in livestock production and to enhance the nutritional status and incomes of livestock producers. At the same time, they will be "monitoring the effects of production on the environment and exploring the integration of production systems with the rational use of natural resources, such as wildlife." These objectives certainly are appropriate in East Africa, where land managers and policy makers struggle trying to balance human well being, wildlife conservation, and ecosystem integrity.

For thousands of years, the pastoral people of East Africa were able to coexist with large herbivores and persist, even flourish, in spite of periods of droughts and disease. They used long-established responses to stresses, such as drought, and had cultural norms that allowed wildlife to persist. Today, pastoralists are often unable to use those same responses, in part due to increasing human populations and a decreasing land-use area. Better watered pastoral dry season ranges have been lost to both colonial and African agriculturalists, game parks, and game conservation areas. Pastoralists have taken up agriculture in an effort to meet their increasing food demands at the same time agropastoralists have expanded their fields into more marginal areas. Pastoral cultures are changing too. We proposed to GL-CRSP to create an Integrated Management and Assessment System for use in East Africa, and to conduct assessments aimed at providing land managers and other stakeholders with more objective information on which to base their decisions.

In this study, we focused upon two semi-arid areas in East Africa. The sites, Ngorongoro Conservation Area in northern Tanzania, and the Kajiado District, southwestern Kenya (Figure 1.1), are both locations of great experiments in balancing human well-being, pastoral land use, and conservation. The remainder of this chapter introduces these unique areas. The difficulties facing managers and other stakeholders of these areas are described in *Chapter 2*.

NGORONGORO CONSERVATION AREA, TANZANIA

The Natural System

Ngorongoro Conservation Area (NCA) is 8,280 km^2 (2° 30' to 3° 30' S, 34° 50' to 35° 55' E), 190 km west of Arusha, Tanzania, and bordered by Serengeti National Park to the west, Loliondo Game Controlled Area to the north, and private and communal lands to the east and south. The Rift Valley passes to the east and south of NCA, and includes Lake Natron to the northeast and Lakes Eyasi and Manyara to the south (Figure 1.2). Nine volcanoes together form the topography of NCA, including those forming Olmoti and Empakaai Craters, and Ngorongoro Crater, which at 250 km^2 is one of the largest unbroken non-flooded calderas in the world. One active volcano remains, Oldonyo Lengai, which is along the Rift Valley. The ash from eruptions has yielded fertile soils for cultivation, and formed the Serengeti Plains within NCA and Serengeti National Park to the west (Figure 1.2).

The climate of NCA is variable across space and through time. Storm systems move

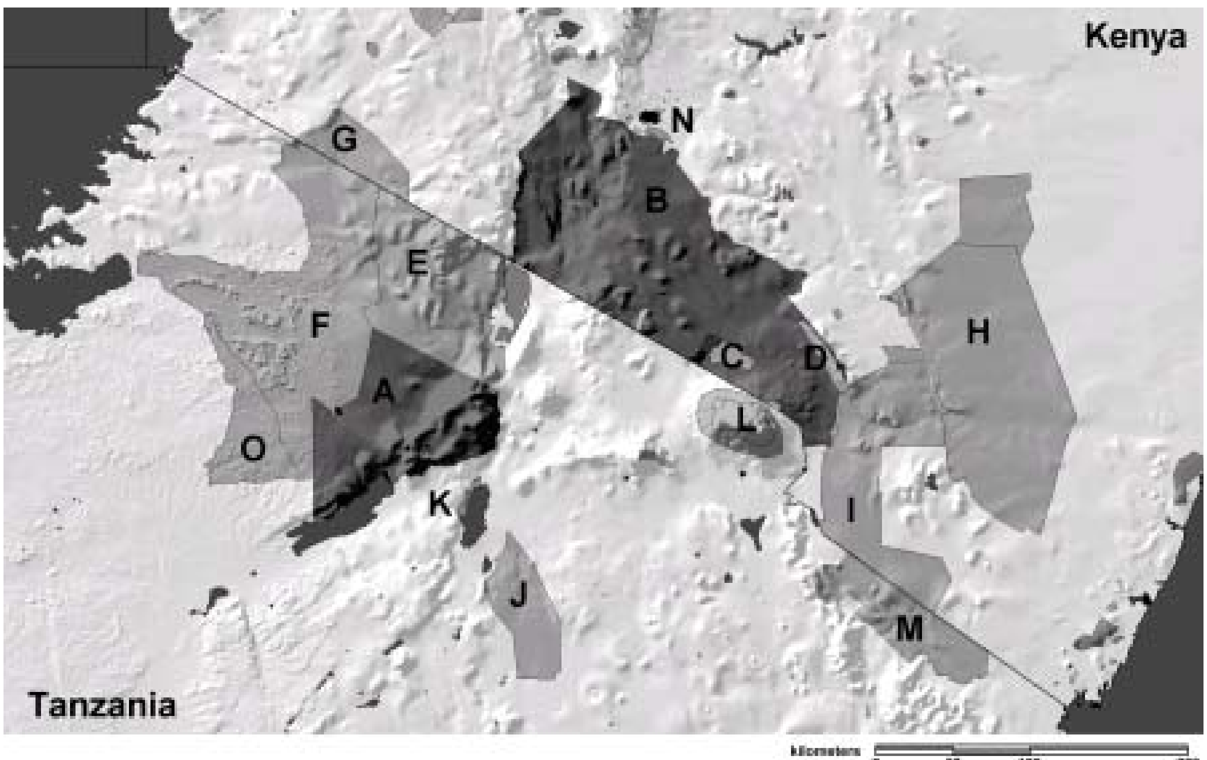


Figure 1.1. The region where the Integrated Management and Assessment System has been applied (inset). Our main study sites were (A) Ngorongoro Conservation Area in Tanzania, and (B) Kajiado District, Kenya. Other areas we have labeled are: (C) Amboseli National Park and (D) the Chyulu Hills Game Reserve in Kajiado District, (E) Loliondo Game Controlled Area, (F) Serengeti National Park, (G) Maasai Mara Game Reserve, (H) Tsavo National Park East, (I) Tsavo National Park West, (J) Tarangire National Park, (K) Lake Manyara National Park, (L) Mount Kilimanjaro National Park, (M) Mkomazi Game Reserve, (N) Nairobi National Park, and (O) Maswa Game Reserve. Water is solid gray, topography is in shades.

from the Indian Ocean to the northwest, dropping large amounts of rain on Ngorongoro Highlands. A strong rain shadow occurs in the NCA, with areas to the west of the Highlands, such as Olduvai Gorge, receiving the lowest amount of annual precipitation (450 mm) of any area in the Serengeti Ecosystem (Campbell and Hofer 1995). The rains fall in a bimodal pattern, with the bimodality less distinct than in other East African regions. The dry season is from June through October with little rainfall and cool temperatures. In November and December, the 'short rains' fall, then January and February may be dry. The wet season 'long rains' fall in March through May. These simple descriptions do not capture the variation in rainfall, however, rarely is the average rainfall pattern seen. Like many semi-arid areas (Ellis and Galvin 1994), the quantity and timing of rainfall in a given year can be highly variable.

The NCA has a complex mix of vegetation associated with the steep elevational gradients of the area. The plains are dominated by low and medium grasses (medium grasses nearer to the Ngorongoro Mountains), which are dry and brown in the dry season, but quickly sprout new growth when rains return. Higher on the hillsides are tall grasses, although low grasses sometimes dominate large open areas of higher elevations, such as in the Bulbul Depression northwest of

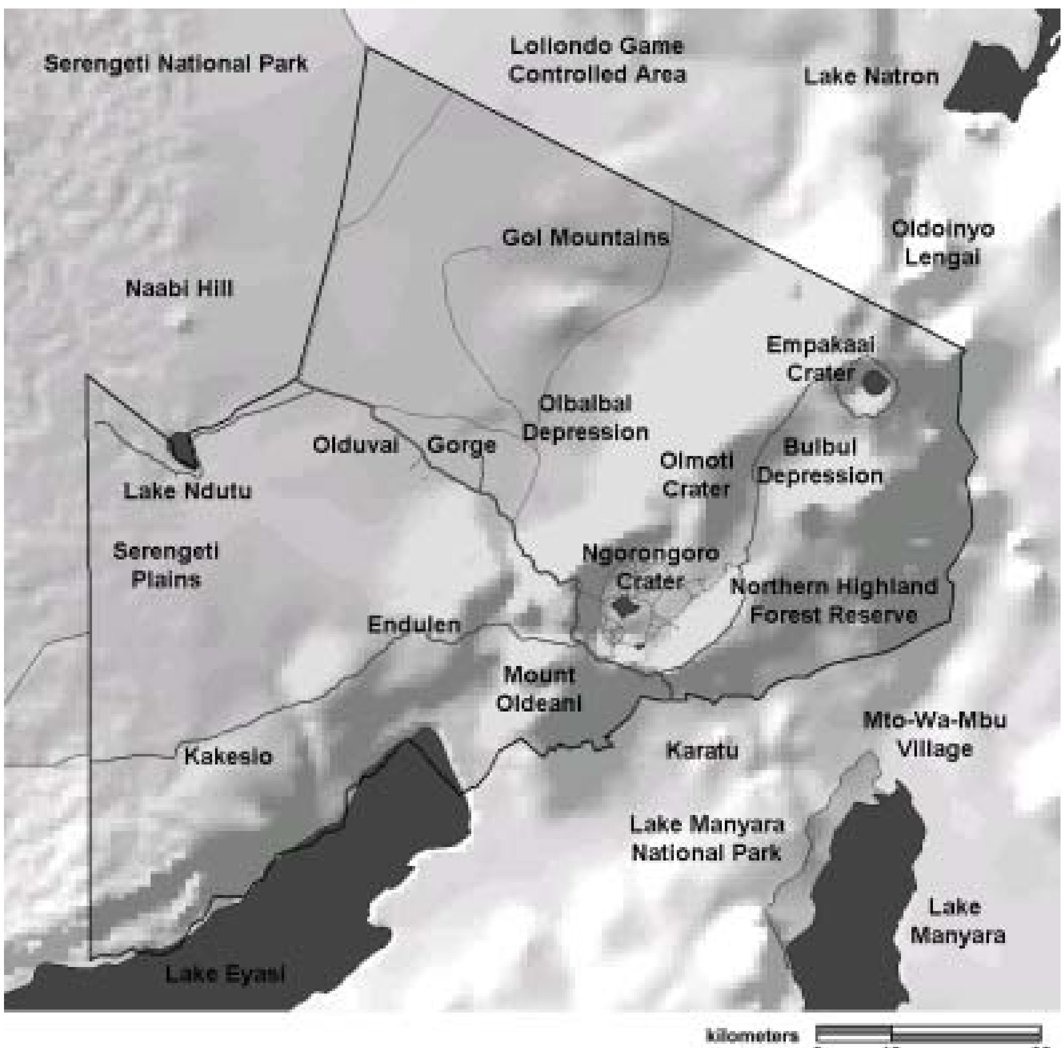


Figure 1.2. Ngorongoro Conservation Area, and the surrounding region. Roads within Ngorongoro are shown, topography is in shades of gray, and water is in solid dark gray.

Nainokanoka. Acacia shrubs and trees dominate the lower slopes of NCA and trace watercourses throughout the area, with Acacia trees scattered through the woodlands. Evergreen trees of many types, as well as heaths and a bamboo forest, occur in the Highlands. Ngorongoro Crater is dominated by Lake Magadi (which can vary greatly in size from year to year), Mandusi Swamp to the north of the lake, Gorigor Swamp to the south, and the Lerai Forest to the southwest of Lake Magadi. However, the bulk of the crater floor provides grazing lands for wildlife.

The wildlife of NCA are dominated by large herbivores, including hundreds of thousands of wildebeest that move onto the area from the Serengeti to give birth. These wildebeest begin moving into NCA in January, and by April reach a peak. Two months later, the migratory herds of wildebeest, zebra, and Thomson's gazelles have moved on, seeking better forage in the Serengeti. Resident populations of these animals remain, often concentrating in Ngorongoro Crater. They are joined by many other species, including buffalo, Grant's gazelles, impalas, kongoni, giraffes, elephants, and the only remaining wild population of black rhinoceros in East Africa, about 14 animals to date inhabiting Ngorongoro Crater.

Humans in Ngorongoro

The NCA includes sites with evidence of early human habitation, including world-famous Olduvai Gorge, where Richard and Mary Leaky made important discoveries of the remains of early humans. Mary Leaky also found the famous Laetoli footprints of early humans, southwest of Olduvai Gorge. Two other especially important archaeological sites are Nasara Rock Shelter and a site near Lake Ndutu, in the southwest.

The lands now comprising Ngorongoro Conservation Area have been colonized by numerous groups that have moved in from the north. The Maasai are only the most recent, moving into the area about 200 years ago. This was the time of European colonization of Africa and though the Maasai were largely spared from laboring on colonial plantations or from fighting in colonial wars, diseases which also broke out at the same time did have a devastating effect. Rinderpest, a disease of ungulates, swept from the north in the 1890s killing 90% of the cattle and much of the wild ungulate populations. This was followed by drought and an epidemic of smallpox; both epidemics are collectively remembered as Emutai - meaning complete destruction (Waller 1988). The Maasai increased their livestock herds, and more slowly, the human population.

The Maasai are semi-nomadic pastoralists, moving sometimes great distances to find adequate forage for their herds of cattle, goats and sheep, with donkeys as pack animals. Their general pattern of movement has been from the midlands and highlands of NCA in the early wet season out into the Serengeti Plains to take advantage of ample forage and water sources. In the dry season, Maasai would move from their temporary households on the plains back to the midlands and highlands of Ngorongoro. This pattern of movement of livestock resulted in adequate livestock condition which has been important in maintaining food security for the Maasai. However, with restrictions on livestock movement and constant livestock disease, the Maasai have not been able to increase their livestock holdings. This, in conjunction with increases in human population, has meant food insecurity for the Maasai. Further, because the Maasai live in a conservation area, there is little opportunity for wage labor or any other means of employment other than livestock herding with some cultivation. Within the last decade, the Maasai have been allowed to interact with the tourist industry by establishing cultural bomas or households where tourists can go and see "traditional" Maasai life. But this has benefitted only a few families in two locations within the NCA. Since 1991, with the permission of the NCA Authority, the Maasai have included agriculture in their activities and are more sedentary than in years past. But they are still pastoralists with little opportunity to diversify. The benefits and costs to such sedentarization are introduced in *Chapter 2*.

The Great Experiment

The Serengeti Region was first gazetted as a game reserve in 1929, and became a national park in 1951. That essentially included what is now Serengeti National Park and NCA. Conflicts between wildlife conservation interests and the Maasai that inhabited the region grew, and in 1959 Ngorongoro Conservation Area was created, to be managed by the Ngorongoro Conservation Unti until 1975, when the Ngorongoro Conservation Area Authority was formed. Maasai were excluded entirely from the Serengeti, but the NCA was established explicitly as a multiple-use area, with management to balance the needs of, and provide benefits to, Maasai and their livestock, wildlife conservation, and the tourism its supports. Thus, the Tanzanian government has directed the NCA Authority in a broad-scale multiple-use experiment for more than 40 years. In 1976, cultivation within NCA was banned, being judged incompatible with wildlife conservation. That position was reversed, to a degree, in 1991 and the Maasai of Ngorongoro are now allowed to have small plots of agricultural crops. In 1979, NCA was placed on the Natural World Heritage Site list, and in 1981, was made a Biosphere Reserve under UNESCO's Man and the Biosphere Programme, along with the Serengeti and Lake Manyara National Park.

KAJIADO DISTRICT, KENYA

The Natural System

Kajiado District is one of 42 such administrative units in Kenya in the southeastern portion of the country (1° 10' to 3° 10' S, 36° 5' to 37° 55' E), encompassing 21,105 km^2. Kajiado is bordered by Tanzania to the southwest (Figure 1.3), Narok District to the northwest, and along the northern border, Nakuru, Kiambu, Nairobi, and Machakos Districts. The southeastern border abuts Taita Taveta District. The Rift Valley runs along the western side of the district, and includes Lake Magadi, a large soda lake, and the northern tip of Lake Natron. East of there are the Kaputiei Plains, an area of rolling topography and containing Kajiado Town and the Central Broken Ground (Ole Katampoi et al. 1990). The southern portion of the district includes the slopes of Mount Kilimanjaro, with the main town being Loitokitok. To the northeast are the Chyulu Hills, which are a game reserve (Figure 1.3). Amboseli National Park is in the southern part of the district, a world-renowned wildlife conservation area with year-round water in swamps, from the slopes of Kilimanjaro, and the sweeping Amboseli Plains. There are a variety of soils in Kajiado, from the heavy clay 'black cotton' soils of the plains to the sandy soils recently derived from volcanic activity, which drain rapidly. In general, there are patches of arable lands in Kajiado, but most of the soils are inappropriate for cultivation.

The driest portion of the district is in the western Rift Valley area near Lake Magadi, where less than 400 mm of rain falls annually. Annual rainfall increases to the north and higher elevations, reaching a peak of about 800 mm near Nairobi, with rainfall also elevated along the slopes of Kilimanjaro and the other district hills (Ole Katampoi et al. 1990). As in NCA, Kajiado has a bimodal weather pattern, which is somewhat stronger than in the NCA. The dry season ends in October when the 'short rains' begin, which lasts until December. Less rain falls in the early part of the year, while the long rains fall from March to May. As in the NCA, temperatures are relatively warm (e.g., mean 30° C) and stable compared to more temperate areas, but vary with altitude.

The vegetation of much of the Kajiado District may be classed bushed grassland or wooded grassland, with an overstory of Acacia shrubs. Woodlands dominate the northcentral part of the district, and grasslands are in the northeast along the Chyulu Hills. Higher elevation areas, such as Oldoinyo Orok near Namanga Town, along the slopes of Kilimanjaro, and near Nairobi, are forested. The Amboseli Basin includes woodland, wooded grassland, and brushland, as well as a fenced forest within Amboseli National Park.

Some large species of wildlife, such as ostrich and giraffe, occur throughout Kajiado District, but much of the focus of wildlife conservation is in and around Amboseli National Park. The park, and areas up to 30 km from the park, form dry season range for wildlife; the wildlife graze in and around the park and can return to the swamps for water. In the wet season, seasonal water sources are available, and wildlife move 60 km or more from the park (Ole Katampoi et al. 1990). About 900 elephants inhabit Amboseli Basin, along with zebra, buffalo, Thomson's and Grant's gazelles, eland, greater and lesser kudus, impala, gerenuk, and other herbivores and their predators.

Humans in Kajiado

By the time the Europeans arrived in East Africa, the Maasai occupied an area of about 155,000 km^2, stretching from Mt. Egon in the north to the Maasai Steppe region of northern Tanzania. By 1913, the area of land occupied by the Maasai in Kenya had been reduced to 40,000 km^2. This area is approximately the size of current day Narok and Kajiado Districts. Other tribes also lost land to Europeans and they in turn, moved into Maasailand and started cropping in the higher potential areas. The migrations, which

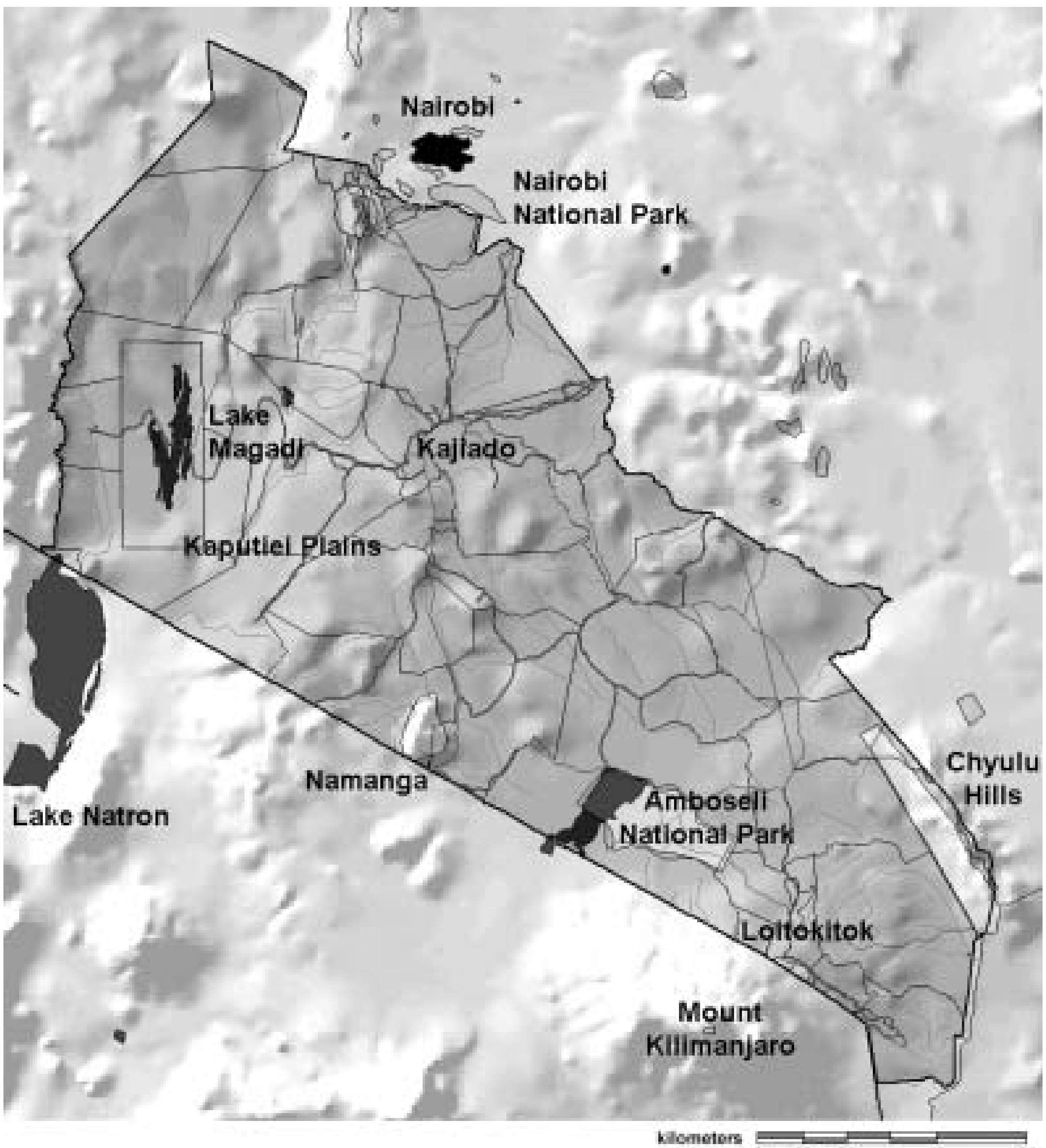


Figure 1.3. Kajiado District, Kenya, and the surrounding region. Roads within Kajiado are shown, topography is in shades of gray, and water is in solid dark gray.

continued into the 1950s, took critical dry-season grazingland from the Maasai. Under the National Parks Ordinance of 1945 the Kajiado Maasi lost access to two areas bordering the District: Nairobi National Park and Tsavo National Park. The Ordinance also established a game reserve in Amboseli (3248 km^2) and game conservation areas at Kitengela (583 km^2) and West Chyulu (368 km^2), restricting the use of these areas by the Maasai (Grandin 1991). Following independence in 1963 much high potential land was transferred to Africans, but this did not occur in the range areas. The Maasai colonial land losses were never regained.

Maasai divided what is now Kajiado District into eight sections inhabited by sub-tribes, with residents moving their herds within each of the sections, but they were unlikely to use the range in other sections. Their cattle, goats, sheep, and pack donkeys would be grazed in the plains during the wet season, then move progressively further up the slopes of the district's hills during the dry season. Today Maasai are more sedentary, with their movements sometimes restricted to a group ranch, described below. People also are cultivating small plots of land, or cold-weather crops along the slopes of Kilimanjaro. Some agriculture is irrigated and some is rainfed, but all provide a diversity of income for the Maasai.

The Great Experiment

Kajiado District is the site of one of the great experiments in international livestock development. In the late 1960s, the government of Kenya requested, and the World Bank implemented the Kenya Livestock Development Program (KDLP), a district-wide project aimed at promoting commercial livestock production among the Maasai herders of Kajiado. The group ranch program had the objective of increasing the offtake of pastoral livestock for commercial sale and thereby meeting the objective of satisfying the beef demand of urban markets and also commercializing livestock production for the benefit of the pastoralists. However, probably more important was the objective of making the group ranch a vehicle for bringing development assistance to pastoralists in terms of communal facilities, such as boreholes, dam, and dips, which when shared by many pastoralists in a group ranch, reduce the unit cost to the individual due to economies of scale. The principal instrument was land adjudication; providing freehold title to groups of Maasai who organized themselves into group ranches. There are many relatively large group ranches (ranging in size from 3000 ha to 151,000 ha) in Kajiado; others have undergone subdivision into individual land-holdings of roughly 10-60 ha in size. In addition, 378 private ranches have been adjudicated since the project began. These ranches average about 800 ha, although some are as large as 2000-3000 ha (Jacobs 1984).

With the subdivision of group ranches through increasing privatization, production strategies that were based on mobile, extensive and subsistence-oriented use of grazing resources are gradually being replaced by a system of land use which is small-scale and based on intensive management of livestock on subdivided and fragmented grazing resources (Galaty 1992). This has increased the level of conflict between people, livestock and wildlife.

INTEGRATED MANAGEMENT AND ASSESSMENT

Governmental organizations (i.e., the Kenya Agricultural Research Institute and the International Livestock Research Institute), and private groups (i.e., the Inuyat e-Maa, a non-governmental organization representing Maasai interests), are working together to benefit East African pastoralists and livestock development. In Kenya, a national wildlife policy has been put into place that calls for developing partnerships among government agencies, local authorities, and private landowners, and an integrated approach to conservation and development based on coordinated ventures and interagency coordination (Ottichilo et al. 1997). In Tanzania, Wildlife Management Areas are being formed, which will bring together competing interest groups to manage for sustainable wildlife populations while assisting area residents (Christophersen et al. 2000). Tools and assistance that would enable these groups to make decisions based upon the integration of available information are needed.

In 1997, we (see *Appendix B* for team members) proposed to GL-CRSP to provide such tools and assistance. We proposed to develop an Integrated Modeling and Assessment System that integrates computer modeling, geographic information systems, remote sensing, and field studies, to provide the information and understanding necessary to improve the balance between pastoral food security, wildlife conservation, and ecosystem integrity. In this volume, we describe the system that was developed, outreach and training efforts made to allow East Africans to use the tools, and results from assessments from Ngorongoro Conservation Area and Kajiado.

Chapter 2

Threats to Food Security, Wildlife Conservation, and Ecosystem Integrity in Northern Tanzania and Southwestern Kenya

Michael B. Coughenour and Randall B. Boone

INTRODUCTION

Land managers and stakeholders in pastoral lands of northern Tanzania and southwestern Kenya face a broad array of problems in managing resources. They must address the concerns of local pastoralists and agropastoralists, local to national regulatory agencies, national and international conservation organizations, international donors, and many others. Unique challenges face those managing the areas we focused upon in the Integrated Management and Assessment System project, Ngorongoro Conservation Area (NCA), Tanzania and Kajiado District, Kenya. In NCA, members of the Ngorongoro Conservation Area Authority have the special challenge put forth in their mandate to balance the needs of Maasai with wildlife conservation. In Kajiado, the repercussions of group ranch formation are still being dealt with by ranch members and national policy makers.

This chapter reports a long list of threats to food security, conservation, and ecosystem integrity, or symptoms from those problems. This list does not include all the problems of the region, of course; such a list would be long for most regions of the world and would be subjective. Instead we highlight significant problems that mainly pertain to livestock, wildlife, conservation, and grazing. Our purpose in citing these threats is not to discourage, but is two fold: 1) to provide the reader with the context of the challenges facing managers, some of which are discussed in the chapters that follow, and 2) to suggest the importance of having an integrated means of assessing potential effects of management decisions. Decisions meant to address one aspect of the problems facing a manager often have unintended effects upon other aspects of the ecosystem under management – the many threats to food security and conservation essentially guaranty this to be true. In the Integrated Management and Assessment System project we have created a system to help predict ecosystem effects that might otherwise be unintended, before policies are actually put in-place.

TYPES OF THREATS

Increased Land Use Intensity

Increases in land use intensity encompasses many of the threats to food security, conservation, and ecosystem integrity in East Africa. At the root of increased use is human population growth. For example, the population in Ngorongoro was about 10,000 when the Conservation Area was created in 1959. In 1999, the population was estimated to be about 51,600 (Figure 2.1a), with a growth rate of about 6% (NCAA 2000). This rapid increase includes both improved survival of the Maasai in NCA and immigration from other areas. Kajiado District has a similar annual population growth rate of over 5% (Njoka 2000). Cattle populations have been relatively stable in NCA (Figure 2.1b), with some increases in goat and sheep populations (Kijazi et al. 1997), and livestock in Kajiado are more variable, building until a drought occurs, then rapidly declining. These patterns of increasing human populations and stable or variable livestock populations have led to an important constraint, the number of livestock (represented

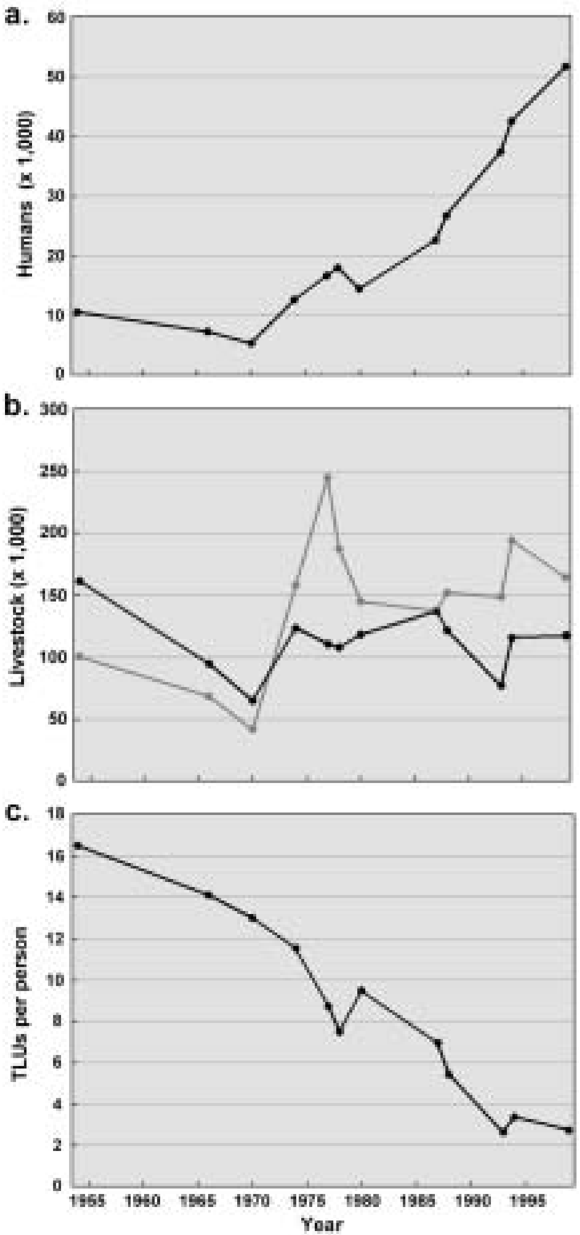


Figure 2.1. The human population of Ngorongoro Conservation Area over the last 45 years has been increasing exponentially (a), whereas cattle (b, black) and small stock (b, gray) populations have been relatively stable. When standardized, the number of topical livestock units (TLU) per person has declined dramatically (c). Adapted from Kijazi et al. (1997) and NCAA (2000), and using the conversion to livestock units from NCAA (2000) of cattle equal to 1 TLU and small stock equal to 1/7 TLU.

by a standardized measure of tropical livestock units) per person has declined through time (Figure 2.1c). Specifically, Maasai of Ngorongoro appear to be chronically undernourished and to be doing poorly economically (food security is estimated and discussed in *Chapter 8*).

In-part to offset a decrease in the number of livestock per person and the insecurity it brings-about, many pastoralists in northern Tanzania and southwestern Kajiado have become agropastoralists. A large part of the land from Arusha to Ngorongoro is now cultivated, with the fertile once forested areas southeast of NCA now cleared and planted (Figure 2.2). Cultivation in NCA was banned in 1975, but reinstated in 1992 to help alleviate hardships for the Maasai. Since 1992 many Maasai have established small plots near their households. The size of the plots are limited by legislation to one ha per wife and children. Areas near Endulen are more densely cultivated by Maasai and other groups, including illegal large plots by non-Maasai. Wildlife and livestock are excluded from cultivated areas, although livestock are fed crop wastage. Debate is ongoing about the effect of the current level of cultivation (i.e., about 0.8% of the total land area, see *Chapter 8*) on wildlife populations. Our analyses of effects of cultivation, based upon simulations, are reported in *Chapter 7*. Wildlife conservationists are concerned with expanding cultivation in Kajiado District as well. In particular, Kimana Swamp, which provides dry season water and grazing for Amboseli Basin wildlife, is being surrounded and converted to cultivated lands. Other swamps and springs are being fenced (e.g., Namelok Swamp) outright to exclude wildlife and protect water sources. Initial estimates of the effects of the loss of swamp access are described in *Chapter 7*.

Increasing land use intensity is thought to be the main cause in the decrease in livestock and wildlife in Kenya (Ottichilo et al. 1997; Rainy and Worden 1999). According to analyses using Kenyan Department of Resource Surveys and Remote Sensing, wildlife and livestock populations have had significant decreases from 1977

Figure 2.2. The southeastern boundary of Ngorongoro Conservation Area can be discerned in this satellite image because of the clearing of the forests outside the boundary for cultivation. The image is a 1991 acquisition from the Landsat Thematic Mapper, band 3, and the boundary of Ngorongoro Conservation Area is 5 km in from the edge of the image. Clouds appear right-of-center, Ngorongoro and Olmoti Craters can be easily seen, a portion of Lake Eyasi is shown to the south, and the black areas to the east and extreme south were beyond the limits of the satellite image.

to 1997 (de Leeuw et al. 1998). In the Serengeti Ecosystem, some wildlife populations have increased through time, with wildebeest increasing from about 250,000 in 1960 to an estimated 1.3 million in 1995 (Sinclair 1995). This dramatic increase is thought to be a long recovery in wildebeest populations that had been decimated in an outbreak of rinderpest in the 1890s. That recovery came to an end in the late 1990s when poaching along the western border of the Serengeti was the major cause of wildebeest populations declining to about 900,000 – poaching is another symptom of increased land use intensity and population growth.

Land use intensification can lead to overgrazing and the associated loss of production and changes in vegetation. Reduced forage quality and quantity can stress livestock, making them less productive and susceptible to disease. Subtle changes in the chemical composition of forage due to overgrazing have been suspected. In NCA, unpalatable plants such as *Eleusine jaegeri* and *Indigofera* sp. are becoming more common in the higher elevations, an area of heavy grazing by cattle (see below). Heavy grazing may contribute to brush encroachment as well, as palatable grasses are removed and less palatable woody plants are favored (Misana 1997). In Kajiado livestock are often concentrated around water sources and market places, causing orbits of overgrazing around these focal points. In general, livestock and wildlife continue to be viewed as competitors for forage (*Chapter 7*), and as posing risks to each other for disease transmission (*Chapter 10* and below). Above a certain livestock density, it appears livestock and wild large herbivores cannot coexist.

Sedentarization, overgrazing and crowding of areas can reduce the options available to Maasai to respond to drought. Whereas in the past Maasai could move to ungrazed reserve areas when rains failed to come, today they are more likely to remain in a given place and lose more animals. Grazing reserves may be unavailable or used earlier in the season because of increase land use intensity. Beyond that, social pressures are reducing the likelihood that families can move, because the value of having children in school and ready access to hospitals and markets is recognized. Lastly, increased human populations can lead to more frequent rustling of livestock and raids between groups.

Other risks from increased land use intensity and human population growth include: reduced water supplies because of increased use by tourists, Maasai, and agriculturalists; over use of wood from the bushlands and forests of Ngorongoro

(Misana 1997) and Kajiado; increased risk of fire in forests started by honey collectors, reducing the water storage capacity of the forested highlands; and increased erosion, water use, and disturbance to wildlife from too many tourists and their vehicles. In Ngorongoro Crater, for example, there have been over 100 vehicles at one time.

This section should not end without mentioning the benefits of development associated with human population growth and increased land use intensity. As examples, access to health care has improved the survival of Maasai children, more children are being sent to schools, and schools and markets are closer than in the past. Improved security and infrastructure has increased the numbers of tourists in northern Tanzania (Sinclair 1995) and southwestern Kenya, which makes the case for wildlife conservation and improving infrastructure stronger economically.

Changes in Land Use, Land Tenure, and Policy

Distinguishing between threats caused by land use intensification associated with human population growth and changes in land use can be artificial, but some threats to food security and conservation are less directly related to intensification. For example, policies have been put in-place to promote wildlife conservation or to encourage financial security for the Maasai.

A well-known and clear-cut loss of access to grazing areas for the Maasai occurred during the creation of the great conservation lands of northern Tanzania and southwestern Kenya. Ngorongoro Maasai used to graze their cattle in the short grass plains during the wet season, in what is now Serengeti National Park. Maasai are also not able to enter the Maasai Mara Reserve (Broten and Said 1995), and can enter Amboseli National Park to water livestock and for minerals only. Maasai were promised various concessions in return for their abandoning their traditional grazing patterns that included using what are now conservation areas, such as improvements to water sources outside the conservation areas to replace those lost. There has been variable success in meeting these promises. Finer scale exclusions have occurred as well, with livestock unable to graze in Ngorongoro Crater since 1974 (Runyoro et al. 1995). Livestock may enter the crater for water and minerals, but must be herded out before the end of the day. Livestock are also excluded from Olmoti and Empakaai Craters, although Olmoti has been used as an emergency grazing reserve in dry years. The Ngorongoro Highlands Forest Reserve is off-limits to herders, although it is also used as a reserve in dry years. Kajiado is both larger and has fewer restricted areas than NCA, with the main limitations already cited (Amboseli and fenced springs and swamps). The district also contains three small forest reserves, one near Namanga, another at the Ngong Hills near Nairobi, and the last on the slopes of Kilimanjaro, near Loitokitok. Two remaining restrictions on grazing we cite are conflicts between clans and the loss of lands because of cultivation. In southwestern NCA, Maasai are much less likely to graze their animals than in other parts of the area because there is a high likelihood of cattle rustling by the Wasukuma population to the southwest (Machange 1997). In both NCA and Kajiado, grazing areas are being reduced through land conversion to cultivation. In most cases these plots simply reduce the area available for grazing, but in some cases, such as those cited for swamps in southern Kajiado, important resources may be isolated or reduced.

Policies have eliminated other resources or tools for pastoralists. It is no longer legal for Maasai to burn grasslands in Ngorongoro, for example, although fires continue to occur. Burning was used in the past to reduce ticks, which can transmit diseases, and to encourage grasses to sprout new nutritious growth. The limitation on burning can also encourage brush encroachment as woody plants are able to become established (Misana 1997). Herders may be restricted from using water sources to preserve those sources for human use, such as fenced springs in southern Kajiado, sources reserved for tourist lodges, or to preserve the sites themselves, as for the watering points in Olduvai Gorge that are off-limits to livestock to prevent trampling.

In the 1960s the World Bank implemented the Kenya Livestock Development Program, with the support of the Kenyan government. The program subdivided Kajiado District into a series of group ranches (Figure 2.3b), which were to be managed jointly by ranch members, which would set livestock densities and management goals, but with individual ownership of livestock. The main rational for creating group ranches was to increase livestock production and improve the food security of residents. Ranches were also formed to increase the likelihood that the land would remain in the hands of Maasai, to prevent individual land owners from selling portions to wealthy outsiders. The development program continued until 1982, when the last phase was abandoned.

The objectives behind group ranch formation have rarely been met (Munei 1990). Group ranches do appear to have stabilized ownership at least for a time, through assigning ownership to the residents, by making joint decisions regarding the sale of land difficult, and ironically, by preventing the sale of lands because ownership is being debated in outstanding court cases. The benefits of group ownership that were anticipated, such as the joint maintenance of boreholes, have failed to materialize and management is based upon individual decisions, but now within the confines of group ranch boundaries (Figure 2.3b). Land tenure has followed management, with more and more of the group ranches being divided into individual ranches. In 1999, 35% of Kajidao was divided into ranches owned by individuals (*Chapter 8*). Ole Katampoi et al. (1990:56) estimate the end result of subdivision will be 10 to 60 ha ranches owned by what are now group ranch members. There is a substantial risk that ranches owned by individuals in financial difficulties will be sold to buyers from outside Kajiado.

The effects of group ranch subdivision have been far-reaching. Prior to the 1960s, pastoralists were able to move their livestock anywhere within eight large divisions, called Maasai Sections (Figure 2.3a). During wet periods, for example, herds would be grazed in the nutritious but short-lived

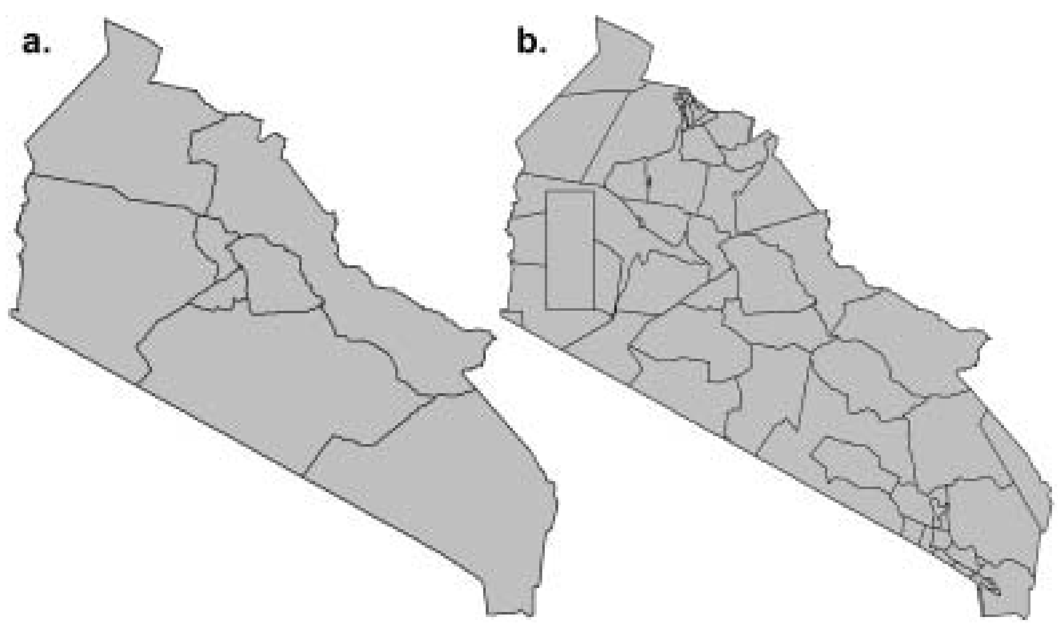


Figure 2.3. Maasai Sections within Kajiado District (a) have been subdivided into group ranches (b). The boundaries shown in (b) combine some ranches and exclude small individual and group ranches, and group ranch boundaries change often.

plains of southwestern Kajiado and elsewhere. During dry periods areas that stay green longer were used, such as along the Chyulu Hills. Today, pastoralists (or more commonly agropastoralists) must confine their movements to their group ranch or to their individual ownership, or make arrangements with neighboring ranches or kin. Some group or individual ranches are relatively lush, and provide ample grazing in times of hardship. But most group ranches and especially individual ranches lack the vegetation and topographic diversity to allow herders to find forage in times of drought (see *Chapter 7* for examples based on simulations). We focused upon land tenure in Kajiado, but the options for broad-scale movements for NCA Maasai are more limited as well because of increased populations and the need for those outside NCA to immigrate to the area during droughts.

Just as limits on grazing have threatened food security, similar limits have reduced wildlife populations. In Kenya, experts have attributed the decline in wildlife populations to efforts to commercialize livestock production (Ottichilo et al. 1997). Fencing to reduce livestock-wildlife competition, and inefficient grazing patterns associated with group ranches have reduced forage availability to wildlife and their access to grazing areas. As an example, land owners around Amboseli National Park must now graze their animals in the area year-round, whereas prior to subdivision they would have moved animals over a wider region. That same area is dry season grazing for Amboseli Basin wildlife, which now must compete with livestock for forage.

Elephants provide an example where cultivation can reduce forage availability. Elephants that inhabit Amboseli Basin move to the swamps in southcentral Kajiado to graze during times when rainfall is low. As mentioned when describing increasing land use intensity, the swamps outside Amboseli National Park have either been fenced outright, or are being surrounded by cultivated plots. These plots limit access by wildlife and draw water from the swamp for irrigation. The long-term effects on elephant populations and on the hydrology of Kajiado swamps are unknown, but the importance of the swamps are suggested in simulations (*Chapter 7*). In a broader sense, cultivation in Ngorongoro (UNEP 2001), northern Tanzania, and southwestern Kenya is not being carried out in appropriate areas. Lands most appropriate for pastoralists and their animals and for wildlife are being used for agriculture. Planning for small-scale cultivation has not been done, so that plots are simply placed near Maasai households or areas where water is most readily available. Evidence from simulations in NCA suggest that decreases to wildlife populations from cultivation will first be evident in elephants (*Chapter 7*).

Ecotourism is variable from year to year, but generally increasing in East Africa. Sinclair (1995) cited a three-fold increase in tourists in the Serengeti since 1987. Tourists bring-in much needed revenue to national parks and NCA, but also cause disturbance. Lodges and camps are increasing, especially "micro-lodges" housing a small number of tourists, which are placed without prior planning. Increased tourism brings more vehicles, increased erosion, more water use, and more disturbance to wildlife and livestock. Benefits to local pastoralists from tourism are generally limited, however. Residents benefit from tourism employment and handicraft purchases, but park fees, for example, are generally not shared with residents. Tourists purchasing all-expense-paid packages prior to their travels is also reducing tourism revenues in East Africa.

There is a disconnect between land-use policies that are put in-place and how people behave in practice. An example has already been cited, where policy makers anticipated Kajiado group ranch members to cooperate on the maintenance of boreholes and livestock dips, but pastoralists worked independently. Another example is the policy preventing Maasai from using the Ngorongoro Highlands Forest Reserve for grazing, even though the Maasai have used the forest as a grazing reserve for decades. Maasai continue to use the forest reserve as grazing lands when forage is sparse elsewhere, but they break the law to do so. In some years, including in 2000, Maasai are removed from the Highlands Forest Reserve by the Ngorongoro Conservation Area Authority.

Disease Risks and Other Threats

Wildebeest populations reached a peak in the mid 1990s of an estimated 1.3 million animals in the Serengeti Ecosystem (Sinclair 1995). Even today, at about 900,000 animals, an estimated 450,000 wildebeest move onto Ngorongoro to have their calves. This pattern leads to what we believe is the most important constraint on livestock production in the NCA – wildebeest calves carry a disease that is fatal to adult cattle. Hundreds of thousands of wildebeest begin moving onto NCA in January, between the short and long rains, and build until reaching a peak in the early wet season, in April. The wildebeest give birth during a relatively brief period, and about one-third of the calves are born infected with *Alcelaphine herpesvirus 1*, the virus that causes malignant catarrhal fever (MCF) in cattle. The remaining calves quickly become infected with the virus. As calves graze, their nose and ocular secretions spread the virus onto grasses and leaves, where it can persist for hours. The virus does no apparent harm to wildebeest, but MCF is almost 100% fatal to adult cattle that eat contaminated forage.

Maasai herders are well-aware of the threat wildebeest calves pose to their cattle. In the days when wildebeest numbered perhaps 250,000 and legal restrictions were not in-place (i.e., before 1960), Maasai built thorn fences to exclude wildebeest from some parts of the short grass plains, and harassed the animals to allow their cattle to graze with little risk (McCabe 1994). Today herders avoid MCF by avoiding the short grass plains during the wet season (Figure 2.4). In the early wet season herders move cattle down to the short grass plains to take advantage of the abundant and nutritious forage. Then as the wildebeest move in, the herders must move their cattle back into the midlands and highlands for the duration of the wet season. As the wet season ends and the wildebeest move on to the plains within Serengeti National Park, the Ngorongoro cattle are moved back down to the plains to feed on any new growth and the forage that remains (Figure 2.4). Finally, cattle must be moved back into the midlands and highlands in the dry season because of a lack of water and forage on the plains (Rwambo et al. 1999), with some use of the areas around Lake Ndutu and Olbalbal Depression.

This pattern induces two separate constraints. First, a relatively small area, perhaps 50% of NCA, must support the cattle in Ngorongoro during the wet and dry seasons. Second, ticks are most dense in the midlands and highlands, and their populations are highest in the wet season, when cattle must occupy these areas. Therefore the high mortality rate in cattle from tick-borne diseases is in-part associated with the prevalence of MCF in wildebeest. These constraints help explain why there seems abundant forage in some parts of NCA but cattle populations have been relatively stable for years, and why some areas of the midlands and highlands show evidence of overgrazing. Some insights into the number of cattle that could be supported on NCA if an MCF vaccine were developed are provided in *Chapter 7*.

Some threats to food security, wildlife conservation, and ecosystem integrity are essentially outside the realm of control of policy makers in our study area:

— Wars in Somalia, Ethiopia and Eritrea, and in Uganda have provided those residents with easy access to weaponry. Well-armed raiders and former refuges then move into northern Tanzania and southwestern Kenya,shooting livestock and wildlife for food, and threatening or injuring herders.

— Long-term global climate change and El Niño/Southern Oscillation weather patterns must be dealt with. In East Africa, the effects of El Niño are relatively predictable, leading to more than normal rainfall (Ropelewski and Halpert 1987). However the magnitude of increase can span from a moderate increase that improves forage production, to floods that drown people, ruin crops, and cause high rates of tick-borne diseases in livestock and wildlife.

Managers have only partial control over other difficult problems:

— Political instability and corruption can occur. Donor agencies have difficulties ensuring that the intended recipients were receiving aid given to overseeing groups, for example. Today donors work more closely with the intended recipients to confirm the destination of aid.

— Funds to repair and improve infrastructure are extremely difficult to come-by. It can take years for roads washed-out from heavy rains to be repaired, for example. Made-made water sources fill with silt and pipelines are trampled by elephants, and repairs can take years. As a cursory example, Ole Katampoi et al. (1990) showed 381 boreholes in Kajaido, but only 36% were operating.

And finally, managers have greater control over other problems:

— Some areas are exhibiting large changes in vegetation communities and land cover. For example, ongoing work associated with the GL-CRSP IMAS project is demonstrating large changes in the vegetation of Ngorongoro Crater in the last 30 years. Another example is changes in the land cover of the Amboseli Basin, mapped and described by Atieno (2000) and summarized in *Chapter 5*.

— Livestock breeds owned by pastoralists in East Africa tend to be extremely robust to disease and drought, but have low productivity.

— Inadequate veterinary services have been cited in Ngorongoro. Efforts are underway by the Danish aid agency DANIDA to improve veterinary services in NCA.

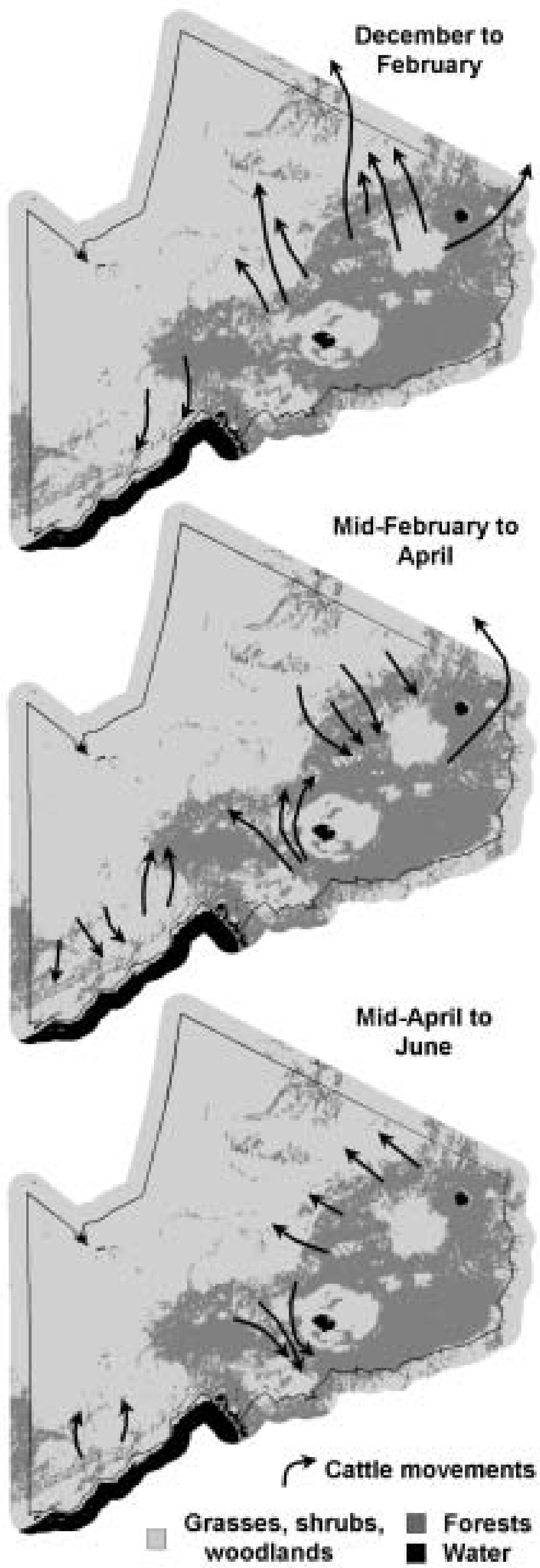


Figure 2.4. Maasai cattle movements, responding to the threat of malignant catarrhal fever. In the dry season (not shown) the cattle occupy the midlands and highlands, with some use of the plains near the slopes and Lake Ndutu. Adapted from McCabe (1995).

CONCLUSION

The many threats reviewed stress the need for a system that allows managers and stakeholders a means of assessing ecosystem effects as a whole. For example, assigning land ownership to groups or individuals to protect property rights and increase stewardship is entirely reasonable, but has had many unforeseen consequences in Kajiado District. If the policy analysts making these decisions had tools in-hand that allowed them to access potential effects to the system as a whole, they may have reached different conclusions. Assessments and tools created in the Integrated Management and Assessment System project and described in the following eight chapters allow policy makers to do just that.

Chapter 3

An Introduction to Chapters Reporting GL-CRSP IMAS Activities

Randall B. Boone

INTRODUCTION

As implied by "collaborative" in the title of our sponsoring organization, the Global Livestock Collaborative Research Support Program, the Integrated Management and Assessment System (IMAS) project brought together a large collaborative team. Many scientists, students, and technicians joined in assessing food security, conservation, and ecosystem integrity in East Africa, and providing tools to build local capacities. Several subprojects combined to form the GL-CRSP IMAS project. In the most general sense, the subprojects performed under GL-CRSP IMAS were designed to support the development of a tool to conduct integrated assessments of alternative policies, with the SAVANNA modeling system at its center. Field work gathered data for use in setting-up the ecosystem model, GIS analyses created layers of information used in modeling plant and animal responses, and disease models and a socioeconomic model were created to broaden the applicability of SAVANNA. However, the interests and expertise of GL-CRSP IMAS scientists, leveraged funding, and other opportunities that presented themselves, allowed us to extend our assessment beyond model support.

We report on the subprojects under GL-CRSP IMAS in seven chapters (Figure 3.1), which were based upon the major efforts underway in IMAS. How those chapters are linked together is described below, and longer descriptions of the chapters appear in the section that follows. In some cases, where subprojects were described was somewhat arbitrary – most of the chapters include information on ecosystem interactions, for example, which is the main topic of the first chapter. Work deducing ecosystem interactions not described in the first chapter are in other chapters because of a more direct link to those main chapter topics.

The GL-CRSP IMAS included three major modeling efforts, as diagramed in Figure 3.1. These included adapting the SAVANNA modeling system to two areas and conducting assessments (*Chapter 7*), modeling socioeconomic relationships using the newly developed PHEWS model (*Chapter 8*), and modeling livestock/wildlife disease interactions using the newly developed SIDRAM models (*Chapter 9*). These modeling tools, and the SavView interface created under GL-CRSP IMAS to allow non-experts to conduct ecosystem simulations, are briefly introduced in *Chapter 6* (Figure 3.1).

Spatial layers were compiled into a database to support the ecosystem and socioeconomic modeling that was conducted, as well as to allow separate spatial analyses to be carried-out. This database and associated analyses are described in *Chapter 5* (Figure 3.1). Field-based analyses were conducted as well, to provide information needed to conduct ecosystem modeling and to add to the assessments of sites surveyed. Stakeholders contributed to the databases constructed based on field interviews. Where field-based work was directed at identifying anthropological relationships, it is reported in *Chapter 8* (Human ecology in Figure 3.1). Where field-based work involved quantifying the risk of livestock and wildlife contracting diseases, it is reported in *Chapter 9* and represented in Figure 3.1 as Disease ecology. Other field work is reported in *Chapter 4*, including analyses of animal nutrition and populations, forage quality and usage, and range condition.

The final chapter reporting activities under GL-CRSP IMAS, *Chapter 10* (Figure 3.1), describes our methods of gathering input from stakeholders before and during our research, to ensure that our results would address their needs. Outreach efforts and training methods are described. Lastly, the effects the GL-CRSP IMAS project has had upon policy is described in *Chapter 10*.

CHAPTERS ON ACTIVITIES

The foundation of understanding ecosystems is in field studies. ***Chapter 4***, by Ellis et al., entitled "*Ecosystem Interactions: Implications for Human Welfare and Wildlife Conservation*," reports on field work conducted under IMAS. Analyses reporting grazing patterns, range condition, and nutrient content of forage in Ngorongoro Conservation Area by M. Maskini, R. Kidunda, A. Mwilawa, and others are reported. Changes in land use and in the human to livestock ratios in Ngorongoro versus Loliondo Game Controlled Area to the north (Lynn 2000) are reported. Land use was analyzed in Kajiado District, Kenya as well (Mworia and Kinyamario 2000), relating livestock and wildlife abundances to patterns of use. The effects of land use on vegetation and soils in Kajiado are reported as well.

Spatial layers from East Africa compiled to support the Integrated Management and Assess-

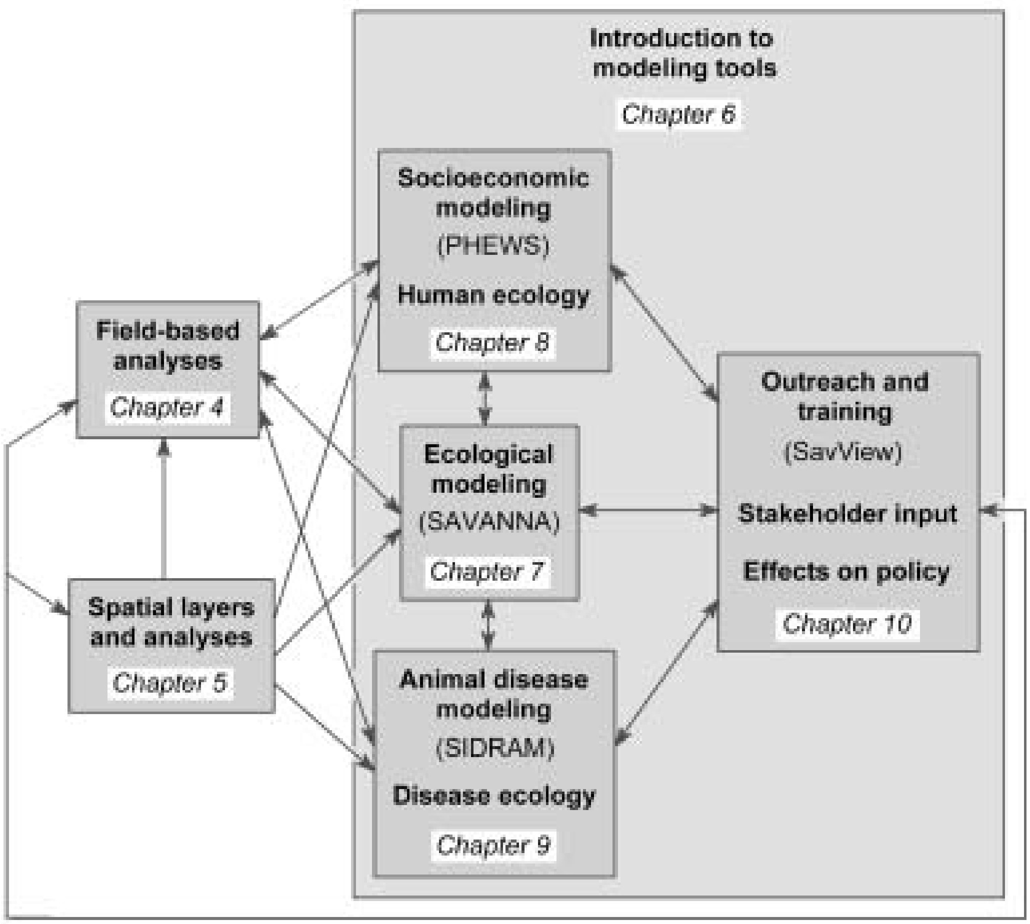


Figure 3.1. A diagram showing the chapters describing activities in the Integrated Management and Assessment System project, and how they relate to each other. General topics of chapters are shown in bold, computer models or tools in a lighter font, and chapters in italics. Arrows represent major flows of information, with the results of field-based analyses being used in socioeconomic and ecological modeling, for example, and feedback from stakeholders affecting the modeling done under GL-CRSP IMAS.

ment System project are reported in ***Chapter 5***, by Reid and Boone, entitled "*Spatial Databases and Analyses in an Integrated Assessment of East African Land Management*." A comprehensive spatial database for use with a geographic information system (GIS) was compiled for Ngorongoro Conservation Area and Kajiado District, Kenya, including land cover maps created by M. Kalkhan and F. Atieno. Important GIS layers were also compiled for the East African region, and selected layers for all of Africa. The GIS layers were used in analyses, such as investigations into spatial and temporal variability in vegetation biomass using indices of greenness generated from satellite images. The layers were also used in ecosystem and socioeconomic modeling.

Chapter 6, by Boone and Coughenour and entitled "*Modeling Tools of the Integrated Management and Assessment System*," introduces the SAVANNA ecosystem model and SMS interface created by M. Coughenour, the Pastoral Household and Economic Welfare Simulator (PHEWS) socioeconomic model developed by P. Thornton, the Spatially Integrated Disease Risk Assessment Model (SIDRAM) created by R. Howe and R. Boone with J. DeMartini, and the user-friendly SavView model interface by R. Boone. The chapter provides a brief introduction into each of the IMAS tools [more detail may be found in publications in *Appendix C*, such as Galvin and Thornton (2000), Boone (2000), and Boone and Coughenour (2000)]. More importantly, potentially confusing links between the different tools of IMAS are explained clearly.

"*Using the SAVANNA Modeling System to Address Potential Management Questions in Ngorongoro, Tanzania and Kajiado, Kenya*" is the title of ***Chapter 7***, by Boone et al. The chapter describes the location and extents of the study areas, then provides detail on how the SAVANNA modeling system was adapted to each area. For the Ngorongoro Conservation Area, management questions dealing with livestock population levels, veterinary practices, access to grazing, water sources, human population growth, and cultivation were assessed using the SAVANNA application adapted for the ecosystem. In the second study site, Kajiado District, Kenya, example analyses addressed more concrete issues of concern in the district, including the effects of managed blocks of land becoming smaller and smaller, loss of access to swamps during the dry season, and the restriction of movements of wildlife away from Amboseli National Park.

Socioeconomic and anthropological results are reported in ***Chapter 8***, by Galvin and Thornton, entitled "*Human Ecology, Economics and Pastoral Household Modeling*." The chapter summarizes an extensive set of field-based analyses where the nutritional status, economies, and land use patterns of Maasai pastoralists in Ngorongoro Conservation Area and Loliondo Game Controlled Area to the north were compared. These comparisons between Maasai with few restrictions on their livelihoods (Loliondo) and Maasai with restrictions aimed at wildlife conservation (Ngorongoro) help to quantify the costs of conservation. Field work quantifying Maasai economies in Kajiado District is summarized and reported. Lastly, the PHEWS socioeconomic model is described, as well as its links to the SAVANNA ecosystem model. The PHEWS model is used to help understand how Ngorongoro Maasai respond to drought and other events, and predicts potential changes in their nutrition and cash reserves.

Efforts to map and describe disease risks in Ngorongoro Conservation Area and Kajiado District, Kenya, are discussed in ***Chapter 9***, which is entitled "*Animal Disease Risk and Modeling in East Africa*," by DeMartini et al. A survey technique called Participatory Rapid Appraisals, combined with a literature review, allowed for a detailed description of the areas of Ngorongoro where livestock and wildlife are prone to particular diseases. Further, the seasons in which diseases are most prevalent are described. The chapter then includes a description of the disease modeling conducted as part of the SIDRAM effort. A model estimating the numbers of cattle infected with malignant catarrhal fever was completed, which is based upon the relative mixing of cattle and wildebeest, which carry the virus. Lastly, a model representing the spread of rinderpest within the Ngorongoro cattle population is described.

Chapter 10, "*Making GL-CRSP IMAS Useful to Stakeholders and Policy Makers*," by Coughenour and Boone, is the final chapter summarizing activities, but it could also have been the first chapter – stakeholder input gathered in 1997 formed the foundation of IMAS activities, and that effort is described in Chapter 10. However, the bulk of the chapter reports on our efforts to inform and train East Africans. Demonstrations and workshops held in Kenya and Tanzania are described, as are training sessions held in Dar es Salaam and Nairobi. Steps we have taken to affect policy decisions and tools we have put in-place in East Africa are described.

Chapter 4

Ecosystem Interactions: Implications for Human Welfare and Wildlife Conservation

Jim Ellis, Stacy Lynn, John Mworia, Jenesio Kinyamario,
Shauna BurnSilver, M.S. Maskini, R. Kidunda, Robin S. Reid,
Mike Rainy, Angello J. Mwilawa, and Victor A. Runyoro

INTRODUCTION

This GL-CRSP Project has focused on two East African ecosystems, both of which support extensive Maasai pastoral-livestock systems and are important centers of wildlife conservation. These are Ngorongoro Conservation Area (NCA) Tanzania and the Amboseli ecosystem, centered on Amboseli National Park (ANP), Kenya. Both areas are experiencing serious conflicts between wildlife conservation and human economic activities. This chapter reviews research results and information synthesis aimed at (1) identifying interactions among ecosystem components, and (2) clarifying causes and potential solutions for the observed conflicts.

In Ngorongoro, migratory wildlife populations travel between NCA and Serengeti National Park, and compete directly with NCA Maasai domestic livestock for space and forage. Human welfare, economic status and food security have been declining for decades in NCA and poverty among the Maasai has reached unacceptable levels (McCabe et al. 1989, Potkanski 1994, Galvin et al. 2000, Lynn 2000, Nordeco 2000). Maasai from other regions in northern Tanzania and southern Kenya are better off economically than NCA Maasai (Bekure et al. 1993, Galvin et al. 1999, Lynn 2000, Galvin and BurnSilver, in progress, BurnSilver in progress). GL-CRSP research on the NCA ecosystem has investigated the causes and effects of wildlife-human conflicts as well as the root causes of increasing poverty among Maasai. We have simulated the potential effects of changes in policy or populations on wildlife, human pastoralists and land use patterns with NCA-Savanna (Boone et al. 2000). Research on the situation in Amboseli is still underway, but demonstrates the opposite sort of problem as in NCA. In Amboseli, economic development, land use change and loss of wildlife habitat threaten those wildlife populations that historically have moved into and out of ANP seasonally. As a result, wildlife populations in the greater Amboseli ecosystem are declining precipitously (Rainy and Worden 1997, de Leeuw et al. 1998), while human populations are expanding, and economic activities are intensifying and displacing wildlife.

HERBIVORE-VEGETATION INTERACTIONS: NGORONGORO CONSERVATION AREA

Maasai livestock are excluded from the shortgrass plains of the NCA through spatial competition with Serengeti wildebeest (see disease-mediated population interactions, below). This raises the question of the adequacy of forage quantity and quality for livestock and levels of forage utilization on the remaining pastures of NCA. GL-CRSP research explored forage quality, quantity, distribution and utilization in the NCA (Maskini and Kidunda 2000, Mwilawa 2000).

Spatial and temporal grazing patterns of livestock and wild herbivores, NCA

The objective of this study (Maskini and Kidunda 2000) was to investigate and quantify variables that affect the distribution patterns and pasture utilization of herbivores. It is also aimed at producing spatial and temporal grazing patterns of livestock and wild herbivores using habitat characteristics. Range condition and trend rating were assessed with the aim of looking for the interactions brought about by livestock and wild herbivores. The study was conducted at Ngorongoro Conservation Area. The area is characterized by a tremendous variation of soils in which there is an east to west catenary sequence (Kidunda et al. 1998) of deep, dark, heavy textured soils on the northeast to gray, dusty alkaline soils on the southwest. Three sites selected for sampling were identified randomly out of six ecological zones. The first site was **Ngorongoro Crater**, which covers an area of 250 km^2 of which 200 km^2 comprises the floor and 50 km^2 the steep sloping walls with a gradient of 45-70^0 (Herlocker and Dirschl 1972). Drainage is internal, and terminates in a large soda lake (Lake Makat) and a series of permanent and seasonal swamps that are interconnected with the lake. Rainfall at Ngorongoro Meteorological Station averaged 800 mm (Dirschl 1966). Short and medium grasslands mostly occupy the caldera floor. *Pennisetum-Andropogon* grassland is found on black cotton soil, which is high in sodium salts and poorly drained. **Malanja depression** was the second site. It lies on the area north of and adjacent to the crater along the way to Serengeti National Park. It belongs to the short grass plains zone, which is a plateau and lowland grassland that covers the western part of NCA including the Eastern Serengeti plains. Important species include *Sporobolus, Andropogon, Pennisetum, Cynodon* and *Themeda.* The central part of the floor of the depression becomes waterlogged in the wet season. The last site was **Esilwa in the Endulen – Kakesio woodlands.** Esilwa is typical of wooded grasslands covering the area between Lake Eyasi and the Endulen-Kakesio area. Species include: *Themeda, Hyparrhenia, Solanum, Commiphora, Acacia,* etc. (Thompson 1997).

Forage yield and chemical composition

One aspect of this study dealt with spatial distributions of grazing pressure by domestic and wild herbivores. The first data set was taken in January 1999. Forage yield and percentage utilization were estimated using a quadrant of 0.25 m^2 and a cage of the same area, but two feet high. Ten quadrants per kilometer transect were taken, thus making a total of forty samples for the crater and thirty for Malanja and Esilwa, respectively. Forage yield was determined as described by Pieper (1978). The same sampling procedure was applied at Malanja depression and Esilwa. All sample locations were geo-referenced. Samples were oven-dried at 70°C for 48 hours to get a constant weight. They were then ground to pass through a 1 mm sieve in a Christy and Norris hammer mill. After grinding, samples were sealed in dry jars ready for chemical analysis. Another set of data was collected in April, the peak of the growing period, to determine potential production as well as utilization levels. Samples were taken along the same transects using the previous GPS readings. Plant samples were analyzed for crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), acid detergent lignin (ADL) and ash. Total nitrogen was determined by the Kjeldah method (AOAC, 1985). The fibrous components (NDF, ADF and ADL) were determined by the methods of Van Soest (1987).

Results for dry matter yield are shown in Table 4.1. Forage yield was significantly higher at the Crater and Malanja than Esilwa ($P < 0.01$). Conversely, the CP and ash values were significantly greater at Esilwa ($P < 0.01$) than the other two sites (Malanja and the Crater). However, cellulose contents (ADF, ADL, and NDF) and dry matter were significantly lower ($P < 0.01$) at Esilwa compared to Malanja and the Crater respectively (Table 4.2). These data demonstrate that NPP is inversely correlated with forage quality at NCA with the woodland site at Esilwa supporting higher quality, but lower forage productivity.

The effect of seasons (dry and wet) on forage yield and quality was also tested for the three sites (Table 4.3). The response of forage yield was significantly higher ($P < 0.01$) in the wet season than the dry season. Crude protein and neutral detergent fiber were significantly greater ($P < 0.01$) in the wet season than the dry season. acid detergent fiber, acid detergent lignin and dry matter showed a significant decrease during the wet season. Ash had no significant difference ($P < 0.01$) for both seasons.

Site	Actual forage yield (mean kg dry matter/ha) Dry season	Wet season	Potential forage yield [cages] (kg dm/ha) Wet season
1. Ngorongoro Crater			
Seneto	2740	2800	3440
Munge	2675	2824	3520
Ngoitoktok	2445	2344	2980
Lerai	2330	2464	3200
2. Malanja	3144	3337	3514
3. Esilwa	896	1552	1872

Table 4.1. Summary of actual forage yield and potential at the Ngorongoro Conservation Area.

Site	Yield (g / 0.25 m^2)	CP (%)	ADF (%)	NDF (%)	ADL (%)	DM (%)	Ash (%)
Crater	282.00[a1]	8.53[a]	42.92[a]	76.16[a]	8.28[a]	25.97[a]	10.92[a]
Esilwa	153.17[b]	9.98[b]	40.56[b]	70.63[b]	6.20[b]	18.18[b]	12.33[b]
Malanja	312.17[a]	8.54[a]	42.26[a]	76.98[a]	8.00[a]	30.36[c]	10.66[a]

[1]Means followed by the same letter are not significantly different at the 5% level of probability.

Table 4.2. Effect of site on forage yield and chemical composition at the Ngorongoro Conserva tion Area.

Season	Yield (g / 0.25 m^2)	CP (%)	ADF (%)	NDF (%)	ADL (%)	DM (%)	Ash (%)
Dry	197.80[a1]	8.46[a]	44.21[a]	71.23[a]	8.61[a]	29.75[a]	11.53[a]
Wet	307.00[b]	10.06[b]	38.99[b]	75.91[b]	5.75[b]	20.16[b]	11.60[a]

[1]Means followed by the same letter are not significantly different at the 5% level of probability.

Table 4.3. Effect of season on forage yield and chemical composition at the Ngorongoro Conservation Area.

Range Condition Assessment

Range condition was determined according to the methods outlined in the Range Improvement Task Force (1981). In this study, paced transects were used to determine range condition using composition, vigor, plant cover, and soil condition data. The transects were the same transects previously selected for determining potential forage yield. A total of 100 observations comprised a transect and at each of the 100 observations, a 3/4 inch diameter metal loop attached to a wire was placed immediately in front of the toe of the right shoe. Hits on vegetation, litter, rock and bare ground were recorded. Hits and tallies were classified as decreasers, increasers and invaders. The composition score was determined from a rating scale. Geo-referenced plots were protected in cages (enclosures) of 0.25 m^2 from January to April, and caged comparisons were used to determine percentage utilization.

Vegetation from protected and unprotected plots was clipped and the difference between the two paired plots was considered the amount removed by grazing (Pieper, 1978). Soil samples were taken every 200 m along a transect selected for determining forage yield. Fifteen samples were collected from the **Crater** and ten each from **Malanja depression** and **Esilwa** respectively. Samples from each location were dried and then mixed thoroughly to produce a composite sample of 250 g from each site (Tisdale and Nelson, 1975). Soil samples were analyzed for nitrogen, phosphorus and pH. Slope was determined by a clinometer in each of the three sampled areas. Multiple regression was used to determine the effect of site-related factors and seasons with forage yield, utilization levels and forage chemical composition. The three sites were compared using forage yield (g/0.25 m^2) and chemical composition.

Range condition rating for the three sites were "good" for the Crater and Malanja and "fair" for Esilwa. The trend for Esilwa was declining, but stable for Malanja and the Crater (Table 4.4). Range condition had a significant effect ($P < 0.01$) on forage yield, chemical composition and dry matter (Table 4.5). The sites in good condition were significantly ($P < 0.01$) higher in forage yield, ADF, NDF, and ADL, while range with a fair condition had a higher ($P < 0.01$) ash and CP content than the Crater and Malanja, respectively (Table 4.5).

Site	Range Condition Score	Class	Trend
Crater	71	Good	Stable
Malanja	69	Good	Stable
Esilwa	55	Fair	Declining

Table 4.4. Summary of range condition and trend ratings at the Ngorongoro Conservation Area.

Malanja

Vegetation at Malanja was characterized as short grassland, which is an extension of the Serengeti Plains. Dominant species were *Cynodon* and *Andropogon*. Other species were *Themeda*, *Cyperus*, *Sporobolus*, *Setaria* and forbs (Table 4.6). Malanja had the highest forage yield (3144 and 3337 kg DM/ha) in both seasons (dry and wet). Although forage yield was highest, the average utilization was only 10%. Soils were rich in organic matter and phosphorus, with an average pH of 6.5. Cation exchange capacity was medium and range condition score was "good" (Table 4.7).

The bottomland at the center of the depression had black cotton soil and was slightly muddy in the dry season. Signs of soil poaching were evident and more forbs were recorded here than on the slopes. Slopes were gentle ranging from 5^0 at the bottomland to 30^0. Malanja depression was experiencing common use of pastures by both livestock and wild herbivores throughout the year. Utilization was highest at the bottom of the depression during the dry season by 17%. This was partly influenced by slope, greener pastures, and particularly, forbs and *Cyperus*. Scores of bare ground were greater at the bottom center than on the slope in both seasons. This could have been attributed to more time being spent by herbivores at the depression center than on slopes. It could also have been attributed to soil moisture that maintained greener pastures at the bottom center than on the slopes. More litter was scored on the slopes than the bottomland. This was a sign of under utilization on slopes. Wild herbivores were seen grazing as far as 20^0 up the slopes. However, Maasai

Condition	Yield (g / 0.25 m^2)	CP (%)	ADF (%)	NDF (%)	ADL (%)	DM (%)	Ash (%)
Fair	163.17[a]	9.98[a]	40.56[a]	70.63[a]	6.20[a]	18.19[a]	12.33[a]
Good	294.93[b]	8.53[b]	42.64[b]	76.51[b]	8.16[b]	28.50[b]	10.80[b]

[1]Means followed by the same letter are not significantly different at the 5% level of probability.

Table 4.5. Effect of range condition on forage yield and chemical composition at the Ngorongoro Conservation Area.

Site	Species	Species composition (%)	Vegetation cover (%)
Ngorongoro Crater			
Seneto	*Chloris*	24	88
	Cynodon	21	
	Andropogon	18	
	Pennisetum	17	
	Cyperus	9	
	Setaria	1	
	Forbs	10	
Munge	*Cynodon*	64	89
	Andropogon	10	
	Pennisetum	9	
	Sporobolus	4	
	Cyperus	7	
	Forbs	6	
Ngoitoktok	*Andropogon*	54	80
	Pennisetum	17	
	Cynodon	11	
	Cyperus	8	
	Forbs	10	
Lerai	*Cynodon*	87	91
	Cyperus	4	
	Sporobolus	7	
	Solanum	2	
Malanja	*Cynodon*	45	86
	Andropogon	18	
	Cyperus	8	
	Sporobolus	3	
	Themeda	13	
	Setaria	9	
	Forbs	3	
Esilwa	*Themeda*	44	60
	Hyparrhenia	20	
	Setaria	8	
	Sporobolus	2	
	Ocimum	8	
	Forbs	8	
	Acacia seedlings	4	
	Solanum	6	

Table 4.6. Summary of plant species composition and percentage vegetation cover for the Crater, Malanja, and Esilwa.

Site	pH	Phosphorus (ppm)	Cation exchange capacity (%)	Organic matter (%)
Ngorongoro Crater	7.5	49	50	3.8
Malanja	6.5	45	39	3.0
Esilwa	6.0	38	23	1.8

Table 4.7. Soil test results for the Ngorongoro Conservation Area.

grazed their livestock on even higher slopes, greater than 40^0, because they were close to their homesteads.

On a comparative basis, Malanja was far less utilized than the other two sites, although it had the greatest amount of forage yield (kg DM/ha). Mean percentage utilization levels for the three sites are presented in Table 4.8 including four sub-locations for the Crater. It had a resident herd of livestock (1420) and wild herbivores (770) in the dry season. The number of livestock raised to 2615 and that of wild herbivores to 1002 in the wet season (Table 4.9). One speculation was that both livestock and wild herbivores partly satisfied their grazing requirements at the Crater when they went for salting and watering.

<u>Esilwa</u>

Esilwa is a wooded grassland with *Themeda* and *Hyparrhenia* in the understory and *Acacia* trees in the overstory (Table 4.6). Vegetation cover was 60%, bare ground 35% and 5% of litter and rock. The terrain was mountainous with a slope of greater than 45^0 in some places. Erosion and overgrazing were prevalent. Leguminous forbs, *Ocimum*, *Solanum* and a number of *Acacia* seedlings were encountered during sampling, and their increase in the Ngorongoro short grassland has been interpreted as a sign of overgrazing (Anderson and Talbot, 1965). Besides being of no browsing value, *Solanum* and *Ocimum* have been reported to be poisonous (Verdcourt and Trump, 1969). *Acacia tortilis* is now regenerating in such localities within the grassland on ridges. Such regeneration of woody species in the absence of fire has been mentioned by Glover (1968).

Site	Mean utilization (%)
1. Crater	
Seneto	10
Munge	12
Ngoitoktok	18
Lerai	16
2. Malanja	10
3. Esilwa	30

Table 4.8. Mean percentage utilization levels.

Soils were shallow and mostly brownish red sandy loams with a pH of 6.0. Organic matter content was low (Table 4.7). Forage yields between the dry and wet seasons were 896 and 1552 kg DM/ha respectively. Although Esilwa was in 'fair' condition, its forage chemical composition was better in both seasons when compared with Malanja and the Crater (Table 4.3). Esilwa had a permanent herd of livestock and wild herbivores, but no figures are available. It was the most heavily utilized area (30% use) (Table 4.8) by Maasai livestock. Besides overgrazing,

	Dry season		Wet season	
Site	Wild herbivores	Livestock	Wild herbivores	Livestock
Ngorongoro Crater	15087	NA*	31291	NA*
Malanja	770	1420	1002	2615
Esilwa	NA*	NA*	NA*	NA*

* Not applicable. Source: Ngorongoro Crater census (1998 and 1999).

Table 4.9. Summary of livestock and wild herbivore densities for the dry and wet seasons for the three sites, Ngorongoro Crater, Malanja, and Esilwa.

there were evident signs of cultivation at Esilwa by Maasai tribesmen and other residents around their homesteads. Crops included maize and Irish potatoes. The area was, therefore, under moderate to high grazing pressure by livestock and to a lesser extent, wild herbivores, which resulted in the invasion of shrubs and leguminous forbs and regeneration of woody species. Both protein and ash were significantly higher ($P < 0.01$) at Esilwa than the Crater and Malanja, whereas cellulose contents were significantly higher ($P < 0.01$) (Table 4.3) at Malanja and the Crater than Esilwa. Hence, plants at Esilwa were more preferred and consequently were utilized more intensively. However, these plants were not as tolerant to heavy use as plants on favorable sites of the Crater and Malanja because of the generally poor growing conditions. Livestock trails were rampant and they all lead downhill toward water points along the direction that overlooked Lake Eyasi.

The Crater

Vegetation in the Crater and Malanja was also characterized as short grassland which is an extension of the Serengeti Plains. Species composition included: *Cynodon, Andropogon, Pennisetum, Chloris, Cyperu, Setaria, Sporobolus,* etc. (Table 4.6). The average forage yield for the Crater was 2547.5 and 2608 kg DM/ha for the dry and wet seasons, respectively. The Crater with its volcanic and alluvial soils from internally drained rivers and springs had the highest organic matter, Cation exchange capacity, phosphorus and a pH of 7.5 (Table 4.7). The Crater had twice the number of wild herbivores in the wet season compared to the dry season (Table 4.9). It had wild herbivores only, with on and off visits of livestock at the southern end of Seneto and part of Lerai to access mineral licks and water. The Crater has four sub-locations as described below.

Seneto

With a utilization of 10%, Seneto was preferred by buffalo. This was the least used area of the four sub-locations in the Crater. Utilization was generally uniform in the whole of Seneto area, except at the entrance site where livestock from Malanja and other adjacent areas kept utilization levels slightly higher, when protected plots and grazed areas were compared. Areas occupied by gazelles showed more use in terms of the differences of the sampling points, although this was not statistically tested. The number of buffalo in the Crater in the wet season was three times as much (9365) compared to the dry season with only about 2564. This increase correlated significantly ($P < 0.01$) with the wet season increase in forage yield and chemical composition (Table 4.3). The dominant forage species were *Chloris, Cynodon* and *Andropogon*. Herbivores at Seneto had to walk about 2 km or more daily in search of water. Gazelles were always seen around water points. Plant cover was 71%, bare ground, 12%, and litter was 17%. Potential production from the cages was 3440 kg DM/ha. The variation of forage between the seasons was significant but utilization remained at 10%. Although utilization was not measured by species, *Chloris* showed more signs of use than *Cynodon* and *Andropogon*.

Munge and Ngoitoktok

The utilization levels for Munge and Ngoitoktok were 12% and 18%, respectively (Table 4.8). Food availability, distance to water, and slope favored utilization in these sites. Utilization was significantly higher at Ngoitoktok compared to Munge, possibly because palatable forbs attracted herbivores. Munge had a higher production potential (3520 kg DM/ha) than Ngoitoktok (2980 kg dm /ha). The two sites were adjacent to each other and shared almost the same type of herbivore species during the two seasons (dry and wet). Herbivore species included: wildebeests, gazelles, eland, hippopotamus, and ostriches. Dominant forage species at Munge were *Cynodon*, *Andropogon* and *Pennisetum* whilst at Ngoitoktok, dominant species were *Andropogon* and *Cynodon*, in that decreasing order (Table 4.6). However, Ngoitoktok had more forbs than Munge. Slope for both sites ranged from 0-10^0 and distance to water was less than 2.5 km.

Lerai

The site was composed of a small wetland forest (Lerai Forest). It is the home for bushbucks, elephants, water bucks and rhinos. *Cynodon* was the dominant forage plant. Its potential production was 3200 kg DM/ha and the actual production for the dry and wet seasons was 2330 and 2464 kg DM/ha respectively. Distance from water was less than 1.5 km. Large herbivore movements were related to availability and preference of food and water (Buss 1962). Water was clearly a critical factor for elephants' survival at Lerai. According to Weir and Amaldale (1973), water is not only needed for meeting metabolic activities in the body, but also supplementing mineral requirements, especially in areas characterized by high concentrations of water soluble sodium and potassium associated with calcium. Signs of debarking and destruction of branches and pole-size trees were evidences of elephants' activities. The average utilization level was 16%. The western area adjacent to the Seneto entrance (bottomland) received higher utilization levels of up to 22% on individual sampling plots. It is suspected that Maasai livestock increased the grazing pressure during salting and watering activities at the southwest end of Lerai. Grazing was evident up to 20^0 slope. Availability of water, as well as salting grounds, was attributed to be part of the key factors that affected grazing use at Lerai.

Conclusion

Forage yield, protein content, and crude fiber increased with annual precipitation. These factors correlated with increased numbers of migratory wild herbivores during the wet seasons. It was evident that spatial and temporal grazing patterns of livestock and wild herbivores were correlated with food availability, quality and other site related factors. However, climate or seasonal variations were the key factors which brought about changes in wild herbivore numbers in the wet and dry seasons respectively. Seasonality was also responsible for the changes in the chemical composition of pastures and dry matter contents.

Estimated forage yields, chemical and mineral composition of preferred forage species, and livestock body condition

In a related study, Mwilawa et al. (2000) investigated variations in the quality and quantity of forages selected by livestock and livestock body condition along transects similar to those used by Maskini and Kidunda (2000). Two transects, one running from Oloirobi to Endulen and another running from Oloirobi to Olbalbal through the Malanja depression, were selected for this study. Objectives were to: a) identify forage species preferred by livestock; b) determine forage nutritive value for the preferred species; and c) assess livestock condition as related to forage nutrient value.

Four pastoral households were selected in each of the two grazing routes. These households were at least 8 km apart; GPS readings were made for each household. Forage yield was estimated in May using double-sampling, a non-destructive method. Forage yield accounts for grazing access by both livestock and wildlife. The forage species identified by pastoralists as those preferred by livestock, were sampled for chemical determination. Forage samples were collected for chemical and mineral determination of dry matter (DM), crude protein (CP), in-vitro dry matter digestibility (IN-VDMD) and in-vitro inorganic matter digestibility (IN-IOMD). Mineral composition was determined for potassium (K), calcium (Ca 2+), magnesium (Mg 2+), phosphorus (P) and sodium (Na). The analysis was done at the Department of Animal Science at the Sokoine University of Agriculture, Morogoro, Tanzania. At the selected households, livestock body conditioning assessment and monthly fecal sampling were conducted. The livestock body condition was meant to provide a field animal assessment in relation to forage and water availability. Fecal samples from cattle and goats were sampled once a month for each household. The fecal samples were later analyzed for diet quality (CP and DOM) determination through NIRS analysis at Debri Zeit

Gan LAB, ILRI, Addis Ababa with assistance from the Livestock Early Warning System (LEWS) Project, a sister project to Integrated Modeling Assessment Systems (IMAS). Mean forage dry matter yields (kg DM/ha) for herbage estimated in the area studied are presented in Table 4.10.

On average, forage DM for the Oloirobi – Endulen route was 2300 kg DM/ha. The highest forage DM estimated were 2600 kg DM/ha close to household number two. Along the Oloirobi – Malanja – Olbalbal route, the average forage DM estimated was 2780 kg DM/ha. The highest yield estimated was 4500 kg DM/ha recorded close to household three. The high yield is attributed to the abundance of *Cynodon spp.* on the Olbalbal depression near to Olbalbal swamp. The amount of forage DM was estimated in a free-range grazing system where the area is accessible to both wildlife and livestock.

Chemical and mineral values of preferred forage species are presented in Tables 4.11 and 4.12. The average DM values ranged from 91.17% to 95.26% for *Aspillia mosambicensis* and "Arang'awa" respectively. The overall mean value for DM was 93.38%. The average CP values ranged from 4.53% to 17.68% for *Pennisetum schimperi* and *Trifolium subrotundum*. On average, the forage sampled had CP of 10.19%. The mean IN-VDM and IN-IOMD were 72.07% and 71.60% respectively. Mineral values for K, Ca, Mg, P and Na ranged from 1.35% - 5.75%; 0.2% - 1.95%; 0.11% - 0.56%; 0.7% - 2.16% and 0.33% - 1.7% respectively. On average, these range forages had low phosphorus (1.21%).

Livestock Body Condition Scores (BCS) during May were M+ for cattle and F for goats. This implied that during this time, livestock were in good condition.

Long-term changes in grazing patterns, vegetation composition and herbivore species composition in Ngorongoro Crater.

In 1975, new rules excluded Maasai livestock from grazing in the Ngorongoro Crater, but cattle herds are still allowed to enter the crater temporarily for water and to use the mineral licks. Since then, there have been major changes in the population composition of wild herbivores in the crater. Wildebeest numbers have decreased accompanied by a compensatory expansion of buffalo numbers, but no net change in overall herbivore biomass has occurred. At the same time, vegetation species composition has shifted and the GL-CRSP is investigating these vegetation changes in relation to the observed herbivore dy-

	Household Number	kg dm/ha
Oloirobi-Endulen route	1	2100
	2	2600
	3	2300
	4	2200
Mean		2300
Oloirobi-Malanja depression-Olbalbal route	5	2400
	6	1800
	7	4500
	8	2400
Mean		2780

Table 4.10. Average forage dry matter yield (kg dm/ha) for herbage estimated during mid to late flowering plant stage in the study area.

Scientific name	Maasai name	Flowering Stage	DM (%)	CP (%)	IN-VDMD (%)	IN-IOMD (%)
Cynodon dactylon	Emurwa	L	94.36	5.52	73.43	71.93
Chloris pycnothrix	Oloibonikipa	L	94.30	7.23	75.31	73.81
– –	Ngaitoktoku	M	93.58	8.75	72.01	71.66
Pennisetum spp	– –	M	92.71	9.51	68.56	71.73
Trifolium subrotundum	Emdapipi	E	92.10	17.68	79.20	78.92
– –	Endaipirikukurti	M	92.50	9.98	73.33	72.80
Lippia javanica	Osindni	M	92.18	11.93	76.03	74.70
Themeda triandra	Orperesi	M	92.62	5.72	64.02	64.02
Solanum incanum	Endulelei	M	93.78	10.98	79.91	78.24
Leonotis molisma	Olbibiayi	M	92.61	11.09	71.53	70.58
Commelina banglansenis	Ngatetey	M	91.27	7.32	72.68	71.40
Aspiria mosambiquensis	Nguyapasei	M	91.17	7.95	79.81	77.54
Acacia spp	Endebesi	E	92.85	13.59	63.30	61.75
Acacia spp	Altarara	E	93.17	15.99	68.14	66.21
– –	Olikipetepole	E	91.93	16.5	80.79	81.75
Leersin hexandra	Lamnyani	M	94.81	6.95	65.04	65.83
– –	Ngusero	M	93.78	9.17	75.36	75.5
– –	Orgujitaonyoki	M	94.32	5.31	67.79	67.82
– –	Engipumbu	M	93.75	10.89	70.81	71.23
– –	Oegujitaonyoki	L	94.00	4.64	67.83	65.20
– –	Lepulunga	M	93.61	8.25	73.67	70.81
– –	Osangashi	L	94.49	6.13	67.57	65.50
– –	Parakay	M	93.53	8.84	77.73	76.14
Cyperus spp	Oseyayi	M	93.76	9.22	72.29	71.23
Leersin hexandra	Lamnyani	M	93.72	6.31	65.75	–
Pennisetum schimperi	Olopikidongoi	L	93.99	4.53	68.26	–
Themeda triandra	Orokojetaonyoke	M	95.32	6.24	66.72	66.46
Aspiria mossambicensis	Oloyapasi	E	92.88	18.58	76.87	75.67
Acacia lahai	Indepesi	E	93.51	17.19	66.34	65.65
Povonia patens	Ngominyara	E	90.33	19.68	80.69	78.06
Cynodon dactylon	Emurwa	M	93.75	11.30	75.56	74.55
Trifolium subrotundum	Emdapipi	E	92.83	15.88	82.14	81.22
– –	Arangawa	L	95.26	5.59	63.74	62.97
Cynodon dactylon	Emurwa	M	94.77	13.66	77.38	77.38
Chloris pycnothrix	Oloibonikipa	M	94.81	8.69	62.88	64.40
Mean			93.38	10.19	72.07	71.60

Table 4.11. Chemical composition of forage species identified as preferred by livestock in the study area. Dashes signify unknown information, and horizontal lines serve only as visual guides.

Scientific name	Maasai name	Flowering Stage	K (%)	Ca 2+ (%)	Mg 2+ (%)	P (%)	Na (%)
Cynodon dactylon	Emurwa	L	2.40	0.27	0.16	1.12	0.80
Chloris gayana	– –	L	3.20	2.80	0.36	0.94	0.85
– –	Ngaitoktoku	M	2.20	0.37	0.20	0.80	0.80
Pennisetum spp	– –		2.70	0.39	0.28	2.16	1.50
Trifolium subrotundum	Emdapipi	E	3.10	0.83	0.24	2.50	1.50
– –	Endaipirikukurti	M	2.25	0.86	0.24	1.33	0.85
Lippia javanica	Osindni	M	3.60	1.94	0.45	3.50	0.33
Themeda triandra	Orperesi	M	8.20	1.95	0.56	2.06	1.40
Solanum incanum	Endulelei	M	2.85	0.99	0.48	1.64	0.85
Leonotis molisma	Olbibiayi	M	3.25	0.49	0.28	1.59	0.80
Commelina banglansenis	Ngatetey	M	3.94	1.07	0.27	1.56	1.70
Aspiria mosambiquensis	Nguyapasei	M	0.65	–	–	0.75	0.75
Acacia spp	Endebesi	E	1.65	0.56	0.20	0.74	0.80
Acacia spp	Altarara	E	1.95	0.45	0.18	0.74	0.85
– –	Olikipetepole	E	3.45	0.47	0.24	1.31	0.95
Leersin hexandra	Lamnyani	M	2.40	0.50	0.28	0.70	0.85
– –	Ngusero	M	3.25	0.44	0.27	1.74	0.85
– –	Orgujitaonyoki	M	1.55	0.24	0.17	0.74	0.80
– –	Engipumbu	M	3.10	0.33	0.23	1.14	0.85
– –	Oegujitaonyoki	L	1.25	–	0.12	0.82	0.75
– –	Lepulunga	M	4.90	0.99	0.44	1.03	1.00
– –	Osangashi	L	2.25	0.20	0.21	0.86	0.80
– –	Parakay	M	2.20	0.37	0.31	0.77	0.90
Cyperus spp	Oseyayi	M	4.00	0.46	0.22	1.03	1.05
Leersin hexandra	Lamnyani	M	1.90	0.39	0.27	0.98	0.90
Pennisetum schimperi	Olopikidongoi	L	2.50	0.18	0.14	1.10	0.85
Themeda triandra	Orokojetaonyoke	M	–	–	–	–	–
Aspiria mossambicensis	Oloyapasi	E	5.45	1.12	0.36	0.89	0.95
Acacia lahai	Indepesi	E	2.95	0.38	0.20	1.15	0.90
Povonia patens	Ngominyara	E	3.00	1.32	0.37	1.03	0.85
Cynodon dactylon	Emurwa	M	2.80	0.35	0.19	0.88	0.85
Trifolium subrotundum	Emdapipi	E	5.75	0.84	0.28	0.91	1.30
– –	Arangawa	L	1.35	0.20	0.11	0.86	0.95
Cynodon dactylon	Emurwa	M	3.65	0.65	0.28	0.78	0.80
Chloris pycnothrix	Oloibonikipa	M	3.15	0.21	0.11	1.03	0.85
Mean			3.02	1.47	0.26	1.21	0.93

Table 4.12. Mineral composition in forage species identified as preferred by livestock in the NCA. Dashes signify unknown information, and horizontal lines serve only as visual guides.

namics (Moehlman et al. 1997, research in progress). The ongoing investigation includes statistical analyses, NDVI greeness analysis, comparing NDVI profiles to trends in plant biomass and observed changes in herbivore numbers. In addition, we compared a recently created Crater vegetation map to a map developed in the 1960s by Herlocker and Dirschl (1972). Both maps include detailed information on vegetation type and cover. GIS analyses were used to quantify cover of each vegetation type within the crater and calculate changes in cover types from 1972 to the present (see Reid and Boone, Figure 5.5, *Chapter 5*).

HUMAN-HERBIVORE INTERACTIONS IN MAASAI PASTORAL ECOSYSTEMS

One of the central themes of this research program deals with the relationship between herbivores, both domestic and wild, and human pastoralists. Human-livestock ratios indicate both the type of economic activities that pastoralists engage in, and the relative level of welfare of pastoral families. The distribution of wild herbivores relative to the distribution of humans indicates the nature of the relationship, whether positive or negative, between pastoralists and wildlife.

Human - Livestock Ratios

The economic difficulties of the Maasai pastoralists in Ngorongoro Conservation Area are well known (Potkanski 1994, Thompson 1997). One objective of our study was to determine whether these difficulties are endemic to Maasai pastoralists throughout northern Tanzania or if they are specific to NCA Maasai. The experimental design of this part of the study involved comparing various aspects of NCA Maasai ecology and economy with their Maasai neighbors outside the NCA in the adjacent Loliondo Game Control Area (LGCA) (Lynn, 2000). *(Note: This portion of the NCA study was jointly supported by the GL-CRSP and the US National Science Foundation.*) A total of 54 heads of Maasai households were interviewed in both NCA and LGCA. These households represented about 1% of the total population of the NCA and probably somewhat more than that for LGCA. Interview data showed that households in LGCA possess about three times the livestock holdings (in Tropical Livestock Units per person) compared to NCA households (Figure 4.1) (Lynn 2000).

Furthermore, most (> 85%) interviewed NCA families have fewer than six TLUs per person, a generally accepted minimum number necessary for subsistence on livestock alone. This supports the previous suggestion that over 50% of NCA Maasai live below the poverty line, as defined by the Maasai themselves (Potkanski 1994). In contrast, less than one-third of LGCA households reported fewer than six TLUs per person, indicating a considerably better level of welfare than found among NCA Maasai (Lynn 2000). The situation is ameliorated somewhat because almost all Maasai in both NCA and LGCA engage in limited cultivation although again, LGCA Maasai have considerably larger agricultural acreage per person than in NCA where plot size is limited by conservation policy (Lynn 2000).

Further confirmation that the Maasai in NCA are in an unusually difficult economic situation comes from our GL-CRSP research in Kajiado District, Kenya (BurnSilver in progress). Surveys on six group ranches in Kajiado found that livestock/human ratios were, in all cases, greater than those found in NCA. The highest ratios were comparable to those found in LGCA, i.e., >10 TLUs /person (Table 4.13). In Kajiado, those regions where people are dependent exclusively on livestock had the highest livestock/human ratios (~ 10 TLU/person) while the lowest ratios occur in regions where rain-fed or swamp-based cultivation is an important enterprise (Burnsilver in progress).

Human - wildlife interactions

"Most of the great concentrations of wild grazing herbivores in East Africa occur in locations currently or formerly occupied by pastoral people." This assertion is often made, but sel-

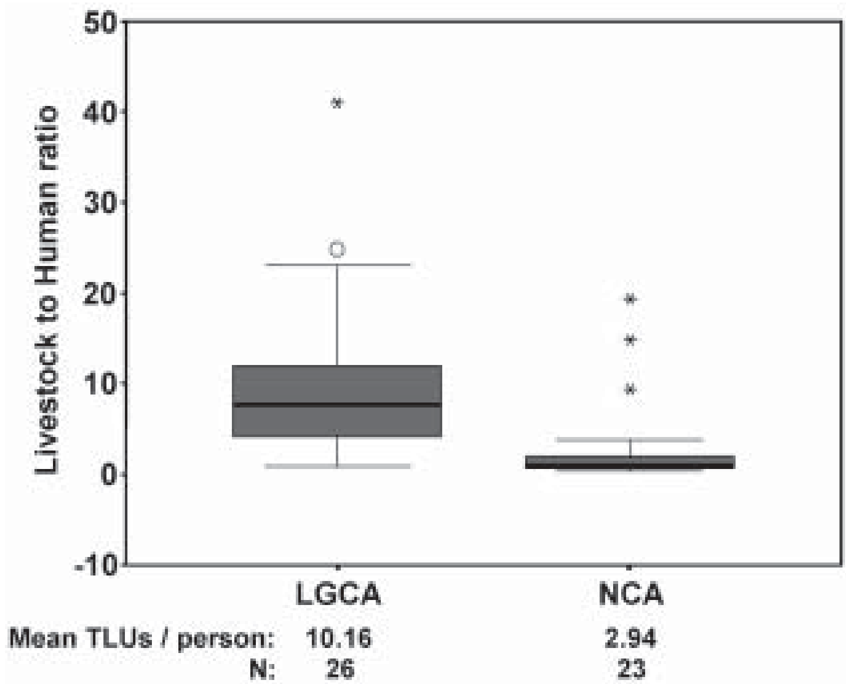


Figure 4.1. LGCA households have approximately three times the livestock (TLUs) per person as NCA households.

dom tested. It implies that interactions among pastoral people and wildlife were, and may still be, positive rather than negative. This has obvious implications for both conservation and the development of livestock and pastoral people. One component of GL-CRSP research set out to quantify the effect of human settlement patterns on the density, spatial distribution and biodiversity of wildlife (Reid et al. 2000). The study took place on pastoral group ranches at the northern edge of the Serengeti-Mara ecosystem in Kenya where livestock herds exist side by side with diverse wild herbivore herds. Intense ground surveys (0.3 x 0.3 km) were conducted in the wet season (April) and dry season (November) of 1999. Spatial distributions of 23 species of wildlife and 4 species of livestock were recorded (GPS) and analyzed (GIS). In both wet and dry seasons, livestock were found to congregate near Maasai bomas while wildlife clustered at intermediate distances from bomas during the wet season. Livestock were most abundant within 1 km of bomas in the wet season; wildlife were most abundant and diverse at 2-3 km from boma sites. Wildlife abundance declined slowly out to distances of about 5-6 km, after which abundance declined dramatically out to14 km from bomas (maximum distance sampled). Wildlife densities exceeded 100 /km^2 within 2-3 km of bomas; livestock densities were on the order of 10-20 / km^2 over this area. Livestock distribution was similar in both wet and dry seasons whereas wildlife were much more evenly distributed over the sampled area in the dry season. Herbivore (both livestock and wild-

Study area	Mean	N	Standard deviation
Selengei	5.23	6	3.363
Lengisim	9.99	6	9.553
Meshenani	10.24	7	5.840
Mbirikani North	6.32	8	4.287
Mbirikani South	5.52	7	1.960
Osilalei	NA	NA	NA
Total	7.41	34	5.582

Table 4.13. TLUs per adult equivalent/ household among Maasai group ranches, Kajiado, Kenya.

life) biomass was around 11,000 kg/km^2 within 3 km of settlements in the wet season; it was about half this level during the dry season.

Livestock and wildlife distributions were clearly complimentary during the wet season with livestock dominating the area within 1 km from bomas and wildlife concentrating at 2-3 kms from bomas. But why do wildlife cluster at this intermediate distance during the wet (plant growth) season? Three alternative hypotheses are under investigation: 1) nutrient concentrations near bomas improve forage quality and attract wildlife; 2) wildlife cluster around settlements to avoid predators; and 3) Maasai tend to locate their settlements in areas preferred by wildlife. Regardless of which of these hypotheses proves correct, this study has documented and quantified, possibly for the first time, the adage that pastoral production systems and wildlife conservation are not only compatible, but represent a positive interaction, at least for wildlife.

HUMAN LAND USE PATTERNS AND IMPLICATIONS

Ecological influences on Maasai land use, settlement patterns, grazing orbits and human wealth and welfare

The project evaluated Maasai land use patterns in northen Tanzania and southern Kenya. In Tanzania, the Ngorongoro Conservation Area is a dramatic and diverse ecosystem. Elevation ranges from ~1500 to over 3000 m; rainfall ranges from 400 mm to ~1000 mm per annum, and vegetation from shortgrass plains to highland forest, with intervening savanna and woodland. The Loliondo Game Conservation Area is only slightly less dramatic in landscape and equally diverse in vegetation. We explored how major variations in landscape and vegetation influenced human activities and the pastoral economy (Lynn 2000). NCA and LGCA Maasai classify these ecosystems in elevational terminology (lowlands, midlands and highlands). Their classification encompasses numerous ecological characteristics and is not always consistent with elevation. But in general, **lowlands** refers to the shortgrass plains and adjacent woodlands and savannas at lower elevations; **midlands** are the mid-grasses, savannas and woodlands occurring on slopes and hills above the plains; and **highlands** include the highland forests and high elevation grasslands (Potkanski, 1994 also noted this indigenous classification). We found no significant relationships between these ecological zones and livestock holdings, either in terms of herd sizes or human:livestock ratios. However, there were significant differences among eco-zones in extent of cultivation. For LGCA and NCA, cultivation areas were largest in the midlands (0.41 acres/person), smallest in the lowlands (.07 acres/person) and intermediate in highlands (0.17 acres/person). Cultivation is rare in the lowlands (too arid), and difficult in the highlands due to cold temperatures and sometimes excessive rainfall. Parts of the midlands ecozone are excellent for farming. Thus, ecozones did influence human access to crop cultivation and presumably food security, but this was offset to some extent by families having farms in midland zones, while their main boma was located elsewhere.

Ecozone also influences pastoral movement distances. Households inhabiting lowlands traveled the longest total distance during the year; households in the highlands the least. Midland households mimicked the shorter highland patterns during the wet season, but undertook longer distance movements (like the lowland pattern) during the dry season (Lynn 2000).

Three settlement patterns were found among Maasai households. Households that have one permanent boma and use one grazing area all year were designated Type A; Type B households also had a single permanent boma, but livestock grazing and watering locations were changed on a seasonal basis. Those households with both a permanent boma and one or more temporary bomas where livestock were taken on a seasonal basis were designated Type C.

Type C settlement patterns were prevalent in highland areas of the NCA where they accounted for 90% of all sampled households. Type

C settlements were less prevalent in the LGCA where they accounted for 36% of sampled households. Type C households tended to be typical transhumant pastoralists, making a single long distance move between dry season and wet season grazing areas. This strategy required a single long-distance movement each year, but because daily movements around the bomas were rather short, overall annual travel distances averaged just over 3000 km/yr.

Type B households, with a single permanent boma, but showing seasonal changes in grazing areas around that boma, were most prevalent in lowland and midland areas where they comprised 85% of households; the majority of LGCA pastoralists utilized this settlement pattern. Although no long distance migratory moves took place for these households, daily travel distances were lengthy, generating the longest annual travel distances of 4158 km/yr. Type A settlement patterns were rare and distributed evenly among ecozones. Annual travel distances for these households was 2800 km/yr.

These comparisons demonstrate that variations in landscape and ecology promote different settlement and land use patterns among Maasai pastoralists. It is likely that the transhumant (Type C) settlement/movement patterns with long-distance seasonal migrations are most vulnerable to constraints which disrupt these migrations. This is precisely the problem befalling NCA pastoralists due to policy-based restrictions on grazing and wildlife usurpation of lowland plains habitats. By contrast, the less extensive movement patterns of Type A or B households may be less vulnerable to these and other restrictions on long distance movements; these are likely to be undertaken only during times of stress such as intensive droughts. These results show how landscape and land use interact in pastoral resource exploitation strategies, and how settlement or movement restrictions may have quite different consequences in different physical and ecological settings.

GL-CRSP research in the Amboseli ecosystem, Kajiado, Kenya is examining pastoralist land use patterns in relation to the influence of development and economic diversification (BurnSilver, in progress). Six study areas have been chosen for the study. These fall within four Maasai Group Ranches: Mbirikani, Olgulului/Lolarashi, Eselengei, and Osilalei. As well as falling along a climatic/vegetation gradient, the study areas represent a range of land tenure types, levels of market access and available combinations of resource/economic infrastructure - all variables that affect the land use strategies pursued by pastoralists within the wider Amboseli ecosystem. These group ranches also form a ring around Amboseli National Park, and as such, contain the seasonal dispersal areas for much of the region's wildlife.

A general settlement survey of all bomas (Maasai compounds) within the six study areas was carried out in order to identify Maasai land use patterns. Table 4.14 illustrates the broad range of land use patterns of Maasai producers across the study areas. These results represent land use at the scale of the settlement. The type and presence or absence of water resources is clearly a deciding factor in the land use and economic decisions taken by pastoralists in this area. Fully, 79.9% of all settlements are engaged in some form of agriculture; however, the type of agriculture ranges from rainfed (in Osilalei and Eselengei areas and the rainfed slopes of Kilimanjaro at Loitokitok.) to swamp-based irrigation (in the Southern Mbirikani study area). The number of households in the Osilalei and Eselengei study areas which are carrying out rainfed agriculture illustrates that at the high end of the precipitation gradient, agriculture currently is considered to be a worthwhile economic diversification strategy by pastoralists. However, even in areas with insufficient levels of precipitation for rainfed agriculture, pastoralists are taking steps to guarantee themselves access to agricultural resources. Column one of Table 4.14 indicates that some pastoralists in particular areas (primarily Northern Mbirikani and Meshenani Ridge) are using a "two-boma system", in which households are split into multiple functioning units that straddle both an agricultural area (e.g., the swamps or Loitokitok) and a dry pastoral area (e.g., N. Mbirikani, Lengism and Meshenani). This strategy of s*patial* economic diversification is an interesting phenomenon, and it remains to be seen if particular labor and capital requirements are necessary in order to make the strategy possible for individual households.

Table 4.14 also illustrates that a significant proportion of pastoral households across the Amboseli study zone are taking part in some form of employment and/or business activities. Business activities range from grain grinding, small shops, and cattle trading to buying and selling of vegetables and other commodities. Employment activities are centered around two major types of activities: work in Nairobi/Malindi , and/or employment linked with the wildlife and tourism sector. Preliminary analyses indicate that up to 55% of all employment across the six study areas is linked with wildlife and/or tourism.

Livestock and wildlife abundance and distribution in relation to human land use; Kajiado/Kiboko

Land use and livestock

The effects of different land use patterns in relation to livestock holding was investigated in and around the Kiboko Range Research Station by Mworia and Kinyamario (2000). This study included a livestock survey and assessment of herd mobility in the 1998/99 drought. The data presented here is from a survey of 169 households of which 126 are in Kiboko Group Ranch (KGR), the rest in the small-scale mixed farms of Muuni and Kiboko. The entire KGR was surveyed. Data for the small-scale ranches of Olkarkar and some small-scale mixed farms are still being processed.

The settlements of Muuni and Kiboko are occupied by the Akamba tribe who are primarily agriculturists. The average land size (Table 4.15) in the settlement scheme is rather small given that this a semi-arid zone (IV – V). Muuni and Kiboko settlement schemes have average land

Study areas	Land use types: Two bomas	Livestock only	Livestock Business Employment	Livestock Irr. agric.	Livestock Rain agric.	Livestock Agric. (Loitokitok)	Livestock Irr. agric. Bus. / Employ.	Livestock Rain agric. Bus. / Employ.	Livestock Agric. Bus. / Employ.	Total bomas
Osilalei	(0) 0.0	(0) 0.0	(0) 0.0	(63) 44.3	(77) 54.2	(0) 0	(2) 1.4	(0) 0.0	(0) 0.0	142
Eselengei	(3) 6.4	(1) 2.1	(5) 10.6	(4) 8.5	(14) 29.8	(0) 0.0	(3) 6.38	(19) 40.42	(1) 2.1	47
Lengisim	(4) 15.4	(2) 2.4	(15) 57.69	(1) 3.9	(1) 3.9	(1) 3.9	(2) 7.7	(4) 15.4	(0) 0.0	26
Meshenani	(12) 27.90	(24) 58.8	(7) 16.28	(4) 9.30	(0) 0.0	(2) 4.7	(0) 0.0	(1) 2.3	(5) 11.6	43
Mbirikani North	(40) 56.3	(1) 1.4	(20) 28.2	(4) 5.63	(1) 1.4	(5) 7.0	(33) 46.5	(4) 5.63	(3) 4.2	71
Mbirikani South	(19) 21.1	(4) 4.4	(4) 4.4	(43) 49.8	(0) 0.0	(2) 2.2	(36) 40.0	(0) 0.0	(1) 1.1	90

Table 4.14. Land use types across the study zones. *The first number in each cell (in parenthe ses) denotes number of bomas with specified land use type (column); the second number denotes the percent of respondents within that study area (row) using that land use type.

Averages	Kiboko Group Ranch	Kiboko Settlement	Muuni Settlement
Households			
Cattle	42	6	3
Goats	37	15	9
Sheep	30	2	2
Donkeys	3	0	0
Chicken	2	10	9
People	9.6	9.9	7.6
Men	1.8	2.6	0.9
Women	2.1	2	1.2
Children	5.1	5.2	5.4
Areas (acres)			
Farm size	--	6.3	7.9
Cropped area	1.8	3.4	4.3
Livestock area	--	2.97	3.9

Table 4.15. The average parameters on the household, herd and land use.

sizes of 7.9 and 6.3 acres, respectively with both schemes allocating an average of 54% to farming. The stocking rates are 0.16 ha/TLU and 0.41 ha/TLU for Kiboko and Muuni settlement schemes, respectively (where 1 TLU = 250 kg live weight). In KGR, it is 2.6 ha/TLU and 39 ha/TLU in Kiboko Range Research Station (KRRS). Most farmers in the settlement schemes rely on the KRRS for grazing either illegally or by paying a grazing fee to the station. In KGR, the total number of cattle has declined by 32% since the last census of 1988 (see Table 4.16). The number of sheep and goats has, however, increased by 23% (from 6920 to 8529). The population of cattle is now similar to that of the early 1970s. This decline could probably be due to the harsh 1993/94 drought and decline in vegetational status. The low numbers in 1977 were due to the devastating drought of 1975/76.

Distribution of cattle among households in KGR indicates a wide inequality in ownership despite being a communal ranch. Households with herds of 0-20 cattle compose 44% of the total households and own only 13% of the total cattle population (Table 4.17). However, it is noted that the wealthier households usually have more people.

An important change in land use in KGR is the increase in cultivation with 96% of the households now practicing farming (no previous data is available for comparison). Farming by the pastoralists is on small patches of 1-2 acres even though there are no limitations to the extent to which one can expand his farm. After the El Niño rains of early 1998, rains in the study area either totally failed in some areas or were very poor. Farmers in Kiboko and Muuni made no harvests in December 1998 (short rains) and May 1999

	Year							
Ranch	1968	1971	1972	1973	1974	1977	1988	1999
KGR	3475	5263	5307	--	7208	1915	7709	5257
Mereushi	3480	--	--	6415	--	--	7970	--
Olkarkar	3428	5851	--	--	5893	2373	7647	BP

Table 4.16. Total cattle numbers in the ranches being studied with exception of Mbirikani. Census of livestock in this study was done in KGR and Olkarkar only. BP= Being processed.

Herd size	Households (%)	Animals (%)
0 - 20	44	13
20 - 40	26	18
> 40	29	68

Table 4.17. Distribution of livestock among households in Kiboko group ranch.

(long rains). Consequently, the farmers relied heavily on food aid distributed by NGOs and government agencies. This probably indicates that the livestock herds/household are insufficient to fall back on.

In the grazing lands of KGR, Olkarkar, Merueshi, Chyulu, and KRRS there was high grass biomass following the El Niño rains. However, after the failure of the short rains in December 1998, fires consumed approximately 60% of KRRS and Northern Chyulu. Brief rains in April 1999 led to some replenishment. Fires were rare in KGR and other ranches due to high livestock utilization and weeds. By May 1999, pastoralists had started to move livestock out of Merueshi and Olkarkar to KGR, mainly to utilize KRRS and Chyulu. By August, the ranches of Olkarkar and Merueshi were literally deserted save for a few donkeys and shoats. By this time, standing crop averaged 74 g in Olkarkar and 80 g m in Merueshi and KGR, while in Chyulu and KRRS it was 221 g and 189 g respectively (g / 0.5 m^2). It is interesting to note that semi-nomadism has remained unchanged in times of drought, despite sub-division and increased settlement. A similar pattern of livestock movement was noted in the 1968/70 drought (Halderman, 1972). In the 1993/94 drought, slightly over 10,000 cattle were using KRRS (source: KRRS farm records) from KGR, Merueshi, Olkarkar and Mbuko.

In the 1998/99 drought, animal movement was assessed in November/December using a questionnaire in the households of KGR, Muuni and Kiboko settlements, and Olkarkar. The results of KGR are presented in Table 4.18.

From the results, only about half the households with less 0-20 animals moved while 97% of the households with over 40 cattle moved. Movement of animals is a labor-intensive activity and hence expensive. Thus, the wealthier households appear to be better suited for this drought response. Generally out of the total number of animals per unit, 88%, 72%, and 30% were moved from KGR, Muuni, and Kiboko, respectively.

<u>Wildlife distribution</u>

Wildlife was counted based a 1 X 1 km grid. This was done with the aid of a GPS, 1:50,000 topographic map on a UTM grid, binoculars and a 4WD vehicle. The following information was taken in each grid cell:

1. wildlife type and number;
2. water source-seasonal pools/ springs/rivers;
3. livestock numbers-cattle, goats, sheep and donkeys;
4. bomas/households and the number of manyattas/houses per each;
5. tree cover - riverine forest, bush thicket (> 80% cover), dense bush (60-80), bushed grassland (30-60) and open grassland (< 30%); and
6. herbaceous cover-bare (< 20%), low cover (20-50), medium cover (50-80), high cover (> 80%).

Not all of the data collected has been processed and only data of Olkarkar, Merueshi, and Mbirikani is considered. Statistical analysis have not yet to be conducted.

Herd size	Households (n)	Households moved (%)	Total animals moved (n)
0 - 20	56	52	394
20 - 40	33	82	823
> 40	37	97	3441

Table 4.18. Livestock movement from KGR in response to drought.

Area	Block size (km^2)	Average density (bomas / km^2)	Average livestock (number / km^2)	Average wildlife (number / km^2)
Mbirikani	83	0.16	4.22	7.26
Merueshi	45	0.40	12.30	5.00
Olkarkar	104	0.63	14.40	1.63

Table 4.19. Animal and household density of the sampling areas.

Wildlife density is inversely related to livestock density (Table 4.19). Thus Olkarkar, which has the lowest wildlife density, had the highest density of bomas and livestock. Olkarkar was among the first group ranches to be sub-divided. Even though Mereushi is sub-divided, the mode of utilization is less sedentary than Olkarkar. Mbirikani Group Ranch is utilized almost entirely on a semi-nomadic mode with very few permanent settlements. The data also showed that Olkarkar had the least herbaceous cover of 20-40%, while Merueshi and Mbirikani had 40-60% cover. Cultivation is also highest in Olkarkar. These two factors probably also contribute to the low wildlife density (Table 4.20). Bomas, livestock, and wildlife are all more common in open grasslands than in brushy areas (Table 4.21).

It would appear that most bomas and livestock were situated very near water sources (Table 4.22). However, it should be considered that data were collected in the wet season when seasonal pools, which were also counted as water sources, are plentiful. Further, during this time grass is abundant and there is no need to graze far away from these sources of water. Nevertheless, there is a higher density of bomas/households near permanent water sources, towns, and roads, especially in Olkarkar. Wildlife, on the other hand, was found furthest from water sources, especially in Mbirikani.

Land use effects on vegetation and soils

The impacts of different modes of human land use upon the ecosystem were assessed in the region in and around the Kiboko Range Research Station. This study was conducted to assess the differences in vegetation structure, composition, production, and associated soil physical and hydrologic status as influenced by land use, management approach, and grazing pressure. The land

Area	Grant's Gazelle	Impala	Kongoni	Wildebeest	Zebra	Thomson's Gazelle
Mbirikani	0.17	0.10	1.40	1.52	3.6	0.41
Merueshi	0.5	0.10	0	0.7	3.0	0.3
Olkarkar	0.7	0	0	0.2	0.3	0.4

Table 4.20. Distribution of the main wildlife species in the study area.

Vegetation type	Bomas (%)	Livestock (%)	Wildlife (%)
Bush thicket	16	0.6	1.6
Bushed grassland	25	30	28.1
Open grassland	56	66	82.1

Table 4.21. Distribution of bomas, livestock and wildlife in relation to vegetation type.

Distance from water	Bomas (%)	Livestock (%)	Wildlife (%)
0 - 1.0 km	64	41	38.6
1.0 - 3.0 km	26	59	61.4
> 3.0 km	10	0	19.5

Table 4.22. Distribution of bomas, livestock and wildlife in relation to distance from water sources.

use patterns studied were group ranches (2), conservation areas (2), small-scale ranches (6), and small-scale mixed farms (4), (Mworia and Kinyamario 2000).

Herbaceous standing crop was determined by clipping 10 samples per site to a 2 cm-stubble height using a 0.5 m^2 rectangular quadrant. Clipping was done by species and litter collected. Herbaceous cover was determined by the line intercept method. Replicated 10 m transects were used at each site. Soil loss status was assessed qualitatively at each site and quantitatively at selected sites. Qualitative classification was based on a scale of one to five, with class one showing no signs of erosion and class five very severe erosion with exposed sub-soil and gullies. Quantitative estimates have not been used in this report because data on runoff plots is not complete. Soil moisture was determined by the gravimetric method. Research was carried out on Kiboko Group Ranch, Olkarkar small scale ranches, Muuni settlement scheme, and Kiboko settlement, all of which border Kiboko Research Station. Selection of study sites within the study area was effected to capture variation in the following aspects:

Management approach: That is, assess the main types of management.

Vegetation/soil types: Systematic sampling using a soil/vegetation base map was used to capture the main types.

Utilization gradient: The intensity of grazing in most of the grazing land was noted to vary radially from heavy utilization such as permanent watering points, that is, a piosphere effect.

In all the sampling sites (Table 4.23), two sets of data were collected. The first is on environmental variables and the second on vegetation variables. To analyze the data, Canonical Correlation Analysis (CCA), a multivariate method that combines ordination with multiple regression, was applied. Data was analyzed using the software PC-ORD.

Correlations of the assessed environmental variables are presented in Table 4.24. Distance to water is strongly correlated to altitude because most water sources are along the Kiboko River and the adjacent plains, which are at low altitudes. Erosion is not strongly correlated to rainfall indi-

Selection criteria	Site attributes	Number
Management type	Group ranch	2
	Small scale individual ranches	6
	Small scale mixed farms	4
	Conservation areas	2
Utilization gradient	Sites located < 0.5 km to water	10
	Sites located 0.5 - 4.0 km to water	10
	Sites located > 4.0 km to water	15
Vegetation and soil type	Soils	
	Ferrous soils	17
	Volcanic soils	18
	Vegetation	
	Grassland	10
	Bushed grassland	11
	Bush thicket	12
	Riverine	2

Table 4.23. Sites selected to examine land use effects on vegetation and soils.

Water distance	1.00									
Altitude	.629	1.00								
Erosion	-.374	-.296	1.00							
Rainfall	-.424	-.184	.011	1.00						
Livestock	.038	-.152	.05	.052	1.00					
Soil N	-.178	-.267	-.211	.13	.644	1.00				
Soil P	-.011	-.051	-.017	.343	.336	.352	1.00			
Soil moist 5	.160	.343	-.231	-.209	-.137	-.072	.214	1.00		
Soil moist 30	-.033	-.058	.204	-.316	-.053	-.173	.086	.571	1.00	
Soil moist 60	.185	.428	-.254	-.385	-.101	-.049	.157	.871	.613	1.00
	WD	**Alt**	**Eros**	**Rain**	**Live**	**N**	**P**	**SM5**	**SM30**	**SM60**

Key: Water distance, WD= Distance to water; Alt = Altitude; Eros = Erosion; Rainall, Rain = Long term average rainfall; Livestock, Live = Livestock density; N = Soil nitrogen; P = Soil phosphorous; Soil moist 5, SM5 = Soil moisture at 5cm; Soil moist 30, SM30 = Soil moisture at 30cm; Soil moist 60, SM60 = Soil moisture at 60cm.

Table 4.24. Correlation coefficients of the 10 environmental variables.

cating that factors that contribute to erosion in the area are a result of land use practices. Soil nitrogen and phosphorous positively correlated to grazing intensity. Soil N was found to be highest in areas of high livestock density. Grazing intensity is negatively correlated with soil moisture at all levels. This is probably due to the effects of livestock trampling on soil physical characteristics and the grazing effects on cover and biomass. Soil moisture at 5 and 60 cm are positively correlated to altitude, a reflection of higher cover, and more rainfall and distance from permanent water points.

Factors related to herbaceous standing crop are seen in Table 4.25. The first, second, and third axes have high eigenvalues of 0.775, 0.640 and 0.456, respectively. The major determinant of the first axis is soil moisture at 5 cm (-0.708). Other than soil moisture at the three depths, erosion level and livestock density are strongly correlated to the first axis. The distance to water largely determines the second axis with altitude being correlated. Soil erosion has the highest correlation (-0.561) to the third axis, with soil moisture and the average rainfall being important.

Variable	**Axis**		
	1	**2**	**3**
Water distance	.334	.416	.199
Altitude	-.102	.365	.088
Erosion	-.508	-.333	-.561
Rain average	.319	.189	-.418
Livestock density	-.457	-.144	.011
Soil N	-.246	-.236	.161
Soil P	.058	.160	.037
Soil moist 5 cm	-.708	.317	.421
Soil moist 30 cm	-.686	-.004	.368
Soil moist 60 cm	-.633	.037	.534

Table 4.25. Interset correlation coeffecients of 10 environmental variables with species biomass axis.

Species and sites to environmental biplots for herbaceous biomass are shown in Figures 4.2 and 4.3. A number of groups of species and sites have been ordinated based on their correlation with environmental variables and land use impacts (Figure 4.2 and 4.3). The groups are discussed briefly. Species whose biomass is strongly associated with high "distance to water," low livestock density (livestock density decreases in the direction of the arrow because it is expressed in hectares per stock unit) and low levels of erosion are shown in the upper right corner of the species biplot (Figure 4.2). This group of species is ordinated chiefly on the second axis. They include *Themeda triandra*, *Chyrosopogon aucheri*, *Eragrostis superba* and others. Sites associated with this group are mainly the conservation areas of Chyulu and the western section of Mbirikani Group Ranch (Figure 4.3).

The second group of species is in the upper left corner of the species biplot (Figure 4.2) and is ordinated mainly along the first axis. The species include *Pennisteum mezianum* and

Cynodon dactylon. The sites are associated with high soil moisture, low levels of erosion and high livestock density (Figure 4.3). These sites can be classified as bushed grasslands that are heavily used. A third group of species and sites are associated with high erosion. The species are shown in the lower left quadrant of the ordination. The sites are close to water sources, eroded and low soil moisture with high biomass of weeds, mainly *Heliotriopium steuderi* and *Blepharis linifloris*, and the grasses *Enteropogon macrostachyus* and *Eragrostis caesipitosa*.

The last group of species is clustered around the centroid. These species are generalists with biomass fairly distributed among the sites. These include *Digitaria macroblephera,* the dominant species in the study area.

It can be concluded that herbaceous standing crop in the prolonged dry season in the study area was generally determined by soil moisture at 5 cm depth, distance to watering points, and the level of erosion. The ordination did not separate clear management groups, however, herbaceous biomass and diversity were highest in sites distant from water and low livestock density. These were mainly in the conservation areas of Chyulu Park. Small-scale ranches (three out of five) were associated with erosion and high weed biomass. Kiboko Group Ranch, in which the pastoralists are largely sedentary, was also associated with erosion and low soil moisture. The density of herbs, shrubs and trees appears to be an important factor in the distribution of herbaceous biomass.

Factors related to herbaceous cover are shown in Table 4.26. The first, second, and third canonical axes have eigenvalues of 0.390, 0.185 and 0.132, respectively. The major determinant of the first axis is soil moisture at 60 cm, with altitude and soil moisture at 5 cm being correlated. The second axis is determined chiefly by soil nitrogen with distance to water and livestock density being correlated. Axis three is determined by average rainfall with soil moisture and soil phosphorous being important. Thus, from the current data set it would appear that soil moisture,

	Axis		
Variable	**1**	**2**	**3**
Water distance	-.296	.481	-.085
Altitude	-.656	.496	-.088
Erosion	-.071	-.340	-.140
Rain average	.542	-.008	-.444
Livestock density	.328	.415	.030
Soil N	.197	-.515	.220
Soil P	.127	-.061	-.233
Soil moist 5 cm	-.644	-.077	-.291
Soil moist 30 cm	-.385	-.227	.038
Soil moist 60 cm	-.732	-.138	-.090

Table 4.26. The interset correlation coeffecients of the 10 environmental variables with species cover.

fertility and average rainfall are the key determinants of cover with livestock density and altitude being associated. Soil moisture at 60 cm is an important variable because it could reflect the hydrologic status of a site. Sites and species to environmental biplots are shown on Figures 4.4 and 4.5, respectively.

Grouping of species and sites as a result of their correlations to environment variables and superimposed land use impacts can be inferred from the species to environment biplot. In the upper right corner of the species biplot (Figure 4.5) a group of species that includes *Themeda triandra, Bothriochloa insculpta, Chyrosopogon aucheri,* etc., are ordinated, principally along the first axis. Low soil moisture and high altitude characterize these sites; they are also associated with high "distance-to-water" and low livestock density (Figure 4.4). The sites are located mainly in the conservation units of Chyulu and Kiboko Research Station. In the lower right corner, sites are characterized by high nitrogen and low soil moisture. Sites ordinated in this group are mainly in Kiboko Group Ranch where they are located close to permanent watering points. Also ordinated in this group are small-scale mixed farms (Figure 4.4). The sites have a high proportion of bare ground. *Hermannia ulhligii* is important in these sites while *Chloris roxburghiana* is the main grass associated with the sites. In the lower left corner, sites are ordinated mainly along the second axis; that is, they have high soil nitrogen and livestock density, but unlike the previous group, they are associated with high soil moisture (Figure 4.4). Important grass species in terms of cover that are associated with these sites are *Pennisteum mezianum* and *Enteropogon macrostachys* (Figure 4.5). Sites ordinated are mainly in the small-scale ranches of Olkarkar and Merueshi. Sites characterized by low rainfall and associated with great distance from water are shown in a final group in the left upper corner. These consist mainly of sites in Mbirikani and Kiboko Group Ranch. Important species ordinated in this group are *Pennisteum stulmanii*, *Sporobolus fimbriatus* and *Cynodon plectoschyum* (Figure 4.5).

In conclusion, ordination of sites in respect to cover produced a relatively distinct grouping of sites under similar management. Small scale ranches of Olkarkar and Meruseshi were associated with high soil nitrogen, high livestock density and was dominated by *Pennisteum mezianum*. Sites in the conservation areas of Chyulu reserve and Kiboko Station were associated with low stocking density and great distance-to-water, while sites in Kiboko Group Ranch and small scale mixed farms were associated with high nitrogen, low soil moisture, and high percentage of bare ground.

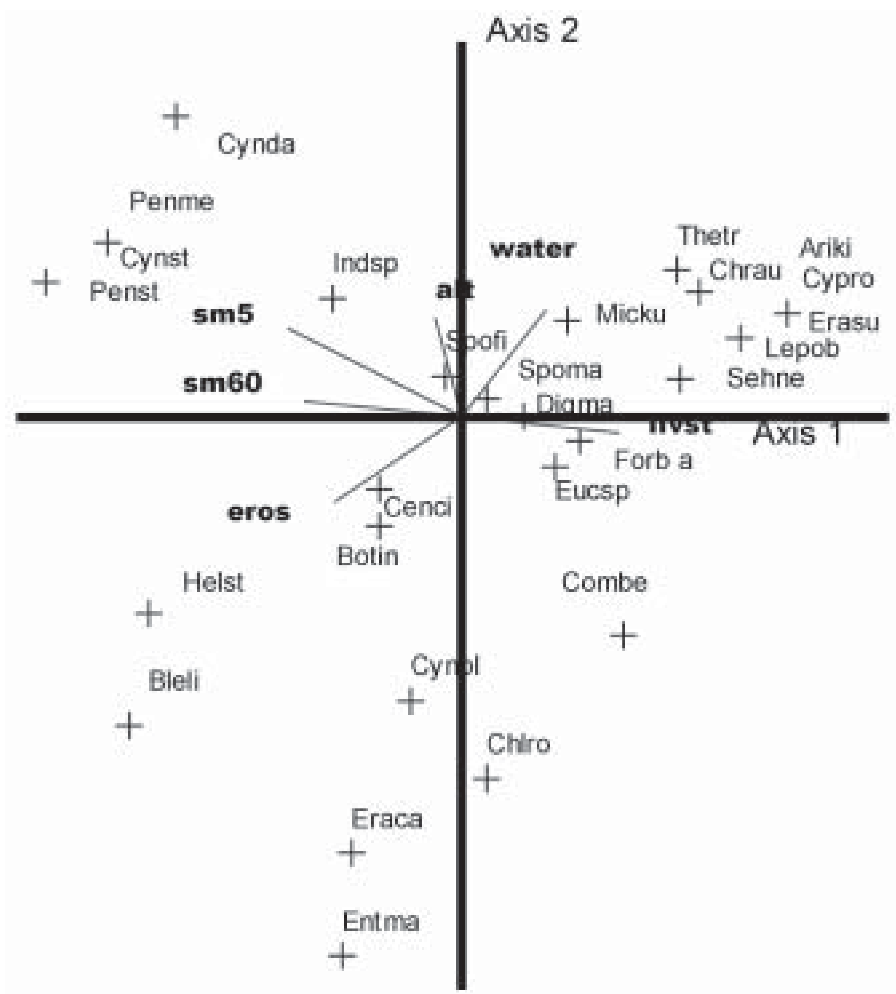


Figure 4.2. Species to environment biplot for herbaceous biomass.

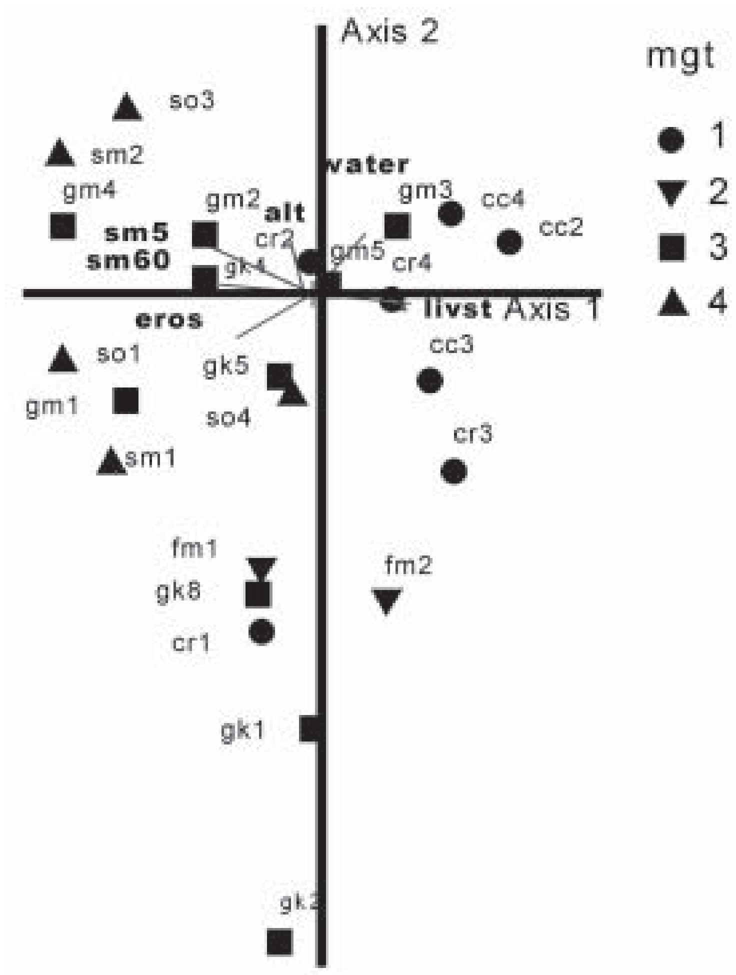


Figure 4.3. Sites to environment biplot for herbaceous biomass.

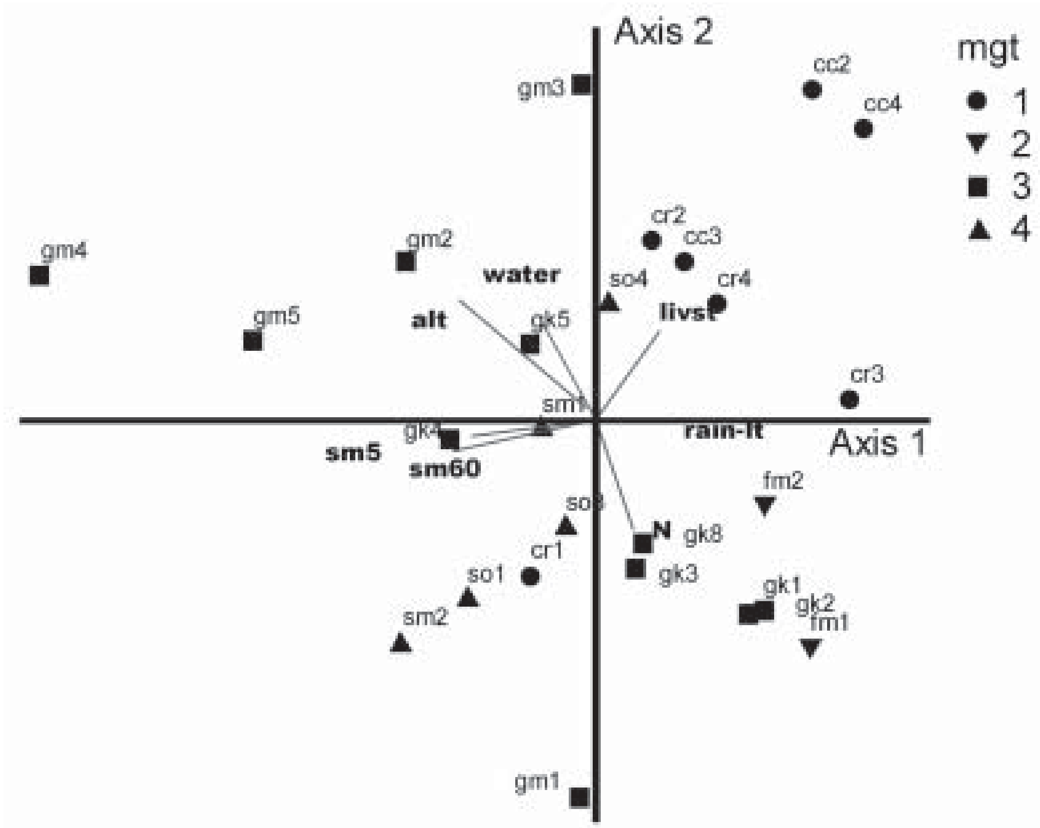


Figure 4.4. Site to environment biplot for herbaceous cover.

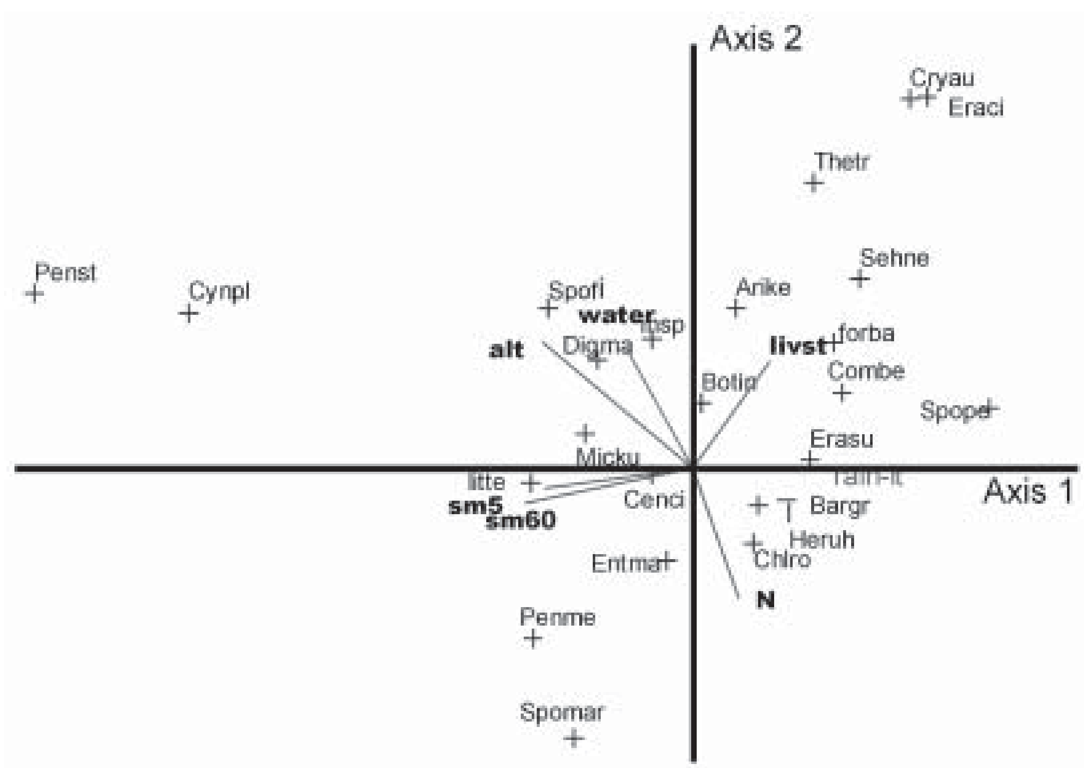


Figure 4.5. Species to environment biplot for herbaceous cover.

Chapter 5

Spatial Databases and Analyses in an Integrated Assessment of East African Land Management

Robin S. Reid and Randall B. Boone

INTRODUCTION

Spatial layers and analyses conducted using Geographic Information Systems (GIS) are becoming indispensable in understanding processes at landscape and larger spatial scales. Advances in spatial software design and a reduction in its cost have gone hand-in-hand with calls from ecologists for more work at landscape and regional scales (Kareiva and Andersen 1988; Brown 1995). Broader scale spatial and temporal questions may be addressed using GIS analyses. In addition, ecological relationships at local scales may be extrapolated in rigorous ways to broader spatial scales increasing the return on investments of resources for research. Lastly, remotely sensed spatial layers, such as satellite images, can provide data across large regions that are collected using consistent methods which are inexpensive and updated frequently.

We (the GL-CRSP IMAS team) sought to compile spatial data and conduct analyses as part of the GL-CRSP Integrated Management and Assessment System. The information gathered supported spatial analyses outlined in this chapter, as well as ecosystem modeling using the SAVANNA model, described in *Chapter 7*, the socioeconomic modeling in *Chapter 8*, and wildlife and livestock disease description and modeling described in *Chapter 9*.

SPATIAL LAYERS CREATED OR COMPILED

Region

Landsat TM Data

M. Kalkhan coordinated the purchase of three Landsat Thematic Mapper images from 1991 and 1993 for use in vegetation mapping in the Serengeti Ecosystem. An additional 1993 image of central Kajiado District, and a portion of an image for northern Kajiado, were also purchased. These images were coarsely georectified and merged by the I-Cubed Corporation (Fort Collins, Colorado, USA), then merged into our spatial database. Cooperation with D. Reed of the State University of New York recently added another set of Landsat TM scenes of the Serengeti to our spatial database.

NDVI Images and Viewer

We have compiled and georectified a large collection of Normalized Difference Vegetation Indices (NDVI) which are spatial layers based upon weather satellite images, and depict vegetation biomass and vigor (Figure 5.2). We had three resolutions (i.e., the size of the cells in the grid comprising the geographic layer) and three sources of NDVI layers available to us. The highest resolution available, with cells 1 km on a side, were from the Global Land 1-km AVHRR Program (USGS 1998). These data were available for the entire world from 1992 to 1996, with many missing periods, including all of 1994. The images were provided in a dekadal format, meaning that images were available every 10 days, for a total of 36 images throughout the year. We gathered these images from the source sited, then selected from them the area covering Kenya, Uganda, and Tanzania. Although highly resolute, these data are variable, so we created average responses for the dekadal images over the period they were available (1992-1996), and used them in analyses.

A second set of NDVI images had been received by M. Coughenour from personnel at the US National Aeronautics and Space Administration (NASA). The cells in these images were 4 km on a side, and were from 1982 to 1988, with two images per month.

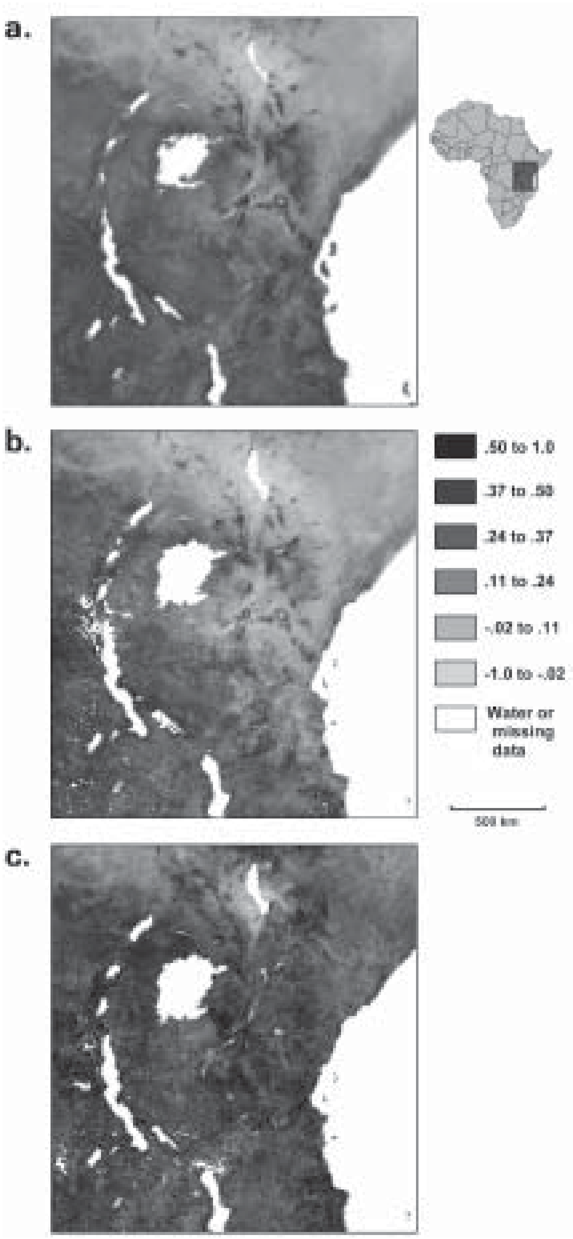


Figure 5.1. Example images of Normalized Difference Vegetation Indices (NDVI) based upon satellite images. This example shows: a) long-term mean vegetation greeness; b) greenness reduced during a the drought of 1997; and c) greenness extremely high during the heavy El Niño rainfall of 1998. See Boone et al. (2000) for details.

A final set of NDVI images were provided by the Global Inventory Monitoring and Modeling Studies (USGS 1999) of NASA and distributed by the African Data Dissemination Service (USGS 2000a). Cells within the images were 7.6 km on a side, and the images summarized a 10-day period (dekade). We obtained the entire collection of 7.6 km data, essentially from the launching of the satellites in 1982 to the present, including over 600 images.

NDVI data often were not registered well with other spatial layers from East Africa, especially prior to the late 1990s. Given that water appears distinctly in NDVI images (e.g., Figure 5.1), we used lake and ocean boundaries from the Digital Chart of World as a reference layer, and manually aligned each of the NDVI images with the water bodies. The accuracy of this alignment varied, but in general, we believe each image is placed within the span of one cell width (i.e., 1, 4, 7.6 km) from its actual position on Earth. This relative accuracy is reflected in the analyses we conduct; it would be inappropriate to conduct site-specific analyses using the 7.6 km resolution data.

The hundreds of NDVI images contain a great deal of ecosystem information, such as

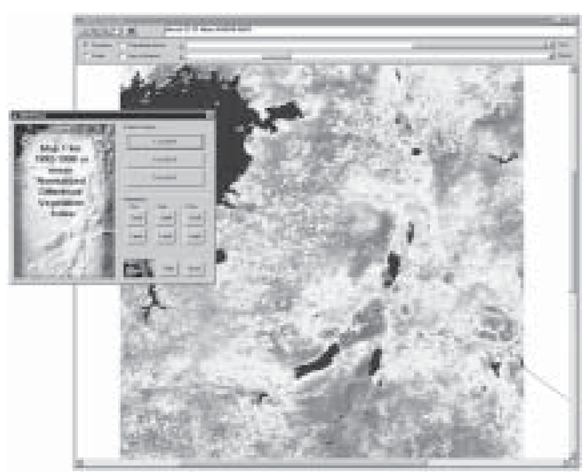


Figure 5.2. The NDVIView utility was written to allow users to easily browse and use satellite images of vegetation greenness.

responses to drought and wet periods, but using the information can be tedious. We created a tool called NDVIView to simplify viewing the NDVI images of the region (Figure 5.2). NDVIView allows a user to browse the three resolutions of NDVI data and overlay boundaries and populated places. The tool also includes animations of NDVI images, which prove a powerful means of understanding how vegetation biomass changes though the year (1 km data) or decades (7.6 km data).

Other Regional layers

J. Acen, a graduate student at Colorado State University, has compiled a set of geographic layers she will use to support her analyses of policies affecting land management and use in East Africa. To date, J. Acen has compiled administrative boundaries for Kenya and Tanzania (e.g., Figure 5.3) with national, district, and sub-district boundaries for both countries; layers depicting protected area boundaries in Kenya and Tanzania, including national parks, game reserves, and conservation areas; demographic data for the region for 1990; and agricultural statistics for Kenya. Spatial layers for physical attributes Acen has compiled are: (a) soils maps for Kenya; (b) digital elevation models for Kenya; (c) hydrography layers, including streams, rivers, and lakes, for Tanzania and Kenya; and (d) climatic surface layers. The sources of these data are varied. For example, administrative boundaries and elevation models were acquired from the African Data Dissemination Service (USGS 2000a), climatic data were imported from the Almanac Characterization Tool layers for East African countries (Corbett et al. 1998), and soils were acquired from the project entitled KenSOTER (Rossiter 2000).

R. Reid, R. Kruska, and others (e.g., see Reid et al. 1999) have compiled or created estimates of human population size in the years 2000, 2020, and 2040 for all of Africa. They also compiled continental estimates of livestock populations, land use, and conservation areas. Spatial analyses, described later in this chapter, generated GIS layers of continental-scale threats to large mammal diversity.

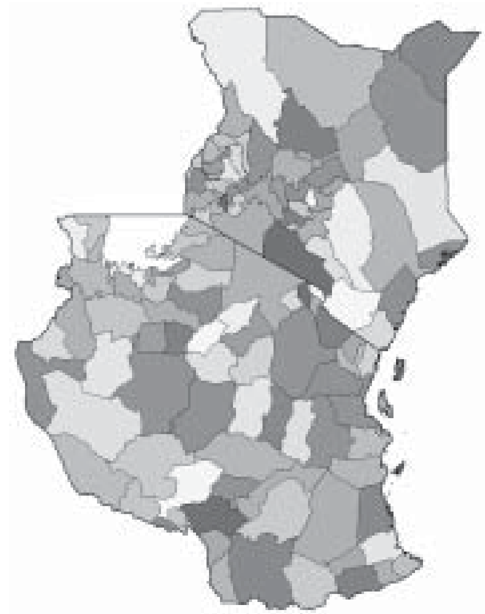


Figure 5.3. Administrative subdistricts in Kenya and Tanzania. The subdistricts are shaded randomly.

Other layers we have compiled include a 1-km resolution digital elevation model for East Africa (USGS 1999) and layers from the Digital Chart of the World (Environmental System Research Institute, Redlands, California, USA) for Kenya, Tanzania, and where available, Uganda (e.g., political boundaries, river network, populated places, topography, geology, utility lines, roads, rails, and land cover). Digital Chart of the World layers are useful for their coverage and completeness across regions, but are not spatially resolved. We have also acquired from the Global Land Cover Characterization project 1-km resolution cover maps of Africa (USGS 2000b), human and cattle populations as compiled by Corbett et al. (1998), and African country boundaries (USGS 2000a).

K. Campbell, of the Environmental Sciences Department, Natural Resources Institute (Kent, UK) provided us with highly detailed (1:50,000) hydrography and hypsography data for portions of the Serengeti region, which had been digitized from maps created by the Tanzanian government. He also provided detailed data from aerial surveys in the early 1990s, including cover estimates, boma (i.e., groups of households) surveys, and animal density estimates. We created maps from these data, which were used in ecosystem modeling to help guide the distributions of people, plants, and animals.

We have available layers created under related research projects not directly supported by GL-CRSP. Layers are available of locations for selected household surveys throughout Loliondo Game Controlled Area, Ngorongoro Conservation Area, schools, and markets (Smith 2000), and areas in Maasai defined as lowlands, midlands, and highlands (Lynn 2000). Points within these regions were classified based upon inputs from Maasai, but the spatial distribution of the regions were defined quantitatively. Soils maps of Serengeti National Park have been digitized to support research being conducted by K. Metzger of CSU.

Figure 5.4. The main vegetation types from Herlocker and Dirschl (1972) were digitized. Vegetation types were shaded randomly.

Ngorongoro Conservation Area, **Tanzania**
Land Cover

In the late 1960s, Herlocker and Dirschl conducted field work to map the land cover of Ngorongoro Conservation Area (NCA), publishing their map in 1972. The major vegetation types of that map were digitized, georectified to the degree possible, and merged into our spatial database (Figure 5.4). Later, we parsed-out Ngorongoro Crater from the map and digitized additional information from Herlocker and Dirschl (1972). The full detail of the map was digitized, including overstory,

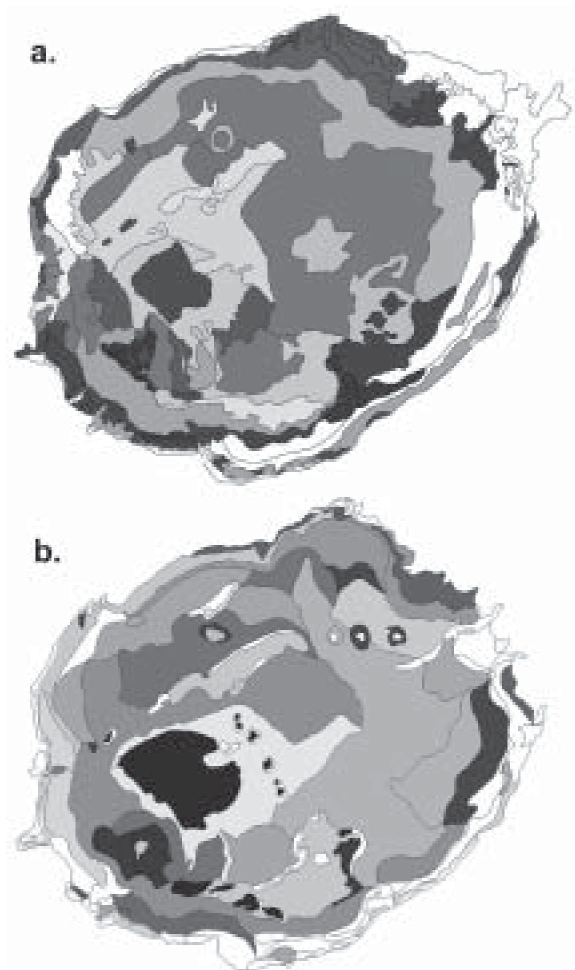


Figure 5.5. The full detail from (a) Herlocker and Dirschl (1972) for Ngorongoro Crater, and (b) the Crater map by Chuwa and Moehlman were digitized. Vegetation types were shaded randomly, but with the same shades where both maps shared types.

understory, height, and cover information (Figure 5.5 a). A map of land cover of Ngorongoro Crater created by S. Chuwa and P. Moehlman in the mid-1990s was digitized for use in comparisons to Herlocker and Dirschl (1972). The recent map included the same types and formats of information as the older map and was digitized in full detail (Figure 5.5 b).

Misana (1997) published a map showing vegetation change, which she had created by analyzing Landsat Multi-spectral Scanner satellite images from 1979, 1985, and 1987, and from aerial photographs from 1958, 1982, and 1983. We digitized this map to help identify areas of change, aligned it to the degree possible with georectified layers, and added it to our spatial database.

M. Kalkhan used Landsat Thematic Mapper (TM) data, Herlocker and Dirschl (1972) and other literature sources to create a land cover map of Ngorongoro Conservation Area and the surrounding sites. Kalkhan used unsupervised classification techniques of six TM bands to form 100 clusters sharing spectral signatures. He referenced the maps from the literature and detailed signature statistics to merge the 100 clusters into 27 land cover types (Plate 1a). The resulting map has not been assessed, but experts in land cover of Ngorongoro have judged the map to be a good represention of cover.

Water Sources

Water sources for Ngorongoro Conservation Area were mapped using Aikman and Cobb (1997), which included tables of the existing and failed water sources in Ngorongoro, along with their status and geographic coordinates. For rivers shown as water sources in Aikman and Cobb (1997), we referred to Landsat TM data to map them. We used the notes within Aikman and Cobb (1997) to create seasonal and permanent water source maps (e.g., Figure 5.6). T. McCabe, an expert in Maasai herding in NCA, reviewed our water source maps and suggested changes, which were incorporated.

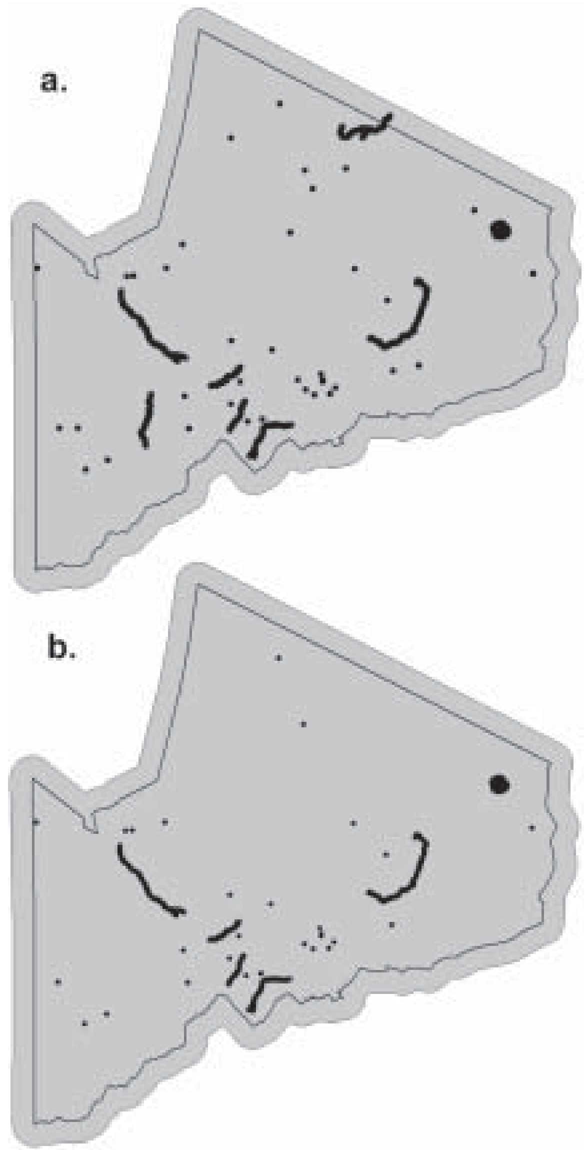


Figure 5.6. Seasonal (a) and permanent (b) and permanent water source maps were created for NCA.

SAVANNA Layers

The SAVANNA Modeling System incorporates grid-based spatial layers in its processes. The spatial layers inform SAVANNA of the attributes of each of the grid cells, for its use in modeling. We created a series of maps for Ngorongoro Conservation Area and the areas within 5 km of the site (see *Chapter 7*), often based on spatial layers already cited. Two resolutions were created with 1 x 1 km blocks, and 5 x 5 km blocks. For example, we resampled the existing digital elevation model for the area (0.95 km resolution) to 1 km resolution, then created aspect and slope layers from elevation. These layers were then generalized to 5 km resolution. The high resolution land cover map created from TM data was reduced to 15 vegetation types, and resampled to 1 km and 5 km resolutions. A layer showing the density of households was generated based upon a 1991 aerial survey of bomas (i.e., groups of households), with data provided by K. Campbell (see Chapter 7 for a figure). This layer guided the placement of households in SAVANNA. A soils map and subarea map were created as well.

We created distance to water layers where each cell contained an integer value storing the distance in km to the nearest water source. A layer was created for the distance to permanent water in: (a) the dry season, based on permanent water sources; (b) what we termed the transitional period based on a merging of seasonal and permanent water sources; and (c) a wet season map which included the same water sources as the transitional season map, with any value > 3 km set to 3 km. In SAVANNA, this signifies that in the wet season water may be found within 3 km of any cell.

Layers called force maps were created for each of the animal groups modeled (see *Chapter 7*). Simulated animals in the SAVANNA system are located based on attributes such as habitat quality and quantity, slope, shade available, and herbaceous green biomass. These attributes cannot capture some limitations on the movements of animals. For example, in NCA, livestock cannot graze in Ngorongoro Crater because of legal restrictions. The force maps for livestock therefore contain a zero value for cells within Ngorongoro Crater, which in SAVANNA will prevent them from entering the crater. Examples of force maps appear in *Chapter 7*.

Figure 5.7. Weather station locations were added to our spatial database. The 55 with adequate data for use in modeling are shown.

Other Layers

A map of the regions within Ngorongoro Conservation Area that are prone to different diseases was created under the GL-CRSP IMAS project (Rwambo et al. 1999; see *Chapter 9*). Ngorongoro Environmental Monitoring Program sites, (22 locations throughout the grasslands of NCA that have long-term monitoring of vegetation attributes) have been entered in our spatial database along with the underlying environmental data provided by P. Moehlman. Weather sites in and around NCA (e.g., Figure 5.7) were added to our database, along with the underlying data for 1963 to 1992. More recent weather data are available to us, but have not yet been merged into our database. Sites of household surveys conducted by A. Mwilawa have been added to our database. Roads were digitized from an existing map of NCA and referencing Landsat imagery, in which roads were often visible.

Kajiado District, Kenya

Land Cover

As part of GL-CRSP supported effort to understand changes in the Amboseli Ecosystem, F. Atieno created two land cover maps for Amboseli and the central Kajiado District (Atieno 2000). Atieno used printouts of 1998 and 1988 Landsat TM imagery as base information to delineate areas of different spatial reflectance or patterns. He then digitized the patches and labeled them using data on vegetation collected from the field and results from interviews of local residents. Atieno created a map with 12 vegetation types, and later reduced the types to 8 to yield high accuracies (Plate 1b, Plate 1c) in assessments (i.e., 85.7%).

Kajiado Atlas

In 1990, the ASAL Programme of Kajiado and the Ministry of Reclamation and Development of Arid, Semi-arid Areas and Wasteland produced an atlas for the district (Ole Katampoi et al. 1990). Under GL-CRSP, ILRI personnel digitized layers from that atlas, including boundaries, towns, roads, human population data down to sub-location level (Figure 5.8), ground ranches, Amboseli National Park boundary, wildlife management zones, soils, parks, rivers and streams, and land use/land cover. These layers have proven valuable in modeling and analyses.

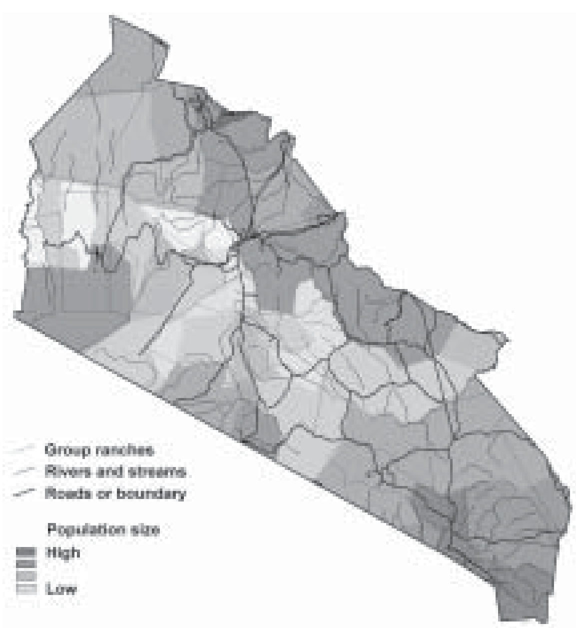


Figure 5.8. Human population levels mapped in example layers digitized from the Kajiado Atlas (Ole Katampoi et al. 1990).

DRSRS Layers

M. Waweru of ILRI and the Kenyan Department of Resource Surveys and Remote Sensing (DRSRS) coordinated GL-CRSP IMAS acquisition of DRSRS data. DRSRS conducts periodic (annual when resources allow) aerial surveys of regions of Kenya, including Kajiado. Their aerial surveys included multiple observers doing animal counts with one observer recording land cover characteristics. Photographs were used to verify counts of animals in groups of greater than ten individuals (de Leeuw et al. 1998). The data met quality control standards (see de Leeuw et al. 1998 for details on the surveys and summaries

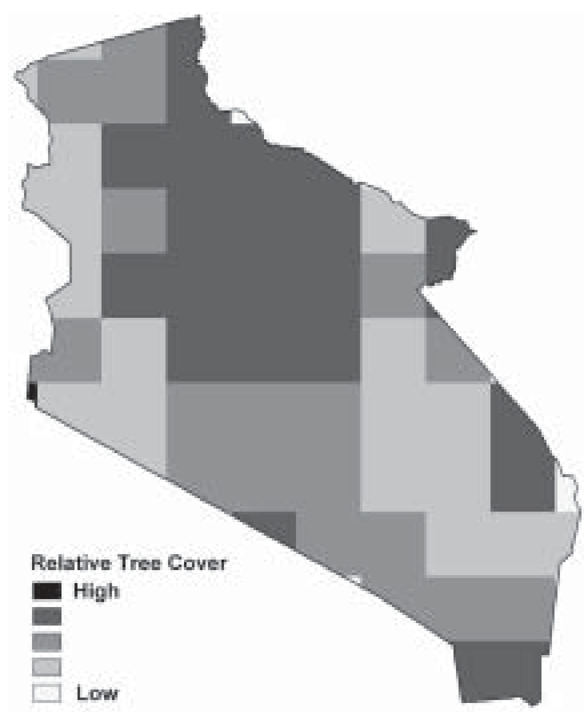


Figure 5.9. Relative tree cover in southern Kajiado District; an example of data provided by the Kenya Department of Resource Surveys and Remote Sensing.

of data from 1977 to 1997). Waweru summarized land-cover observer data for Kajiado District generalizing the information to 15 x 15 km cells at the request of DRSRS. These include herbaceous, shrub and tree cover, and height data (Figure 5.9). Animal counts from 1995 were summarized at the same resolution, including livestock, wildebeest, buffalo, zebra, hippopotamus, elephants, giraffes, and others. We were also provided with summaries of the distribution of livestock and wildlife as single groups, calculated at full resolution and based upon five years of survey data (Figure 5.10). The distributions from DRSRS were valuable in assuring the animal distributions modeling in SAVANNA were reasonable.

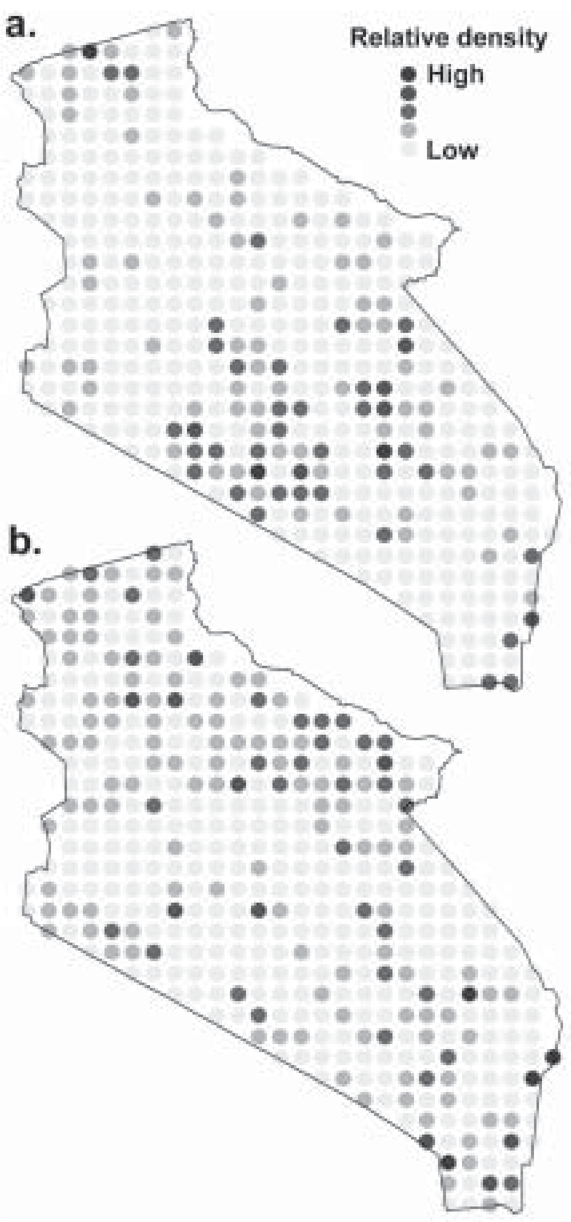


Figure 5.10. Relative densities of (a) wildlife and (b) livestock from DRSRS surveys. Each dot represents the center of a 5 x 5 km survey block.

Other Layers

Water sources were provided to GL-CRSP IMAS by the Kenya Ministry of Water Resources. Soils data were obtained from KenSOTER as cited in Rossiter (2000). Another more detailed soils map for the Amboseli region was provided by Ministry of Agriculture, the Kenya Soil Survey, and Ministry of Tourism and Wildlife. We merged the finely-detailed layer of soils in the Amboseli area with the more general KenSOTER soils map to yield a map of the highest resolution available that covered our entire study site. Weather data was gathered for Kajiado District (e.g., Figure 5.11) by Atieno. High-resolution hysography (i.e., togographic contours) have been digitized by ILRI. We used that data to generate a relatively high resolution digital elevation model for Kajiado. Lastly, fence lines for Kimana and Namelok

Figure 5.11. Weather stations within or near to Kajiado District, southwestern Kenya.

swamps were digitized based upon global positioning system locations.

SAVANNA Layers

As for the NCA, we required Kajiado grid-based layers of spatial information for use in the SAVANNA modeling system. For the southern Kajiado area modeled (see *Chapter 7* for a map of the area modeled), we generalized maps to three resolutions based on the dimensions of the square cells in each grid: 1 km, 2.5 km, and 5 km. From the digital elevation model cited for the region, we created slope and aspect layers, then resampled elevation, slope, and aspect to the three resolutions. Force maps were created for the animal groups of the Kajiado application (see Chapter 7). The force maps were relatively straightforward, and incorporated fences around swamps, exclusion of livestock from Amboseli National Park, exclusion of large wildlife from fenced forests within Amboseli, and limits on the movements of wildlife to the wet season grazing orbits shown in Ole Katampoi et al. (1990). We also had the spatial locations of the training sites where Atieno collected vegetation information and the underlying data, which was used in modeling.

To conduct SAVANNA modeling, we required a vegetation map that covered the entire 10,732 km^2 area, but the best available land cover map (Atieno 2000) covered only a third of that area. We used classification trees (Breiman et al. 1984) to predict the vegetation at sites not mapped. A series of 50 spatial layers were merged into a database for use in analyses, including 36 NDVI images throughout the year showing a greenness profile for each pixel, elevation, soil, slope, maximum and minimum temperature, and a coarse-level existing vegetation map (USGS 2000b). These layers served as independent variables and the 12 classes mapped by Atieno served as dependent variables, in a classification tree analysis. For the area mapped by Atieno, the agreement between the estimated map and the original map was good [Cohen's Kappa Statistic 0.633 (Landis and Kock 1977)]. We then predicted the vegetation in the unmapped portions of the study site and resampled the resulting map to 1 km, 2.5 km, and 5 km resolutions.

Water sources purchased from the Ministry of Water Resources included attributes describing the source and whether or not it was permanent. We used that information to create three types of distance to water layers for use in SAVANNA; one set each for livestock and wildlife. Wildlife layers included ground catchments, rivers, rock catchments, and water holes. Livestock layers included those sources, plus bore holes, dams, wells, and springs. Each set included a layer for the dry season using permanent water sources, and a transitional season map using seasonal and permanent water sources. Wet season layers were created using methods described for NCA. Some of the water sources may be inoperative or may exclude wildlife, for example, but we believe we have described the major patterns well. From the layers of water sources, GIS techniques were used to calculate the distance to the nearest water for each of the cells in the grid (e.g., Figure 5.11), then the grids were generalized to 1 km, 2.5 km, and 5 km resolutions.

SPATIAL ANALYSES

Human-Livestock-Wildlife Conflicts Across Africa

Our ability to better balance human welfare and environmental conservation depends partly on anticipating future conflicts among people, livestock and wildlife. In Africa, these 'tension zones' currently occur in places where protected areas are adjacent to high human populations. It is also important to consider what areas support the most diverse assemblages of large mammals to identify which areas may be most vulnerable to human use. To identify current and future conflict areas, R. Reid, R. Kruska, and others developed a fine-resolution GIS scenario of human population densities for the years 2000, 2020 and 2040, and analysed these with GIS themes on

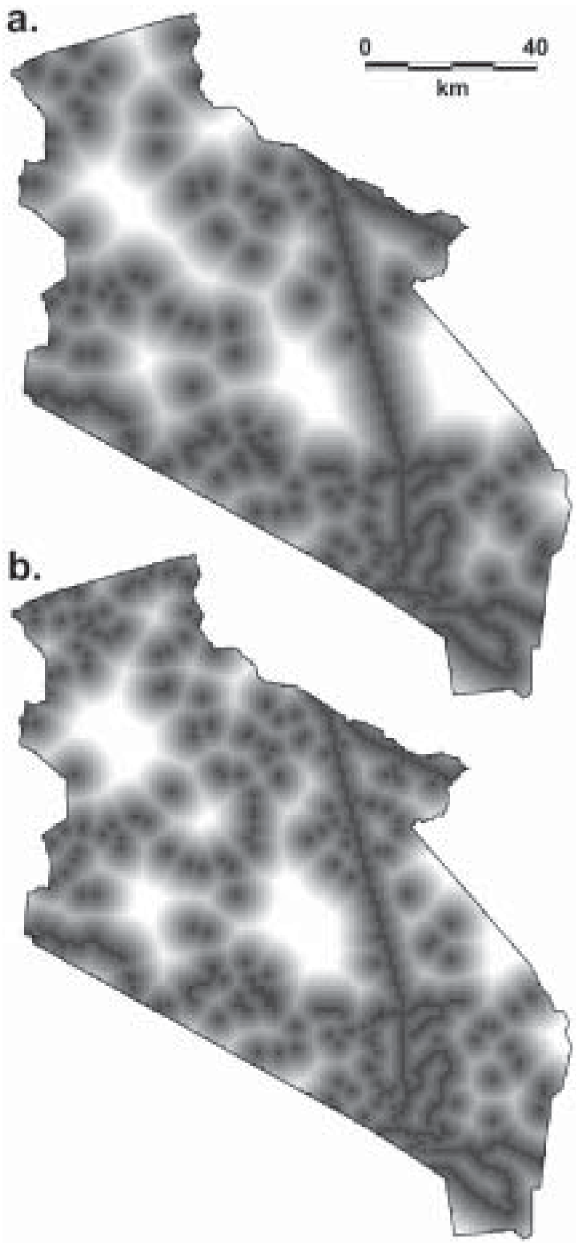


Figure 5.12. Distance to water maps for livestock in southern Kajiado District, for the dry season (a), and the transitional season (b). Areas darkly shaded are near water, those lightly shaded are far from water.

livestock populations, land-use, and conservation areas (**Plate 2a**). Current and future population pressure on conservation areas was measured by creating a spatial index of pressure, correlation analysis of land-use, and the density of human and livestock populations. To identify biologically diverse areas, we developed the first continental map of the density of medium and large mammal species from 281 species contained in databases developed by the Institute of Ecology in Rome, Italy. The resulting map shows the number of mammals in each 5 x 5 km grid cell across the continent (Reid et al. 1999). In West Africa, the remaining pockets of coastal rainforest will be under high pressure by 2040, but this is an area where mammal biodiversity is currently low to moderate. Central and southern Africa will see light pressure except in northern Zimbabwe, Malawi, and parts of Mozambique, where pressure will be moderate to high. However, in East Africa most of the conservation areas (including the Serengeti) will be surrounded by more people than any other area on the continent. East Africa also supports more mammals than any other region of Africa. We conclude from this analysis that the focus of the CRSP projects on human-wildlife-livestock conflicts in East Africa is urgent and well-placed. The lessons learned in Kenya, Uganda, and Tanzania may be useful in Ethiopia and Malawi in the present and in most of southern Africa in the future.

Ngorongoro Conservation Area, Tanzania
Comparative Analyses

R. Boone used NDVI images at three resolutions to calculate vegetation greenness profiles for: (a) all of NCA (7.6 km resolution NDVI images); (b) landscape units within NCA, such as the plains or the Ngorongoro Highland Forest (7.6 km and 4 km); and (c) the 22 individual sites of the Ngorongoro Environmental Monitoring Program (1 km resolution). P. Moehlman and Boone are relating the vegetation greenness profiles as seen from space to changes in vegetation biomass and species composition in the Environmental Monitoring sites.

Detrended correspondence analyses were used to identify how vegetation of the Environmental Monitoring sites varied with gradients. P. Weisberg identified the most significant gradient was structural, from low grasses to tall grasses. Plant species composition was shown to be changing as well.

We have focused our efforts upon Ngorongoro Crater. Moehlman and Boone are quantitatively comparing the changes in crater vegetation maps created 30 years apart (Figure 5.5 a versus 5.5 b). Matrices showing the change in vegetation types across the periods have been produced. We are correlating these changes in plant species composition with overall palatablity to grazers and to documented changes in the ratios of animal species. The removal of cattle from the crater in 1974 may have altered the balance of buffalo and wildebeest grazing patterns, causing the recent declines in wildebeest and dramatic increases in buffalo.

Cluster Analyses

K. Galvin, S. Lynn, and N. Smith had gathered household survey data from dozens of sites in the Loliondo Game Controlled Area and NCA. There were patterns of responses in the survey data that they believed could be generalized to a broader region. But to what region? We developed a method of generalizing household data that correlated changes in Maasai livestock ownership and sales to change in vegetation biomass. We used hierarchical cluster analysis of 1 km resolution cells with each cell storing its annual NDVI greenness profile. This process yielded clusters of land with cells that had similar greenness profiles. Lastly, we compared the clusters to the household survey results identifying clusters that best discriminated survey results. Discrimination was considered ideal when a group of households with a given response, such as selling some number of goats, occurred entirely within one cluster. Two variables were significantly related to vegetation greenness, the number of goats and sheep sold in 1998, and the change in the number of small stock sold between 1997 and 1998. These variables were generalized across the landscape in a quantitative, repeatable way. For more detail on our methods and for figures, see Boone et al. (2000), and for the results and their anthropological implications, see Galvin et al. (in press).

Other Analyses

T. McCabe of the University of Colorado, worked with R. Boone and the wildlife/livestock disease modeling team to define movements of Maasai cattle throughout the year. Researchers conducting aerial surveys of bomas in NCA in the early 1990s had divided the area into 16 blocks, following general land forms and plant communities. We used those blocks (see *Chapter 9* for figures) as the foundation to define the movements of cattle. Matrices were created for each of five transition periods throughout the year: early wet-to-wet season, wet-to-transition season, transition-to-dry season, dry-to-short rains season, and short rains-to-early wet season. McCabe assigned draft probabilities of cattle moving from every block to every other block in each of the matrices. These probabilities were used in modeling the spread of disease as cattle move about NCA. We wish to finalize and refine the movement probabilities in future work; a quantitative representation of Maasai herding patterns may be used to address many questions, such as optimum responses to drought.

In other CSU research associated with the IMAS team, but not directly supported by GL-CRSP, N. Smith conducted GIS analyses identifying distances to markets, schools, and hospitals, and relating them to the placement of bomas and villages. S. Lynn conducted detailed analyses of the movements of Maasai herders, measuring minimum distances traveled from grazing areas, to bomas, to water, and returning to grazing. For both Smith and Lynn, the focus was making comparisons between results in Loliondo and NCA. A detailed vegetation map of the Serengeti Ecosystem, including NCA, is being created by K. Metzger using rigorous spatial statistics methods.

Kajiado District, Kenya

Change in Cover

A study was undertaken to map out and document the land cover, the changes, their possible causes and effects on vegetation species diversity and abundance within the Greater Amboseli Ecosystem. Remote sensing, GIS and ancillary data, together with ground-based techniques, were analyzed. Cover change analysis was carried out between the years 1988 and 1998 using maps produced from Landsat TM scenes. Land use-land cover maps for 1998 and 1988 were produced (**Plate 1b**, **Plate 1c**) with an accuracy of 85.7% from which it was revealed that tremendous land use/ land cover changes have occurred, coupled with significant differences in vegetation species composition, diversity and structure across the study site. Bushed grassland, cultivated land and water bodies increased from 45% (140,409 ha) to 54% (167,572 ha), 3.7% (11,469 ha) to 11.5% (35,766 ha), and 0.01% (31.2 ha) to 0.24% (756 ha) out of the total land area respectively. Vegetation cover, however, decreased generally from 96% to 88% during the ten year period. Overgrazing, abandonment and erosion most likely have resulted in a change in wooded grasslands and grasslands. Four land use types were identified ranging from intensified rain-fed agriculture on the mountain slopes, down slope expansion of sparse agriculture under a more extensive land use system, and extension of swamp-edge/riparian cultivation increasing in outside park tourism including campsites and wildlife sanctuaries. There occurred overall landscape fragmentation and changing numbers, diversity, and density of land cover patches due to changes in land use.

A large portion of the study area has been converted to small-scale agriculture, and some degraded in terms of vegetation resources as a result of overgrazing, failing to take into consideration the vulnerability of the range ecosystem. In sum, declining vegetation cover, formation of erosional sites, abandonment of cropping fields, declining water availability, and wildlife reduction in number and species diversity can be seen to be the outcomes of recent land use changes, settlement, expanding cultivation and changing climatic conditions within the study area. The Maasai pastoralists can now be seen to be expanding their small-scale agriculture into the swamps for their livelihood. However, it would be ironical to believe that this is a sustainable way of food production since the swamps will continue to diminish and dry off as cultivation continues. This land use change consequently will have negative impacts on the existing biodiversity which will in turn negatively affect pastoral strategies involving mobility and resource base, especially as more dry grazing zones disappear. This presents a questionable scenario for the survival of a pastoral production system considering the increasing human population pressure which will definitely seek more ways to increase food production.

Water Development and Wildlife

A GIS analysis of the impact of people on wildlife in Kajiado District was completed. The intention was to analyze the impacts of changes in land tenure on wildlife, but no land tenure data layer was available for this analysis. Instead, the team focused on the impacts of water development on the distribution and diversity of wildlife, comparing the semi-arid savanna in Kajiado to arid savannas in northern Kenya. In the arid savannas, human presence and livestock grazing and browsing excludes wildlife from within 5-10 km of water points, effectively reducing the abundance and diversity of wildlife in the region. In Kajiado, where forage is more abundant, wildlife and livestock strongly intermix with no exclusion of wildlife by livestock and people. We concluded that the impacts of water development are lower in wetter savannas, but that the strong intermixing of livestock and wildlife in these same savannas will lead to more frequent transmission of disease between livestock and wildlife, more people-wildlife conflicts, and more side-by-side competition of livestock and wildlife for forage.

Other Analyses

R. Boone has produced NDVI images and greenness profiles that D. Western and Boone are correlating with long-term data vegetation and animal counts Western collected in the Amboseli Basin. As in NCA, the resolution of NDVI data were matched to the area being summarized, so that 7.6 km NDVI was used to calculate a 20-year greenness profile for all of Amboseli Basin, 7.6 km and 4 km data were used to calculate profiles for landscape units within Amboseli, and 1 km resolution data were used to calculate profiles for the 18 individual sites where vegetation data had been collected.

DISCUSSION

The spatial layers described supported analyses in the GL-CRSP IMAS project, but also were merged with spatial databases in CSU, ILRI, and in outreach sites such as the Community Conservation Centre at the African Wildlife Foundation, Arusha, Tanzania (see *Chapter 10*). Thus, in addition to allowing the ecological questions cited to be addressed, institutional and local capacities to conduct spatial analyses were improved.

We have excluded model output from the list of spatial layers available to us, but note that the SAVANNA modeling system (see *Chapters 6* and *7*), the PHEWS socioeconomic modeling tool (*Chapter 8*), and the SIDRAM disease modeling tools (*Chapter 9*) each produce spatial and temporal output. For example, the SAVANNA model produces maps of dozens of variables (e.g., precipitation, herbaceous green biomass, tree cover, animal distributions, digestability of forage for each animal group, household densities, areas in cultivation), one map per month over the duration of the simulation (e.g., 15 years). Users must be aware of the assumptions and limitations of the given simulation models when using these layers in other work, but they do provide a wealth of information. For example, we used SAVANNA model spatial output showing the distributions and densities of cattle and wildebeest to estimate the number of cattle that would be infected with malignant catarrhal fever (see *Chapter 9*).

Plates 1 and 2

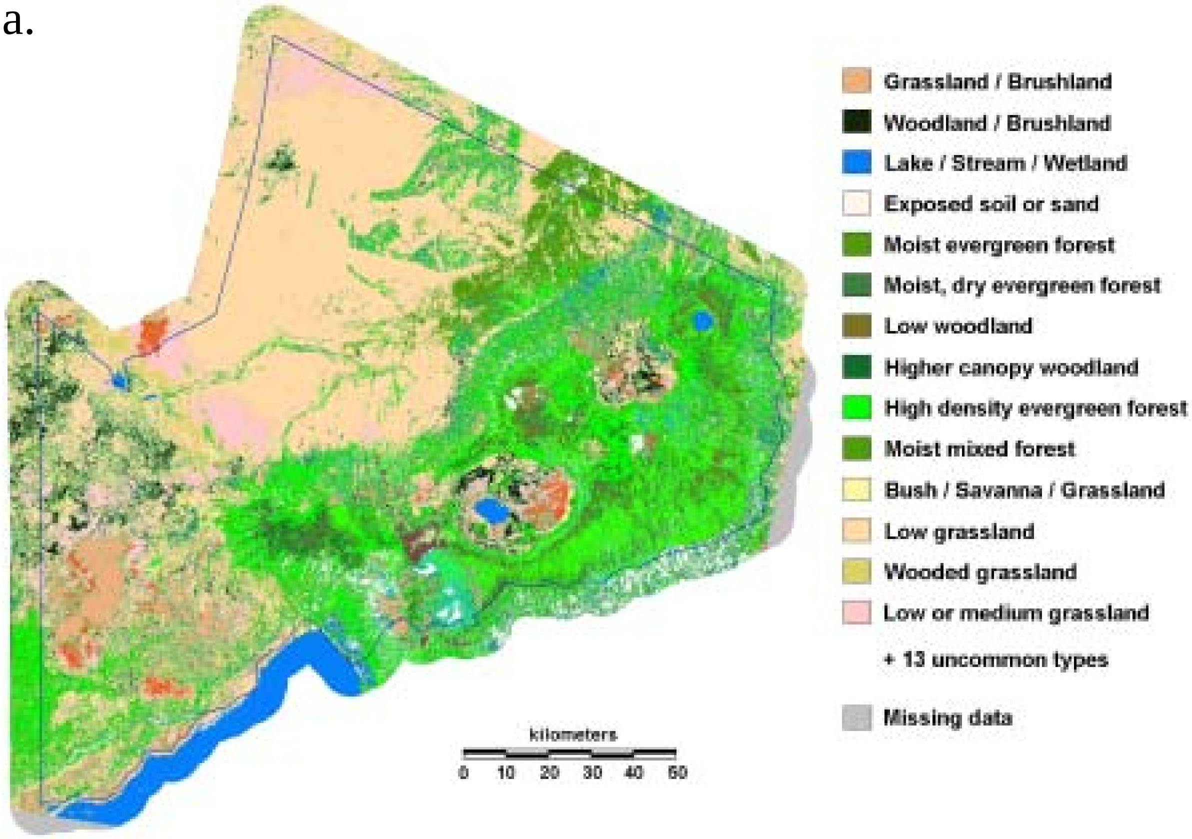
Plate 1 a. A land cover map created by M. Kalkhan (of NREL, CSU) using Landsat Thematic Mapper satellite images and existing land cover maps (e.g., Herlocker and Dirschl 1972). The map includes 27 land cover types. See *Chapter 5*.

Plate 1 b, c. F. Atieno (of ILRI, Nairobi) delineated and digitized land cover in the Amboseli Basin using prints from Landsat Thematic Mapper satellite images from 1988 (b) and 1998 (c). Land cover types were labeled using field data collected for the purpose and published sources. See Atieno (2000) for details. See *Chapter 5*.

Plate 2 a. Human population estimate and projections for the years 2000, 2020 (not shown) and 2040 were developed and compared to biological diversity represented by the number of large mammal species in natural areas, derived from databases from the Institute of Ecology, Rome, Italy. In 2000, human population densities were high in East and West Africa, but mammal diversity was relatively low in the west but high in the east. In 2040, human population densities in East Africa were pojected to be very high. See *Chapter 5*.

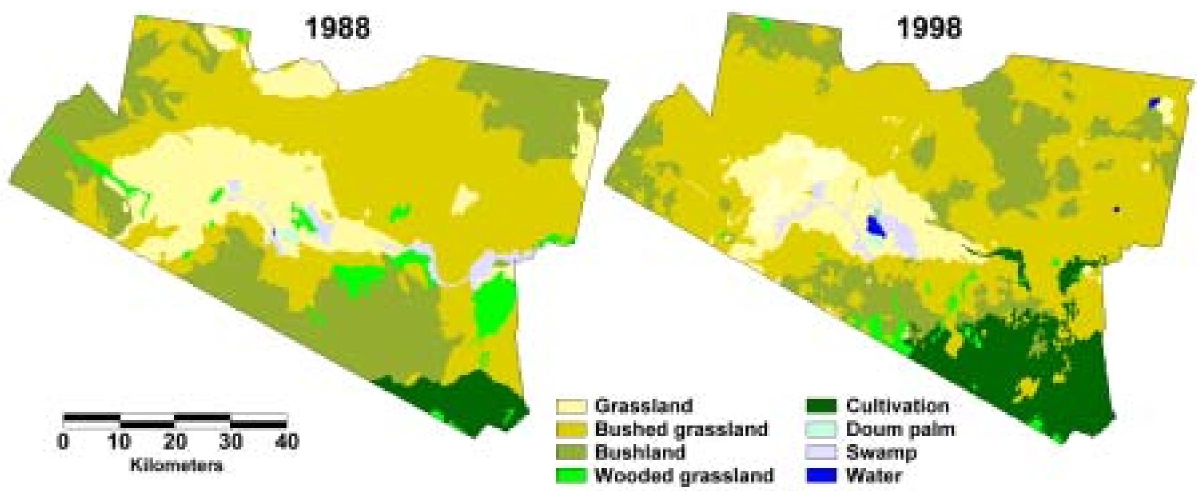
Plate 2 b. Study areas with land uses, in Kajiado District, Kenya. See *Chapter 8*.

a.



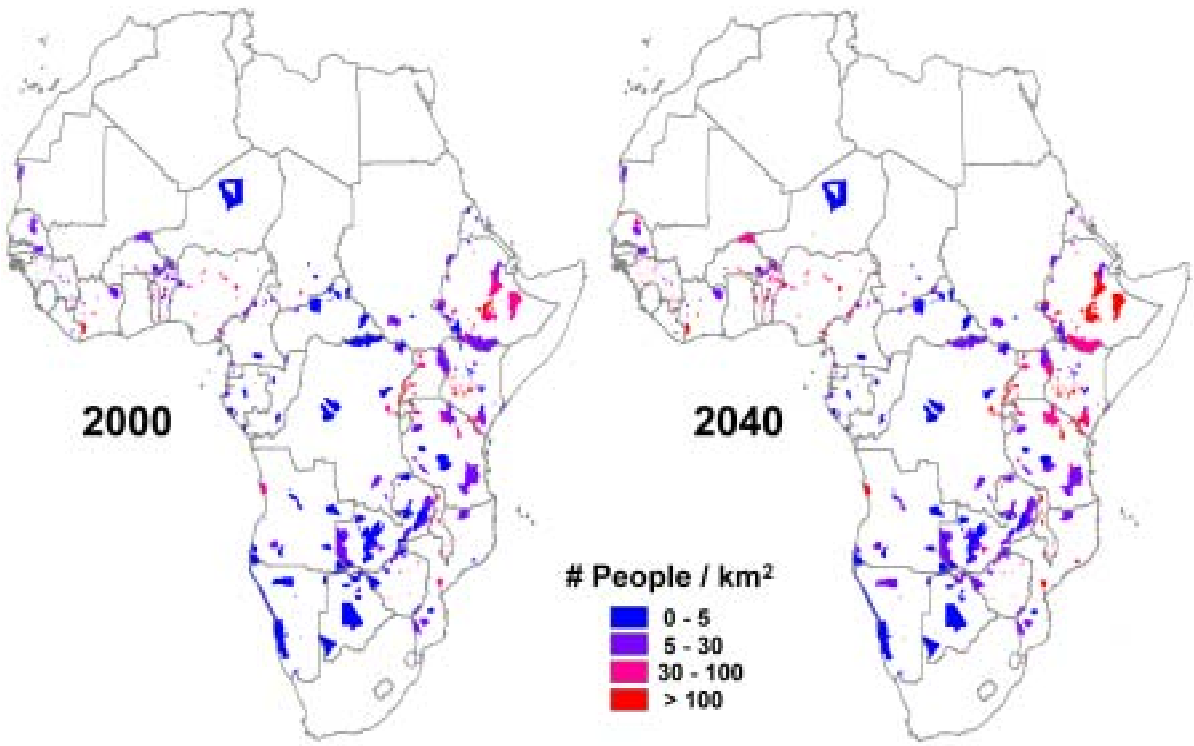
Grassland / Brushland
Woodland / Brushland
Lake / Stream / Wetland
Exposed soil or sand
Moist evergreen forest
Moist, dry evergreen forest
Low woodland
Higher canopy woodland
High density evergreen forest
Moist mixed forest
Bush / Savanna / Grassland
Low grassland
Wooded grassland
Low or medium grassland
+ 13 uncommon types
Missing data
kilometers
0 10 20 30 40 50

b. c.



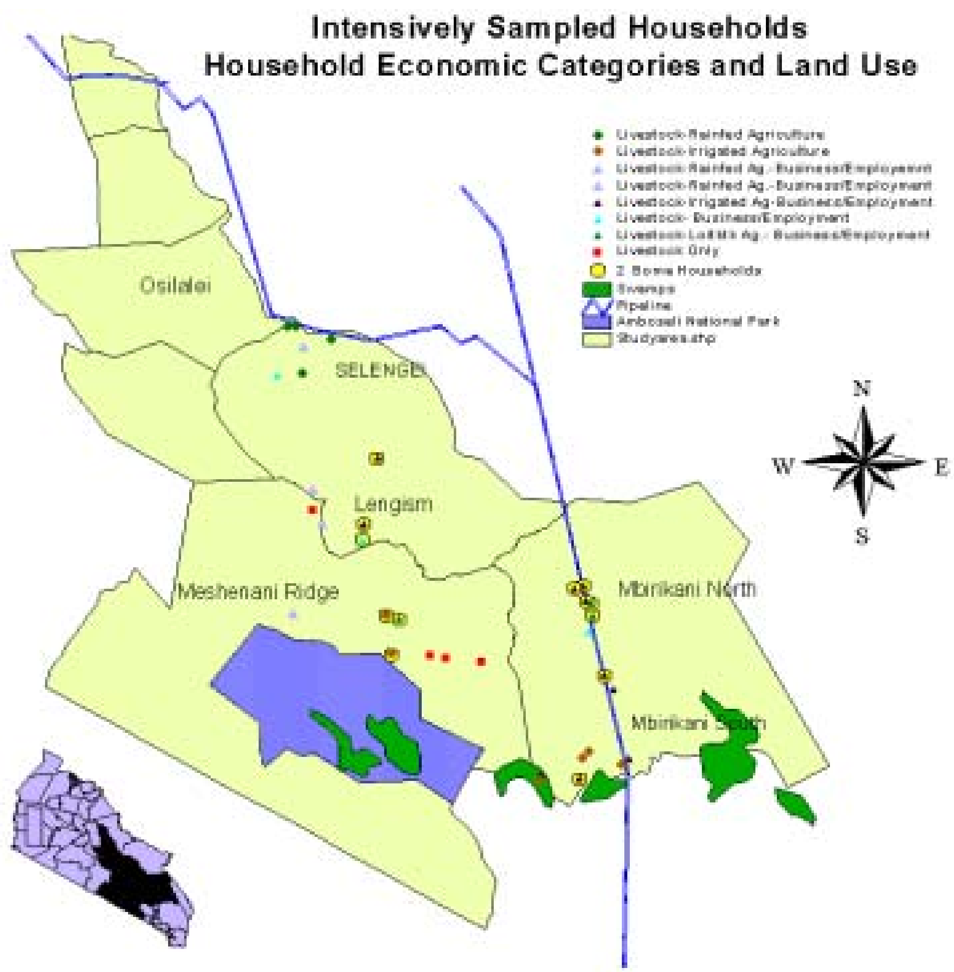
1988
1998
0 10 20 30 40
Kilometers
Grassland
Bushed grassland
Bushland
Wooded grassland
Cultivation
Doum palm
Swamp
Water

a.



2000
2040
People / km²
0 - 5
5 - 30
30 - 100
> 100

b.



Intensively Sampled Households
Household Economic Categories and Land Use
Livestock-Rainfed Agriculture
Livestock-Irrigated Agriculture
Livestock-Rainfed Ag.-Business/Employment
Livestock-Rainfed Ag.-Business/Employment
Livestock-Irrigated Ag-Business/Employment
Livestock- Business/Employment
Livestock Only
2 Boma Households
Swamps
Pipeline
Amboseli National Park
Studyarea.shp
Osilalei
SELENGEI
Lengism
Meshenani Ridge
Mbirikani North
Mbirikani South
N
W
E
S

Chapter 6

Modeling Tools of the Integrated Management and Assessment System

Randall B. Boone and Michael B. Coughenour

INTRODUCTION

Ecological modeling is used in the Integrated Management and Assessment System to allow users to address potential management questions. The system allows users to simulate putting management practices in place and interpret the results, allowing the users to anticipate important ecological and socioeconomic effects. As examples, users may simulate droughts and estimate ecosystem response or fine-tune the drought responses of pastoralists. The effect of adding water sources may also be simulated to estimate changes in range condition and herbivore populations.

The GL-CRSP IMAS includes five main components (Fig. 6.1) joined together to conduct these analyses. In the strictest sense, users need only understand the interfaces to the IMAS modeling tools (SavView and perhaps SMS), but a more thorough understanding of how the different modeling tools work together to simulate ecological and socioeconomic responses is helpful. Three of the components (SAVANNA, SMS, and SavView) are described below. The remaining components (PHEWS and SIDRAM) are cited briefly below, and described in-full elsewhere in this report.

MODELING TOOLS

The ecological modeling components of the Integrated Management and Assessment System are shown schematically in Fig. 6.1. The central model, SAVANNA, is linked programmatically to the PHEWS model, which models socioeconomic relationships, and to the SIDRAM model, which incorporates livestock and wildlife diseases. Very detailed output from these linked models is viewed by those adapting the system to a new area, and users if they wish to see detailed output, using SMS. Users that may not be experts in modeling interact with the system using the SavView interface. Explanations of each of these components follow.

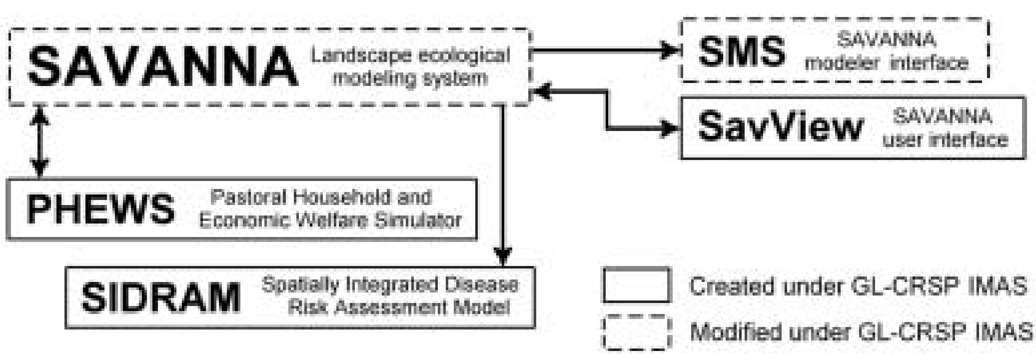


Figure 6.1. A diagram showing the relationship of the ecological and socioeconomic modeling tools of the Integrated Management and Assessment System, and how they are linked. Links between the interfaces SMS and SavView and the submodels are not shown.

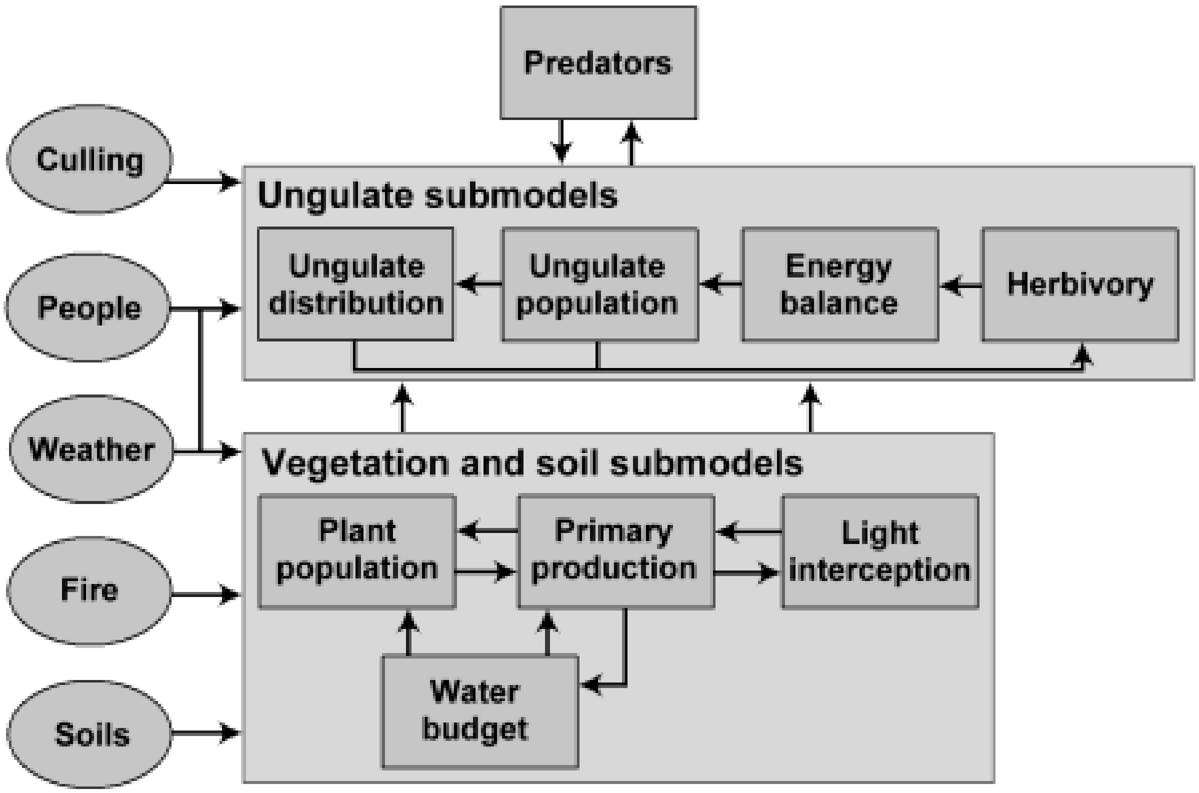


Figure 6.2. The SAVANNA ecosystem model represented as a flow-chart. The major components of the model and how they are linked are shown.

SAVANNA

The SAVANNA ecosystem model (Fig. 6.2) is a process-oriented model of carbon and nitrogen flows through three trophic levels, plant and soil water budgets, and plant and animal population dynamics. It is a spatially explicit multi-species model that simulates in time and space: (1) vegetation dynamics in terms of plant functional group competition, (2) plant production, (3) plant responses to climate, including seasonal patterns, (4) plant responses to herbivory and fire, and (5) animal and pastoral responses to their environment. The model assesses the state of the system once per week, and runs of 5 to100 years for landscape composed of 1,000 to 10,000 grid-cells are common. The model has been adapted for and validated, tested, and used in numerous grazing land sites in Asia, Australia, Africa (Ngorongoro Conservation Area, Tanzania, Kruger National Park, South Africa, South Turkana, Kenya) and North America (Yellowstone National Park, Rocky Mountain National Park, National Bison Range, Pryor Mountain Wild Horse Reserve, etc.). SAVANNA is linked to geographic information systems (GIS) data. GIS data inputs include maps of soils, vegetation, topography, land use, pastoralist density distributions, and livestock grazing ranges and watering points.

The plant growth submodel represents above and below ground biomass components, as well as plant nitrogen. Plant water use is central to the plant production submodel. The model simulates photosynthesis as a maximum rate, multiplied by effects of light, plant available soil moisture, plant nitrogen, photosynthetically active radiation, and temperature. Stomatal conductance is computed from photosynthesis rate, humidity, and CO_2. Photosynthate is allocated to plant parts based upon allometric rules and plant stresses. Dead tissues are partitioned to resistant and labile litter pools that enter the decomposer submodel. Plant population dynamics are dependent upon basal cover, seed banks, the resulting establishment and mortality, and are affected by water stress and temperature.

Animal submodels simulate foraging, energy balance, population dynamics, and spatial distributions. A diet selection submodel distributes herbivory among plant types and tissues within each grid-cell, with forage intake rate following a functional response and influenced by forage quality. Energy intake is the product of forage intake rate and forage digestible energy content. Energy use depends upon body size, gestation, lactation, temperature, and animal activity. Energy budgets are translated into weight gains and losses, which affect ungulate population dynamics. Ungulates are dynamically distributed in response to environmental conditions, such as green forage biomass, topography, woody cover, and distance to water. Distributions may be constrained by boundaries; for example, movement of animals among paddocks or seasonal grazing ranges can be prescribed at set times throughout a simulation.

SAVANNA was modified for GL-CRSP IMAS applications in several ways. Human population growth and cultivation were incorporated into the model, which included the addition of a module mapping households. The method used to inform SAVANNA of the distance to water sources was streamlined, and an option was added to allow herbivores to use specific water source maps. This modification allowed some water sources to be available to livestock and humans, but not to wildlife. A draft disease model was incorporated pending the inclusion of the SIDRAM model. In the draft model, livestock could succumb to a disease similar to East Coast Fever, a tick-born disease associated with high elevations and increased rainfall. Lastly, SAVANNA was modified so that wild herbivores will avoid the disturbance of humans and their livestock to a degree set by the modeler.

PHEWS

The *Pastoral Household and Economic Welfare Simulator* (PHEWS) uses a small set of rules to simulate the behavior of individual households. Pastoral, or agro-pastoral, households are categorized into three levels of wealth, each with some number of people and livestock, and perhaps some land under cultivation. In a simulation, the total livestock units (TLUs) per person are tracked, serving as the basic measure of the pastoral system. In addition, cash flows and energy flows are tracked through time. If energy flows fall below that required to maintain the health of household members, for example, rules are applied to guide household decisions. If TLUs are relatively high, livestock may be sold or slaughtered, or if the household cash box contains a surplus, maize may be purchased. In difficult times, the household may rely upon relief aid for a portion of its energy. For a full description of the PHEWS model, see *Chapter 8*.

The SAVANNA model is linked to PHEWS through variables that inform the socioeconomic model about the population size, condition, and age classes of livestock. PHEWS uses these data to estimate how much energy a household should gain from the milk-yield of animals, or from the meat of slaughtered animals, for example. The PHEWS model also uses a measure of rainfall provided from SAVANNA to estimate crop yield. The PHEWS model does not modify these numbers, except for the livestock population size, which is adjusted when animals are sold, slaughtered, or traded. Output files are created by the PHEWS model to be read by SMS, and spatial data are provided to SAVANNA to be written-out in a format usable by SMS.

SIDRAM

The *Spatially Integrated Disease Risk Assessment Model* (SIDRAM) simulates rates of disease infection and spread for selected livestock and wildlife diseases important in East Africa. The SIDRAM model simulated the rate of infection of adult cattle by the virus causing malignant catarrhal fever, which is carried by wildebeest calves. SAVANNA provided weekly estimates of wildebeest and cattle densities for each of the blocks into which the landscape had been divided. The SIDRAM model used estimates of the proximity of the two herbivores, the infectiousness of the disease, and exposure rates over time to estimate the number of cattle infected with malignant catarrhal fever for that time period.

The SIDRAM model also simulates the spread of a rinderpest outbreak amongst cattle. The study area, Ngorongoro Conservation Area, was divided into blocks, and the movement of cattle between blocks in each season was estimated. SAVANNA provided population estimates of cattle for each of the blocks, and methods similar to those used for malignant catarrhal fever were used to estimate infection rates. However, these estimates of infection rates were influenced by the numbers of animals moving into a given block that were already infected with rinderpest. For a full description of the SIDRAM model, see *Chapter 9*.

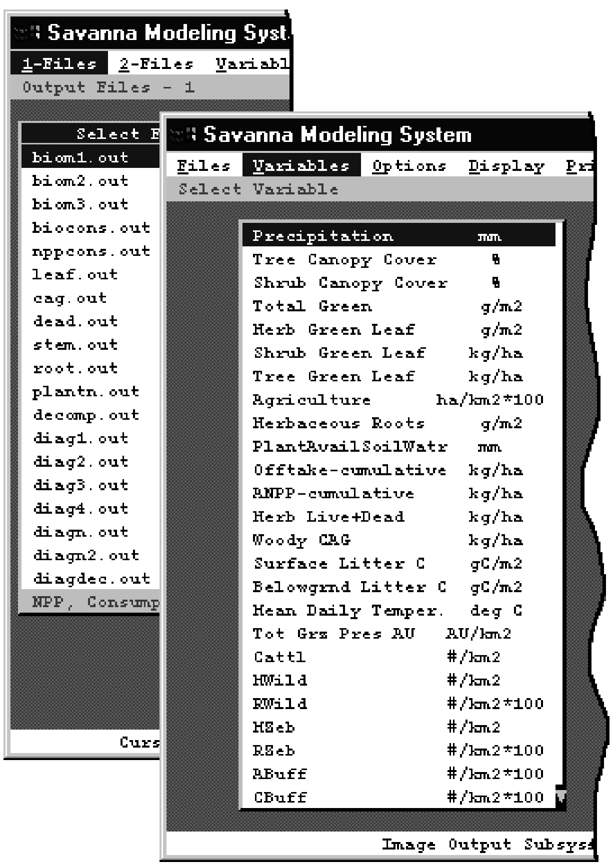


Figure 6.3. Example menus from SMS, showing detailed SAVANNA output that may be viewed as charts (back) or maps (front).

SMS

The name SMS (SAVANNA Modeling System) was given to an interface that has been used to interact with SAVANNA. In IMAS, SMS is used by ecosystem modelers to look at SAVANNA results in great detail (Fig. 6.3). For example, using SMS, an ecosystem modeler (or a user wanting more detail than SavView provides) may make charts showing changes in the biomass of vegetation types being modeled, their components, such as leaves, stems, and roots, or changes in the populations and body conditions of herbivores. A suite of detailed diagnostic outputs may be plotted as well (Fig. 6.3). SMS also creates maps from SAVANNA output, allowing users to view spatial changes over time in precipitation, plant biomass, herbivore distributions, and dozens of other variables (Fig. 6.3).

SMS was modified under the GL-CRSP IMAS to include information required for modeling cultivation and human population growth. Changes to files that SMS read to format output correctly for each area in which SAVANNA was adapted were also modified.

SavView

A graphical user interface called SavView was constructed for use with SAVANNA. The SAVANNA modeling system is powerful, but its direct use requires understanding some 50 parameter files and how the system references them. For example, to conduct an analysis that changes the cattle population and how it is modeled may require careful adjustment of values in three parameter files [i.e., dens.dat, simcon.prm, and cull.prm; see Boone (2000) for details]. SavView makes those adjustments automatically, eliminating the need for expert knowledge to conduct experiments. SavView follows Windows© program standards, allowing users with experience in other Windows© programs to correctly anticipate how to use SavView without referring to the supporting documents. Also, SavView was written in a popular programming language, Microsoft's Visual Basic (Redmond, Washington, USA), making updates straightforward.

The interface essentially includes three sections. The first, a parameters section, allows users to change parameters to address a given management question (see Fig. 6.4 for examples), the second shows charts depicting changes in trends over time (Fig. 6.5), and the third shows maps of changes in spatial patterns over time (Fig. 6.6). Each section makes use of an 'explorer' style similar to that in Microsoft's Windows Explorer. The parameters section, for example, presents a window with the default parameter settings (herbivore populations) shown to the right, and an explorer tree to the left, allowing the user to choose other parameter types to adjust. The charting section shows attributes that can be added to a chart, and the mapping section shows attributes that can be mapped.

In practice, managers using the IMAS tools to anticipate some consequences of a proposed practice would make changes to the settings used in SAVANNA displayed under the parameters section of SavView, run the SAVANNA model, then use the charting and mapping sections to view the results. The settings used for each simulation are saved in a format appropriate for SavView, so that a record of analyses conducted may be maintained.

SavView was written to be flexible, so that the interface can be adapted to new areas with relative little of the interface requiring changes. A comprehensive on-line manual describing some details of the SAVANNA model and the use of SMS and SavView is available (Boone 2000). In addition, a streamlined version of the manual

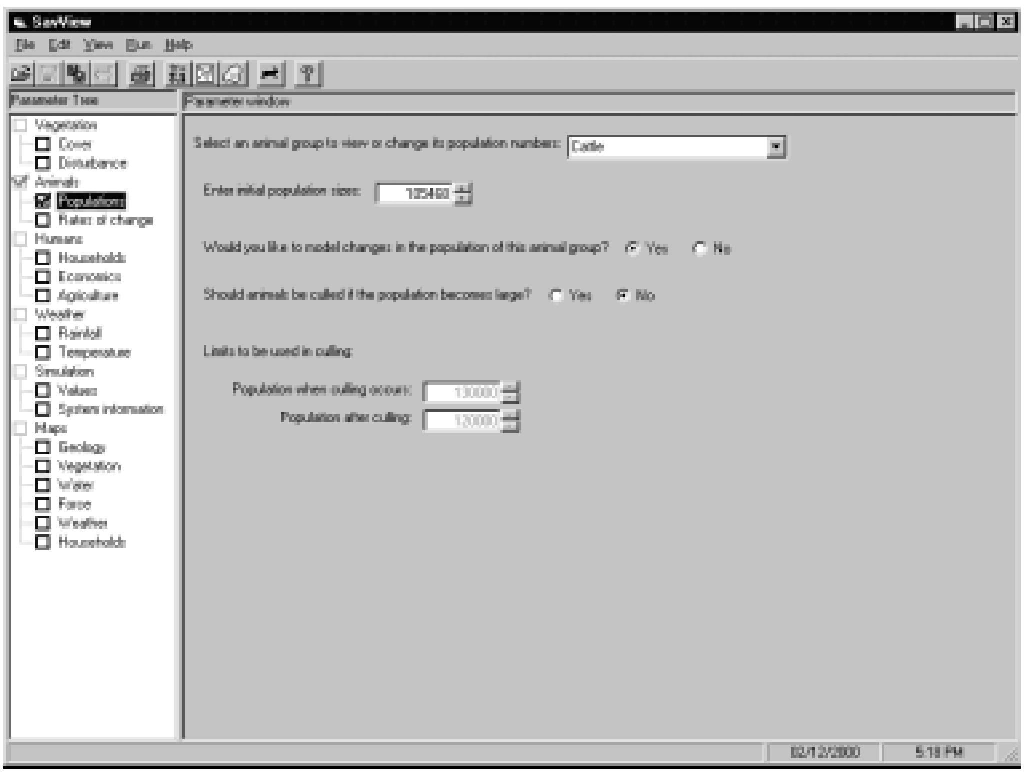


Figure 6.4. The parameter section of the SavView graphical interface to SAVANNA, which allows non-experts to conduct experiments. The window shown allows users to change livestock and wild herbivore populations and to set population modeling methods. Other windows allow users to modify: (1) population rates of change, representing changes in animal survival; (2) household and cultivation settings; (3) rainfall attributes that might represent droughts, for example; (4) maps representing changes to water source; and (5) maps representing change to areas in which herbivores are allowed to graze.

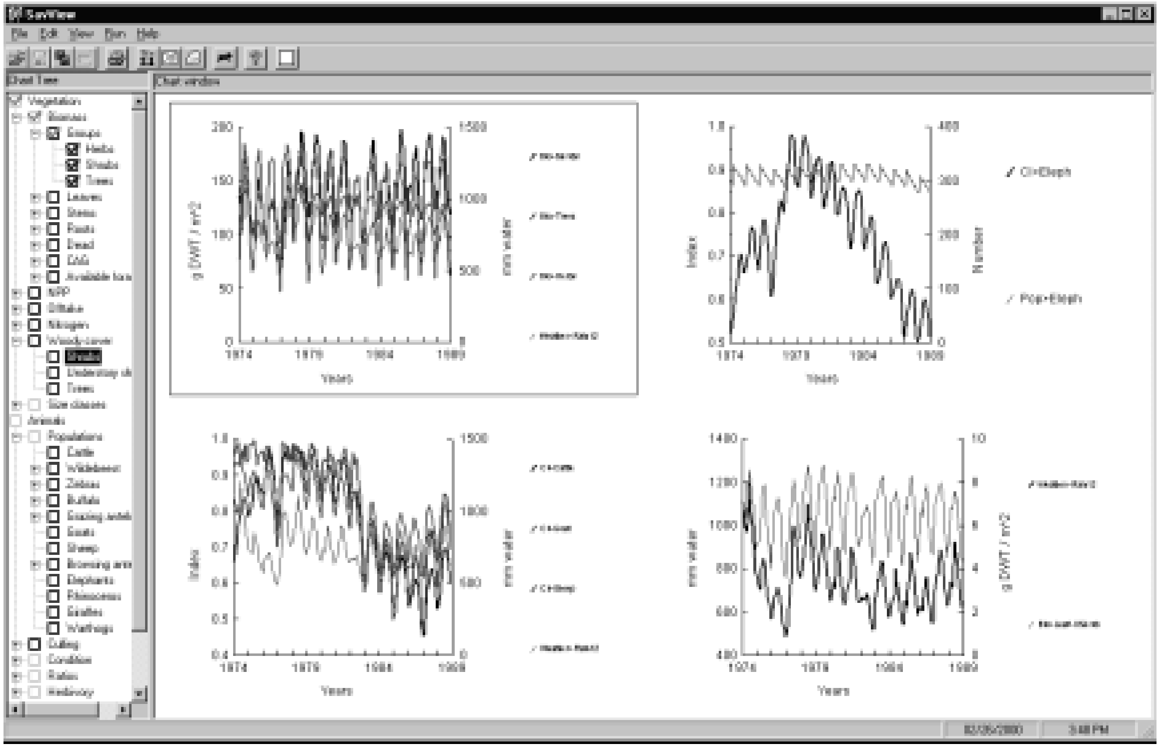


Figure 6.5. The charting section of the SavView graphical interface to SAVANNA. From one to four independent charts may be displayed, mapping different types of information. Each chart may include an overlaid data type.

containing the information about SAVANNA, SMS, and SavView that would be of interest to an end-user of the ecosystem modeling component of IMAS was compiled (Boone and Coughenour 2000).

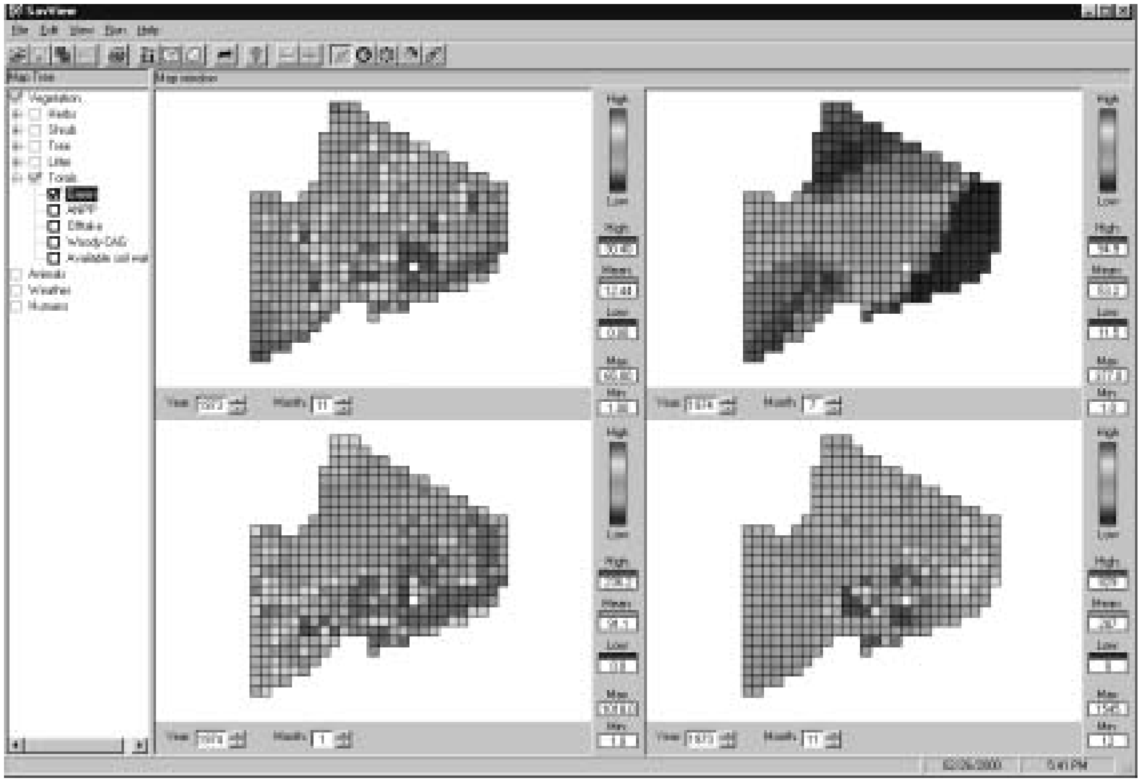


Figure 6.6. The mapping section of the SavView graphical interface to SAVANNA. From one to four independent themes may be mapped simultaneously with up to twelve maps shown. For example, with a single theme shown, up to twelve months of output may be viewed. SavView will animate maps by month or year, under the control of the user..

Chapter 7

Using GL-CRSP IMAS to Address Potential Management Questions in Ngorongoro, Tanzania and Kajiado, Kenya

Randall B. Boone, Michael B. Coughenour, Kathleen A. Galvin, and James E. Ellis

INTRODUCTION

Land managers, such as the Ngorongoro Conservation Area Authority and Kajiado Group Ranch committees, have the complex task of balancing competing demands for resources and attempting to improve upon the problems outlined in *Chapter 2*. Managers need tools that allow them to assess the effects of pending management decisions that might affect livestock and wildlife populations, limitations on grazing or cultivation, for example. We adapted the SAVANNA modeling system to Ngorongoro Conservation Area (NCA) and the southern half of Kajiado District, Kenya, including Amboseli National Park (Figure 7.1). These adaptations allow land managers and other stakeholders to estimate potential effects from management options, with the results forming a common foundation for discussions and decision making.

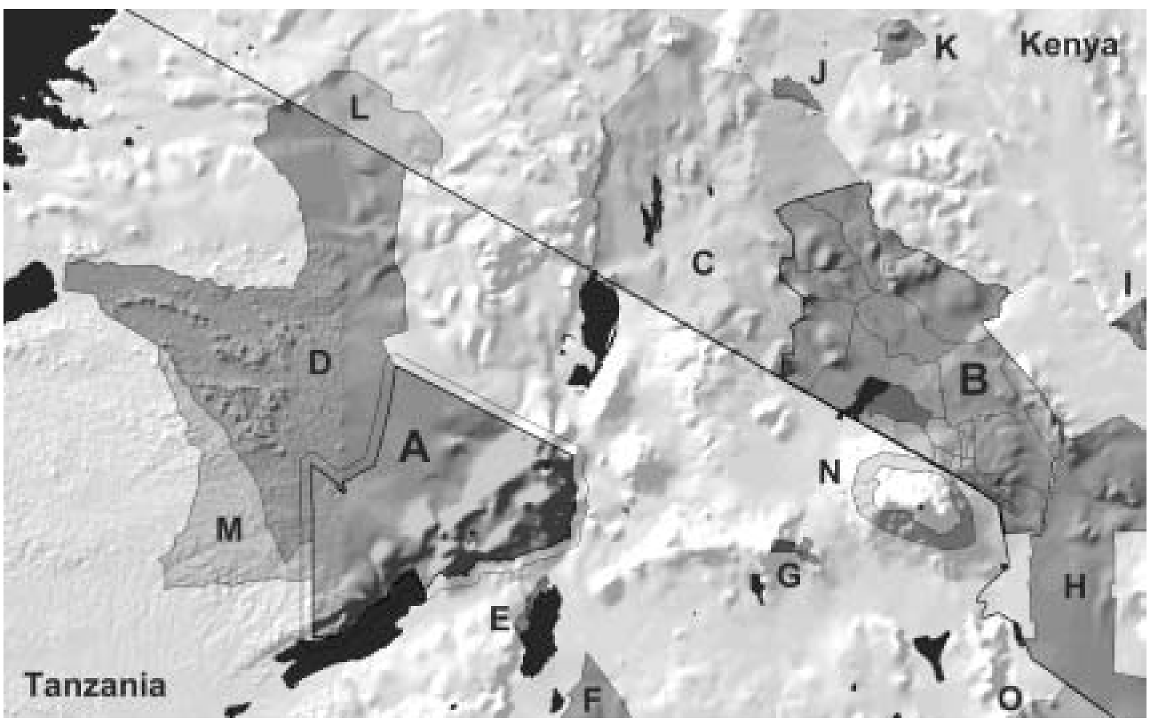


Figure 7.1. The focal region of GL-CRSP IMAS. The study areas modeled were Ngorongoro Conservation Area, Tanzania (A) and areas within five km (line), and Kajiado District, Kenya (B), with Amboseli National Park shown in a darker shade in the south-central portion of our study area. The northern portion of Kajiado (C) was not modeled. Additional national parks include the Serengeti (D), Lake Manyara (E), Tarangire (F), Arusha (G), Tsavo West (H), Tsavo East (I), Nairobi (J), and Sapuk (K). Game reserves are Maasai Mara (L), Maswa (M), Kilimanjaro (N), and Mkomazi (O).

There were three primary modeling efforts in the GL-CRSP IMAS Program, including the use of SAVANNA in ecosystem modeling, socioeconomic modeling, and livestock and wildlife disease modeling. This chapter reports on the first effort with the socioeconomic component reported in *Chapter 8* and disease modeling in *Chapter 9*. The socioeconomic model has now been incorporated into SAVANNA, for example, but when these analyses were conducted, that component was not part of the model. Thus, this chapter reports on simplified methods to model human populations, cultivation, and wildlife diseases rather than the full models constructed under GL-CRSP, which are reported in the chapters cited.

In this chapter, we briefly review our modeling methods, then present results for a series of potential management questions for each of the adaptations. The questions are not an exhaustive list; many other questions may be addressed using the IMAS tools. Instead, we have addressed these management questions to demonstrate the flexibility of the system.

MODELING METHODS

The SAVANNA Modeling System was introduced in *Chapter 6*, which includes a diagram showing the major components of the model and cites its use around the globe. Briefly, SAVANNA is a series of interconnected computer programs that model primary ecosystem interactions in arid and semi-arid landscapes. SAVANNA is spatially explicit, meaning here that the landscapes modeled are represented by a cell-based grid. Within each cell, a series of plant and animal functional groups (i.e., species or groups of species) are modeled, and components of plant functional groups are further split into layers, such as upper and middle canopy layers, and upper, middle, and lower soil layers.

The model predicts water availability to plants based on rainfall and soil properties. For each plant functional group in each cell, primary production is estimated using water, light, and nutrient availability. From production, SAVANNA calculates plant populations and their dynamics. During each weekly time-step of the SAVANNA model, herbivores are distributed according to habitat suitability, and animals feed on available vegetation, depending upon dietary preferences and consumption rates. Energy is tracked through herbivores, with balances affected by metabolism, gestation, and lactation. Population dynamics are also tracked. Changes in vegetation, herbivore, climate, and human resident patterns across time and space are reported each month of the simulation. For more detail about SAVANNA, see Ellis and Coughenour (1998) and Boone et al. (in press).

Ngorongoro Conservation Area

We included in the model NCA, at 8,288 km^2 and areas within five km of NCA (Figure 7.1), bringing the total area modeled to 10,075 km^2. M. Kalkhan, Colorado State University, created a vegetation map for the area based upon Landsat Thematic Mapper data and existing information (e.g., Herlocker and Dirschl 1972), which was simplified to 15 vegetation types. Elevation, slope, and aspect were calculated from a digital elevation model from the US Geological Survey (USGS). Soil information came from a map by USGS, based upon another by the Food and Agriculture Organization of the United Nations. Water sources and restrictions on grazing were based upon authors within Thompson (1997) and expert review. These GIS layers were generalized to two resolutions with each cell 1 x 1 km and 5 x 5 km. The results presented here are from 5 x 5 km analyses, which were very similar to those from the finer resolution.

When adapting SAVANNA to an area, the modeler must decide upon appropriate functional groups to include, based on the management questions of interest. In NCA, we used 7 plant functional groups and 17 animal functional groups that included 11 species (Table 7.1). In the control model, we included 105,202 cattle, 130,000 goats, and 60,000 sheep (Machange 1997; Thompson 1997). Wildebeest populations were about 900,000, and about half moved onto

Plants
- **Herbs**
  - Palatable grasses
  - Palatable forbs
  - Unpalatable herbaceous
- **Shrubs**
  - Palatable shrubs
  - Unpalatable shrubs
- **Trees**
  - Evergreen trees
  - Deciduous woodlands

Animals
- **Livestock**
  - Cattle
  - Goat
  - Sheep
- **Wildlife**
  - **Migratory**
    - Wildebeest
    - Zebra
    - Grazing antelope
  - **Resident**
    - Wildebeest
    - Zebra
    - Grazing antelope
  - **Crater**
    - Buffalo
    - Browsing antelope
  - **Area**
    - Buffalo
    - Browsing antelope
    - Elephant
    - Rhinoceros
    - Giraffe
    - Warthog

Table 7.1. Functional groups used in the NCA-SAVANNA application. Migratory wildlife are on NCA only during the wet season, peaking in April. Wildlife under 'Area' are populations outside Ngorongoro Crater, and 'Crater' populations are restricted to the crater. Migratory grazing antelope are Thomson's gazelles (*Gazella thomsoni*), and browsing antelope are several species.

NCA during the peak breeding season (A.R.E. Sinclair, pers. comm.). These 450,000 wildebeest were joined by 66,000 zebra and buffalo, 156,000 grazing antelope, 14,000 browsing antelope, 320 elephants and rhinos, and 1,700 giraffes. Other parameters too numerous to cite were set in the model, based on a literature review, previous applications (e.g., Coughenour 1992; Kiker 1998), fieldwork associated with the IMAS project, and expert opinion. Soil attributes, climate and disturbance data were incorporated into the model. Climate information was available from 1963 to 1992, and we selected a 15-year period (1973 to 1988) to model. Note, however, that data on human and herbivore populations represent current conditions, so the period of simulations are designated 0 to 15 years.

We created and assessed a control model (see Boone et al., in press for assessment), designed to represent conditions in NCA in the late 1990s. We then conducted a series of experiments and compared the results to the control model. Note that the control model was intended to emulate current conditions, but only in selected ways. For example, cultivation occurs on NCA, but the control does not include cultivation. This allows us to make more straightforward comparisons in experiments, comparing some level of cultivation against none.

Southern Kajiado District

The landscape used in the Kajiado application of SAVANNA included the southern half of Kajiado District (Figure 7.1), an area of 10,732 km^2. A vegetation map (3,112 km^2) of the Greater Amboseli Ecosystem created by F. Atieno (Atieno 2000) of the International Livestock Research Institute (ILRI), was used as a dependent variable in a classification tree analysis (Breiman et al. 1984). Fifty independent variables (e.g., NDVI vegetation greenness profiles, soils, slope, coarser land cover maps) were used to predict the occurrence of vegetation types in the map. The resulting classification tree was used to extrapolate results across the entire area, yielding a predicted vegetation map for the study area. For the area mapped by Atieno, the agreement between the original and derived map was good [Cohen's Kappa statistic, 0.6333 (Landis and Koch 1977)]. Detailed soils information came from a map of soils for the Amboseli Ecosystem compiled by the Kenya Ministry of Agriculture and the Ministry of Tourism and Wildlife. We augmented that map using the "Soils and Terrain Database" compiled by the Republic of Kenya in 1995. Elevation, slope, and aspect were generalized from a detailed digital elevation model created at ILRI. Draft water source maps were generated from water sources provided to ILRI from the Ministry of Agriculture. These GIS layers were generalized to three resolution, with each cell 1 x 1 km, 2.5 x 2.5 km, and 5 x 5 km. To-date, analyses have only been conducted at the 5 x 5 km resolution.

In the Kajiado District application, 7 plant functional groups and 11 animal functional groups were used (Table 7.2). The plant groups include swamps, which were modeled in SAVANNA by simulating an extremely shallow water table. In the control model, we included 150,000 cattle, 220,000 goats, and 180,000 sheep. In addition, we included 15,000 wildebeest, 16,000 zebra, 1,400 buffalo, 4,025 grazing antelope, 18,855 browsing antelope, 4,000 giraffes, 500 warthogs, and 900 elephants. These values were extracted from charts in de Leeuw et al. (1998) reporting Kajiado herbivore numbers and corrected for our smaller study area. We also used wildlife estimates provided by the Kenyan Department of Resource Surveys and Remote Sensing (DRSRS) and compiled by M. Waweru (ILRI and DRSRS). DRSRS also provided herbivore distribution data based upon aerial surveys which were summarized by M. Waweru. We created maps of animal distributions, then compared them to our simulated animal distributions to ensure realism. Other parameters were set based upon the existing NCA-SAVANNA application, other applications (e.g., Coughenour 1992; Kiker 1998), field work associated with the IMAS project, including vegetation surveys by F. Atieno, and expert opinion.

- **Plants**
  - **Herbs**
    - Palatable grasses
    - Palatable forbs
    - Unpalatable herbaceous
    - Swamps
  - **Shrubs**
    - Palatable shrubs
    - Unpalatable shrubs
  - **Trees**
    - Deciduous woodlands
- **Animals**
  - **Livestock**
    - Cattle
    - Goat
    - Sheep
  - **Wildlife**
    - Wildebeest
    - Zebra
    - Buffalo
    - Grazing antelope
    - Browsing antelope
    - Elephant
    - Giraffe
    - Warthog

Table 7.2. Functional groups used in the Kaj-SAVANNA application. Grazing and browsing antelopes include several species.

Climate information was available from 1969 to 1998, and we used a 15-year period (1978 to 1993) that had a range of climatic responses in our simulations. As in NCA-SAVANNA, because the model was parameterized to represent current conditions as much as possible, years are labeled 0 to 15.

We used three experiments to demonstrate the utility of the GL-CRSP IMAS tools in Kajiado District. These experiments reflect changes in ownership patterns as group ranches were put in place, the effects of isolating Amboseli National Park, and the use of the swamps in the system. Many other questions could be explored; these were selected as a brief demonstration only.

RESULTS FROM SIMULATION EXPERIMENTS

Ngorongoro Conservation Area

We conducted 16 analyses using the NCA-SAVANNA application which reflected management questions under six broad categories: 1) changes in rainfall, 2) changes in livestock populations, 3) improvements in veterinary practices, 4) altered access to grazing areas, 5) changes in water supplies, and 6) changes in human populations and associated cultivation. The following sections summarize the results of each of these experiments.

Changes in Rainfall – Drought

Our initial experiment explored how the simulated system would respond to a drought. Droughts are a common occurrence in the Serengeti Ecosystem influencing the dynamics of the system and the Maasai inhabitants (Galvin et al., in press). We represented drought by reducing rainfall during years 9 and 10 of the simulation (i.e., 1983 and 1984) by 50% (Figure 7.2). In general, the simulated ecosystem responded as expected to drought. Vegetation biomass decreased during the simulated drought with shrub biomass, averaged over the entire study area, declining from 150 g/m^2 to 100 g/m^2 (Figure 7.3). Green leaf biomass declined by one-third during the dry season. Annual net primary productivity for palatable grasses decreased by 50 g/m^2, for example (Figure 7.4). The number of cattle declined by about 20,000 animals as a result of the simulated drought.

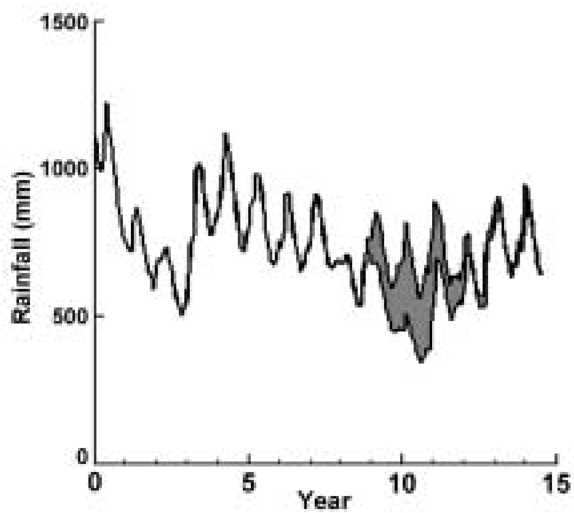


Figure 7.2. Rainfall was decreased by 50% in years 9 and 10 to explore the response of the model to drought. The shaded area highlights the change put in-place in rainfall.

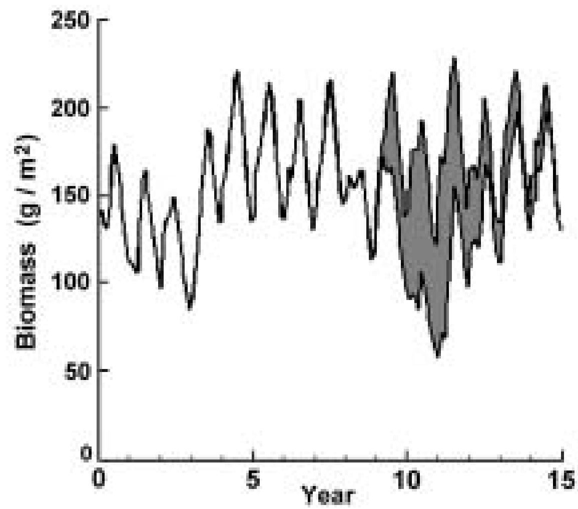


Figure 7.3. A reduction in shrub biomass across the study area, in response to a drought in years 9 and 10. The decrease in shrub biomass is shaded for emphasis.

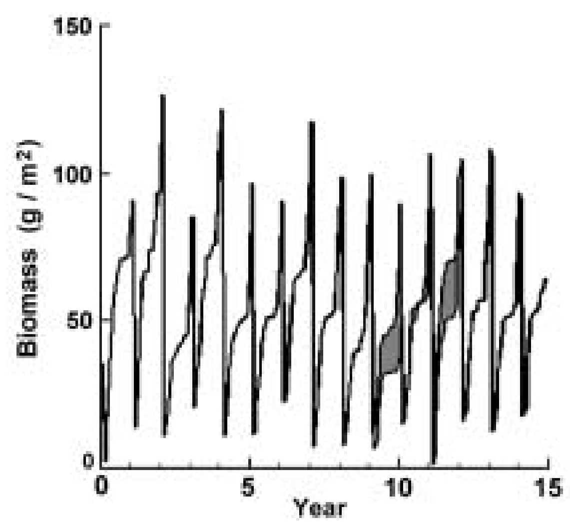


Figure 7.4. A decrease in accumulated annual net primary productivity in response to a drought in Years 9 and 10.

Changes in Rainfall – Rainfall Pattern

Residents and ecologists have noted that the distribution of rainfall during the year can influence ecosystem status as much or more than total rainfall (Ellis and Galvin 1994). For example, IMAS team members that had worked in the Turkana District of Kenya noted that years in which rainfall was more evenly distributed had more forage production than wet years in which heavy rains fell in a single month.

To conduct an experiment reflecting this observation, we modified observed rainfall removing 1% of rainfall from the five wettest months and adding 1% of rainfall to the five driest months (Figure 7.5). That is, there is an average monthly distribution of rainfall in Ngorongoro Conservation Area averaged over 30 years of rainfall measures (the open circles in Figure 7.5). We altered the distribution of rainfall throughout the year for all years. That modification made comparisons between results from this experiment and the control model invalid. We therefore generated another rainfall data set that had the average annual rainfall pattern (the open circles from Figure 7.5)

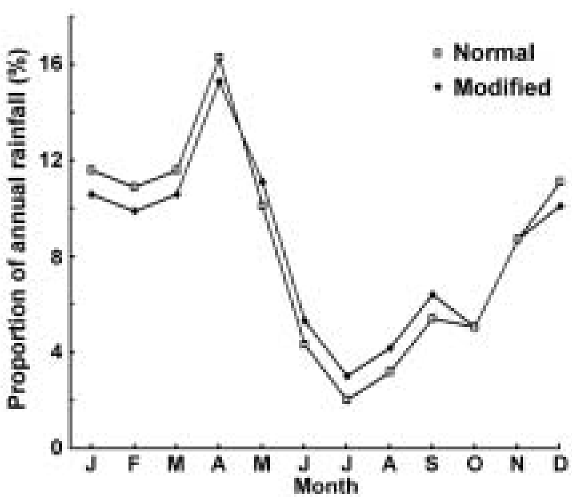


Figure 7.5. A change in the average proportion of annual rainfall occurring in each month, put in-place to explore the effects of more even rainfall on the NCA-SAVANNA results. For the five wettest months, 1% of rainfall was removed, and 1% of rainfall was added to the five driest months.

applied for every year, with each year still retaining its observed quantity of rainfall. A simulation was run using that rainfall data, and the results served as a control model for use in this experiment only. (These details added rigor to our comparisons, but in practice, the results for the normal control model and this control model were very similar. Apparently, the monthly variations in rainfall across years were not important influences in the NCA-SAVANNA model.) Finally, the experimental rainfall data were generated by removing 1% of rainfall from each May, June, July, August, and September, and adding 1% to each December, January, February, March, and April. Overall, within the limits of rounding errors, the amount of rainfall in each year remained the same in the experiment and control simulations.

The relatively minor modifications in the pattern of rainfall reflected in Figure 7.5 had a dramatic effect upon the simulated results from NCA-SAVANNA. There was a large increase in dry-season green biomass (e.g., Figure 7.6a versus Figure 7.6b). Some wildlife populations increased markedly (Table 7.3), with browsing antelope outside the crater increasing 49% and warthogs 31%, for example. Small livestock increased as well, by a moderate amount (Table 7.3). Cattle populations declined; in-part the moderate population changes in livestock were due to a mortality source being included to emulate tick-born diseases (see *Chapter 6*). Mortality increased if livestock inhabited areas of high elevation or of increased rainfall. In the experiment, total annual rainfall was the same as the control, but there were more wet months.

Here we quantified straightforward changes in the NCA ecosystem to introduce the types of output available and the appropriateness of the responses. However, the GL-CRSP IMAS tools may be used to fine-tune Maasai response to drought. Livestock may be scheduled to move about the landscape in predetermined patterns, with those patterns modified to optimize resource use during a drought.

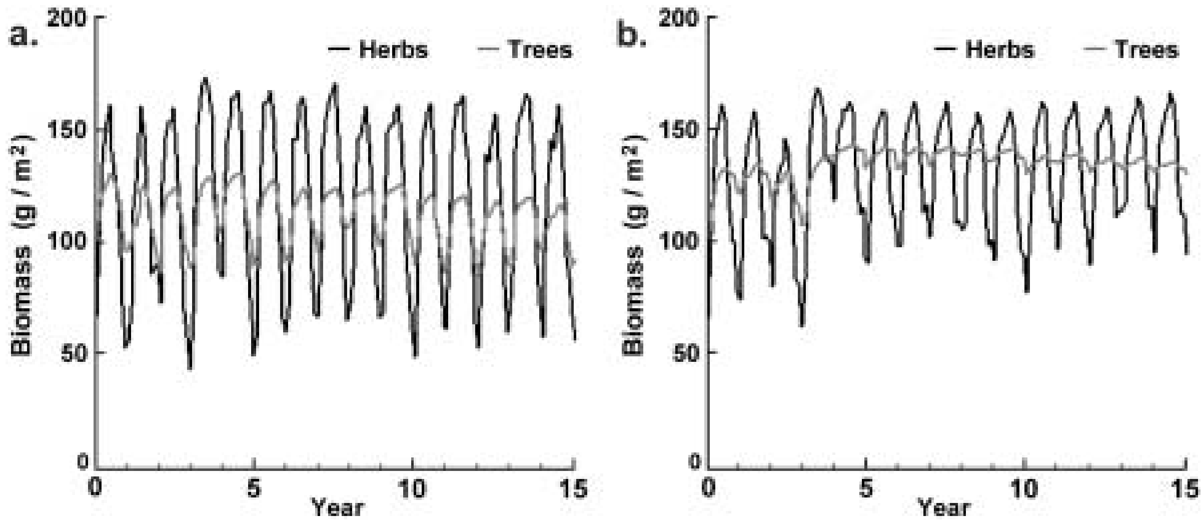


Figure 7.6. Biomass estimates in the control model (a) show large changes in standing herbs and trees, with herbs declining to 50 to 70 g/m^2 during the dry season (including grasses of the Ngorongoro Highlands, which is less arid). When small changes were made to balance rainfall more evenly throughout the year (b), standing biomass increased significantly. Herbs in the dry season, for example, remain > 100 g/m^2 in most years.

Animal group	Change (%)
Livestock	
Cattle	-9.34
Goat	6.36
Sheep	6.02
Wildlife	
Resident	
Wildebeest	0.00
Zebra	16.61
Grazing gazelle	10.88
Crater	
Buffalo	4.94
Browsing antelope	5.23
Area	
Buffalo	3.61
Browsing antelope	49.24
Elephant	4.43
Rhinoceros	2.45
Giraffe	9.60
Warthog	30.80

Table 7.3. Percentage changes in animal populations when rainfall is more balanced. Migratory animals are not shown because their populations were not modeled.

Increased Livestock Populations – Populations changing

The numbers of livestock in Ngorongoro Conservation Area have been relatively stable over the last 40 years (Kijazi et al. 1997), although there has been a shift toward pastoralists keeping more small stock. The most recent population estimate for cattle (117,300) and small stock (164,049) from NCAA (1999), continues a variable, but relatively flat, trend for cattle and suggests a leveling-off in the population for small stock over the long term (Kijazi et al. 1997).

Although livestock populations have been relatively stable, the human population has not. Human populations have increased at an annual rate of approximately three percent (NCAA 1999) due to improved health care, etc., but also because of immigration. Because of this, in NCA the number of animals per person (measured in tropical livestock units) has fallen below (Lynn 2000) the value commonly taken to represent the minimum needed to maintain a pastoral lifestyle (Dahl and Hjort 1976; Galvin 1992). There are, therefore, pressures and ongoing efforts to increase livestock populations in the NCA (Sorensen and Moshi 1999). We used the IMAS tools to assess potential ecological effects of increasing the number of livestock on NCA. Livestock populations were increased by 50%, with cattle going from 105,468 to 158,202, goats from 130,000 to 195,000, and sheep from 63,000 to 94,500.

When simulated, livestock populations remained relatively stable until a dry period in the 1980s. Then cattle populations declined sharply (Figure 7.7), with smaller declines in goats and sheep (Figure 7.7). Declines are evident as well in the condition indices of the livestock (Figure 7.8), which summarize the body weights of individuals in the population and compare the result to an ideal range. Changes in vegetation offtake were evident, with offtake declining after the declines in livestock (Figure 7.9). Wildlife populations decline with more livestock present (e.g., resident zebra -47%, area buffalo -55%, resident grazing antelope -26%, elephants -54%, and warthog -50%), in part, because in the simulation wildlife avoid, to a degree, areas occupied by pastoralists and their livestock. Other wildlife populations (resident wildebeest, crater buffalo, crater browsing antelope, rhinoceros, giraffe) show little or no change because livestock are excluded from their grazing areas or there is little overlap in diets.

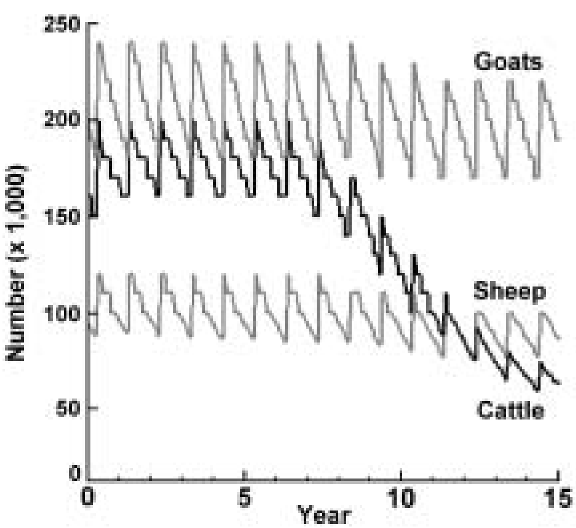


Figure 7.7. When livestock populations were elevated 50%, cattle populations declined sharply during a dry period.

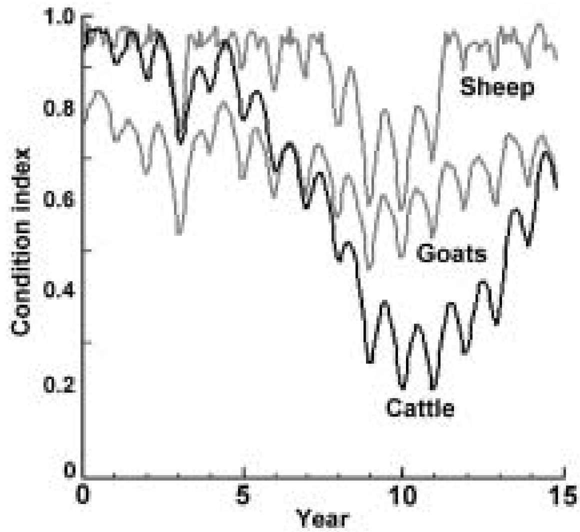


Figure 7.8. When livestock populations were elevated 50%, livestock condition indices declined sharply during a dry period.

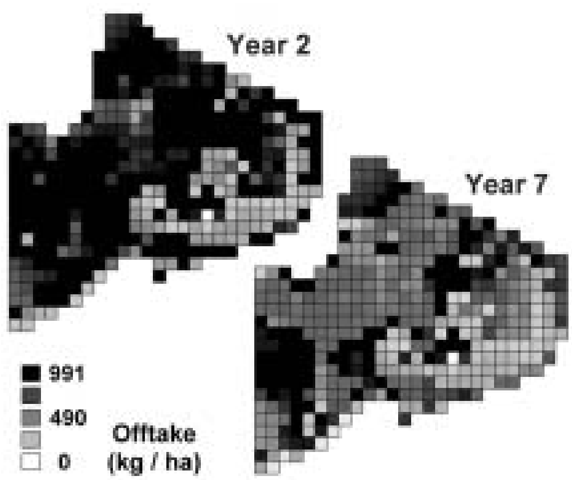


Figure 7.9. Annual accumulated offtake declined following the collapse in the numbers of cattle on the system.

Increased Livestock Populations – Populations Constant

It seems unlikely that the Maasai or authorities would allow cattle populations to decline so rapidly. A more likely scenario would be for populations to be supported by donor agencies or maintained at a given level under governmental regulation. Switches in SAVANNA may be set so that in simulations, populations are kept constant. We repeated these analyses, keeping the livestock populations constant. Standing biomass for palatable grass leaves declined steadily during the 15 year simulation from a peak of 44 g/m^2 in the last year to 35 g/m^2. Similar declines were simulated in palatable dead material. In contrast, unpalatable herbaceous leaf biomass increased over time (Figure 7.10). As in the previous simulation, some wildlife populations declined under increased livestock density (Figure 7.11), whereas others did not decrease because of spatial or dietary separation (e.g., Figure 7.12).

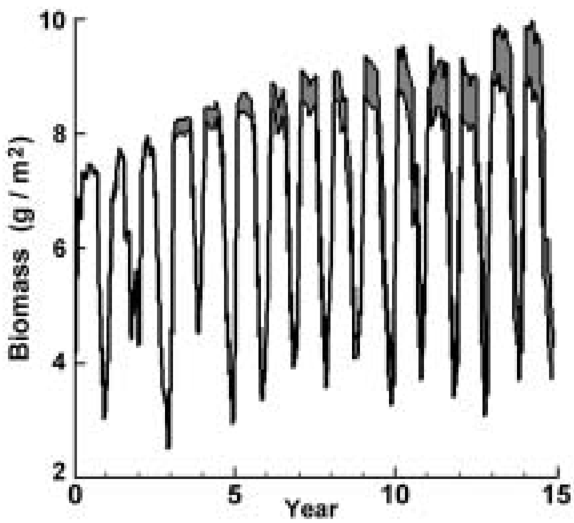


Figure 7.10. When livestock populations were elevated 50% and held constant, unpalatable grasses increased through time, with the increase shaded for clarity.

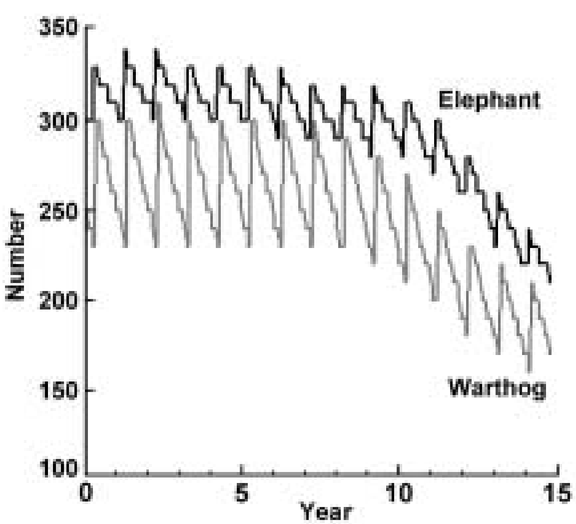


Figure 7.11. Some wildlife populations, such as elephants and warthogs, decreased when livestock were increased by 50% and constant.

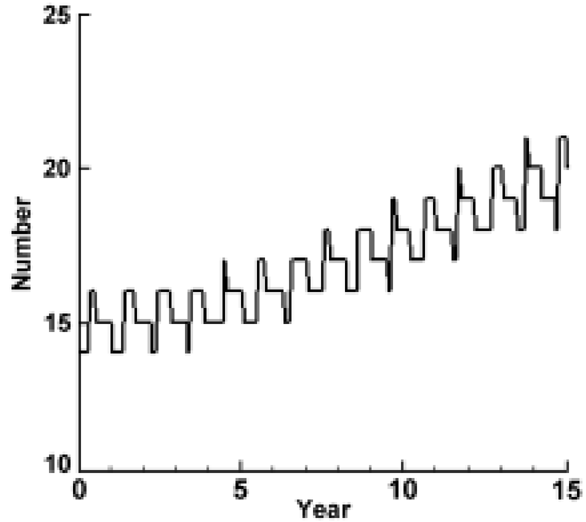


Figure 7.12. Some wildlife populations, such as rhinoceros, which only occur in Ngorongoro Crater, did not decline in response to increased livestock populations, because livestock cannot use the Crater.

Improved Veterinary Practices

Disease is the primary cause of livestock mortality in NCA (Rwambo et al. 1999). Rwambo et al. (1999) cite the need for the development of a livestock management program that will control tick-born and infectious diseases in the NCA. Some progress is being made toward that end by NCA Authority personnel and the Danish International Development Assistance organization (Sorensen and Moshi 1999), with efforts underway to improve veterinary practices in the area. We used the SAVANNA modeling system to quantify the benefits that can be expected from improving veterinary care. Administrators may use the IMAS estimates of benefits and the known costs of implementing projects to assess the overall utility of proposed programs.

Results from the previous section demonstrate that livestock populations cannot be allowed to increase indefinitely without dramatic changes in the ecosystem. Our allowing populations to increase would confound results of improved veterinary practices and increased livestock populations. Instead, in these experiments we cull the livestock to maintain relatively stable populations.

There is already some portion of animals in the control model that are sold or slaughtered by the Maasai. The number culled in these experiments represent additional animals that the Maasai may sell, slaughter, or trade. Cattle were culled if their population exceeded 125,000, with the total population reduced to 120,000. Goats and sheep were culled if their populations exceeded 160,000 and 80,000 respectively, with each population reduced by 5,000 animals when culled.

The following sections sometimes cite high mortalities from disease, but also high probabilities of survival in the SAVANNA application. This apparent contradiction is caused by the sources of mortality in NCA-SAVANNA which are split between a general source of "mortality" that captures all sources that might remove an animal from the system (e.g., death by old age, selling, trading), except tick-borne disease and a component that represents tick-borne disease. General survival probabilities may be high, but they exclude losses from tick-borne disease, which can be substantial (Rwambo et al. 1999).

Improved Veterinary Practices – Survival of Young

Losses of first-year livestock in NCA due to disease can be highly variable, from 15% to 75% (Rwambo et al. 1999). We increased female calf survival from 80% to 87%, male calf survival from 75% to 82%, female kid survival from 74% to 81%, males from 68% to 75%, female lamb survival from 73% to 80%, and male lamb survival from 71% to 78%. When simulated, every few years there were up to 4,500 additional cattle that could be sold or slaughtered (Figure 7.13), up to 5,000 additional goats almost every year (Figure 7.14), and up to 4,500 sheep that could be sold or slaughtered every two to three years (Figure 7.15).

Improved Veterinary Practices – Birth Rates

Birth rates are, to a large degree, determined by the gestation period of herbivores and are relatively stable. However, SAVANNA incorporates birth rates as a percentage of animals producing offspring each year, which includes the intrinsic birth rates and possible reductions in births due to infertility or abortions from poor body condition. Improved veterinary care may decrease the number of infertile females or aborted pregnancies.

To assess the potential value of increased birth rates from improved veterinary care, we increased birth rates for livestock by 5% (i.e., cattle from 64% to 69%, goats from 83% to 88%, and sheep from 82% to 87%). The overall results of the simulation show that increased birth rates may lead

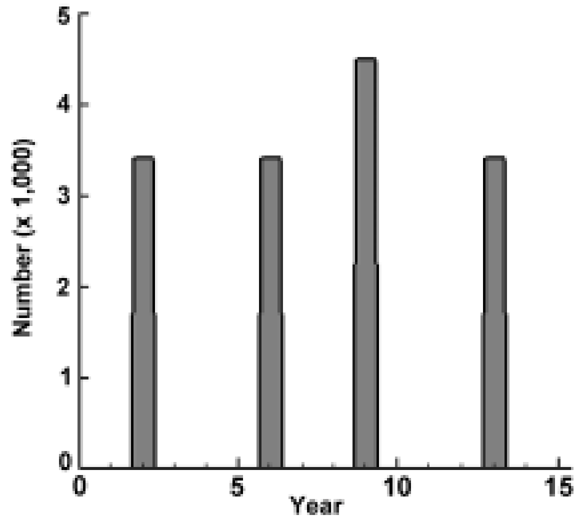


Figure 7.13. Cattle culled when juvenile survival for livestock was increased by 7%.

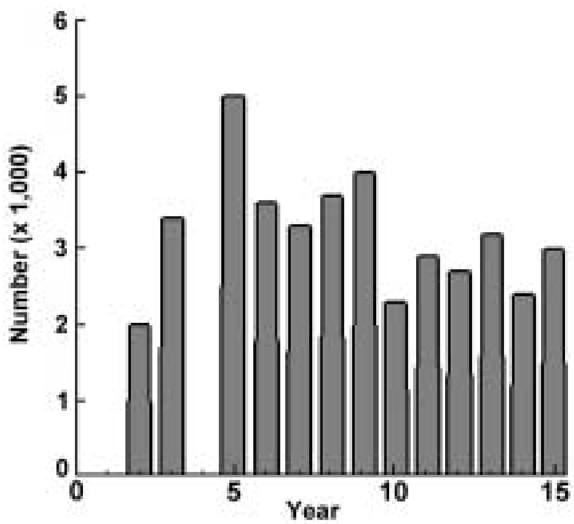


Figure 7.14. Goats culled when juvenile survival for livestock was increased by 7%.

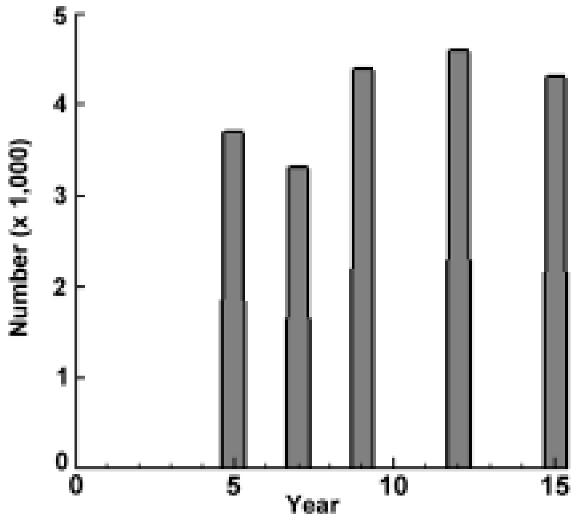


Figure 7.15. Sheep culled when juvenile survival for livestock was increased by 7%.

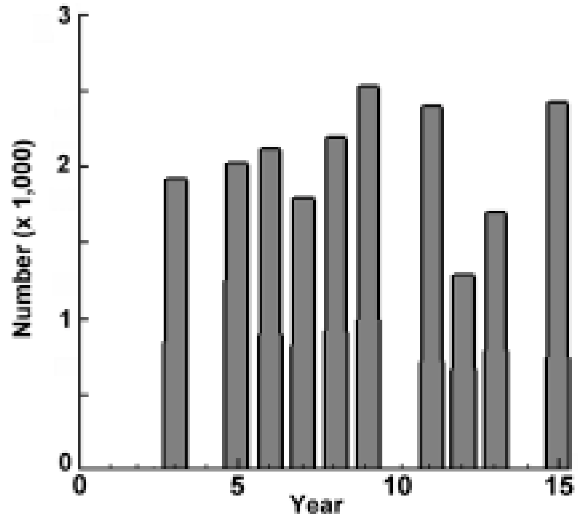


Figure 7.17. Goats culled when livestock birth rates were increased by 5%.

to relatively few additional animals being available for the Maasai to sell or slaughter. About every five years, cattle populations had built-up enough to warrant culling 4,000 (Figure 7.16). About 2,000 goats were culled in all but the driest years (Figure 7.17), and only a single culling event occurred for sheep (Figure 7.18).

Veterinary Practices – Adult Survival

Using resources to improve veterinary care can be expected to increase adult livestock survival. NCA-SAVANNA can estimate what the benefits of that improved survival would be, allowing managers to balance costs and benefits. To estimate the effect of increased adult livestock survival, separate from tick-borne disease relationships that were altered in a succeeding experiment, we increased overall survival by 5% for each group. Female cattle survival was increased from 92% to 97%, female goats from 82% to 87%, and sheep from 83% to 88%. Male cattle survival was increased from 82% to 87%, goats from 75% to 80%, and sheep from 73% to

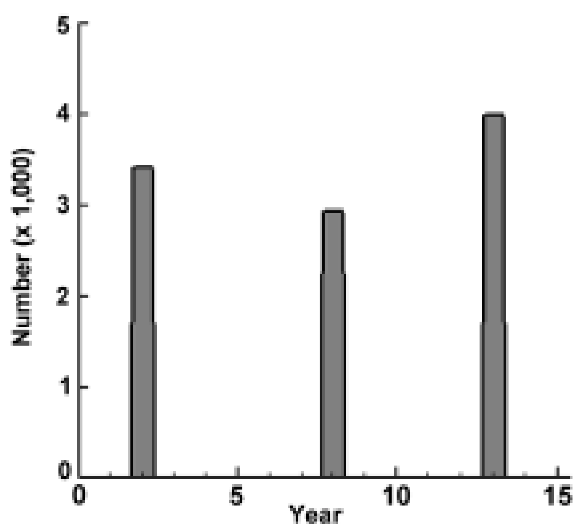


Figure 7.16. Cattle culled when livestock birth rates were increased by 5%.

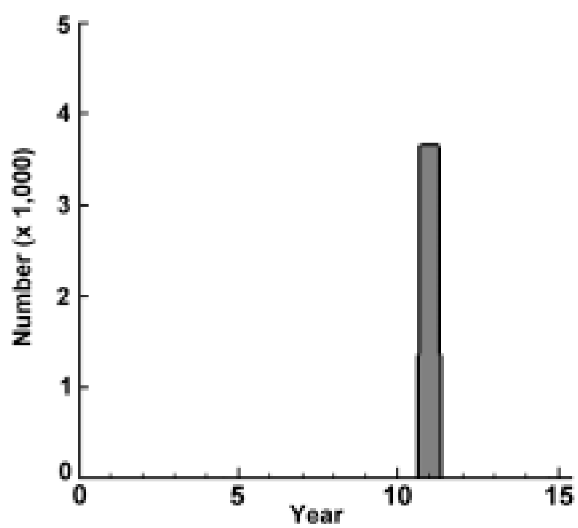


Figure 7.18. Sheep culled when livestock birth rates were increased by 5%.

78%. When simulated, NCA-SAVANNA results suggested that the effects of improved adult survival are dramatic. In wet periods, there were between 4,000 and 7,000 additional cattle available to the Maasai for sale or slaughter, and in drier periods, from 5,000 to 8,000 cattle could be culled in alternate years (Figure 7.19). Thousands of additional goats were available for culling every year (Figure 7.20), and several thousand sheep were culled every other year (Figure 7.21).

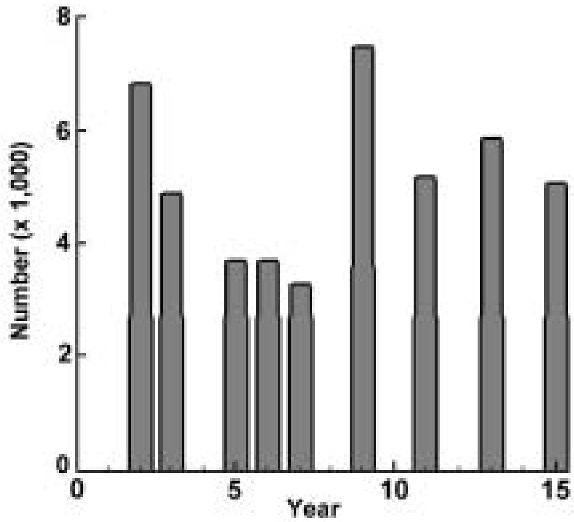


Figure 7.19. Cattle culled when adult livestock survival was increased by 5%.

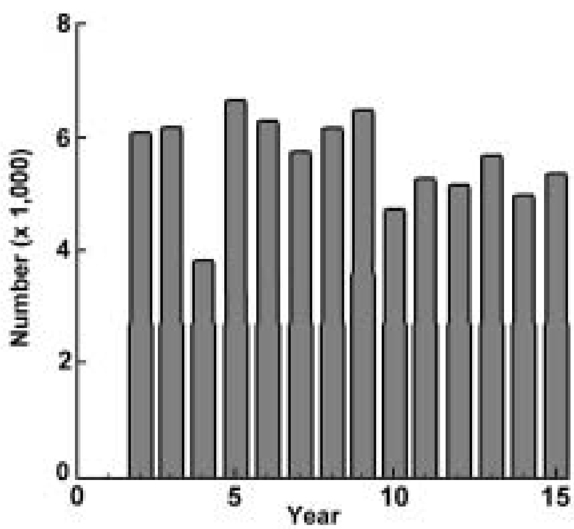


Figure 7.20. Goats culled when adult livestock survival was increased by 5%.

Improving Veterinary Practices – Reduced Disease

Ecologists working in Ngorongoro Conservation Area suspect that cattle populations have been at levels below what the system might otherwise support because of diseases. As described in *Chapter 2*, Maasai do not herd their cattle in the short grass plains during the wet season because of the risk of the cattle becoming infected with malignant catarrhal fever, spread by wildebeest. Instead, the cattle are confined to the midlands and highlands during the wet season, increasing their exposure to ticks that can spread diseases, such as East Coast fever. Efforts are underway to reduce mortality from tick-borne diseases (Sorensen and Moshi 1999). We modified NCA-SAVANNA to include a source of mortality emulating tick-borne diseases in a general way. In the draft modification, livestock mortality increased if they inhabited high-elevation areas or areas of increased precipitation. Using the model, we provided a general estimate of the benefit of reducing mortality from tick-borne diseases.

In the experiment, we reduced mortality due to tick-borne diseases by half by adjusting an index in NCA-SAVANNA. The results of the simulation suggest that tick-borne diseases are an important source of mortality, and reducing that

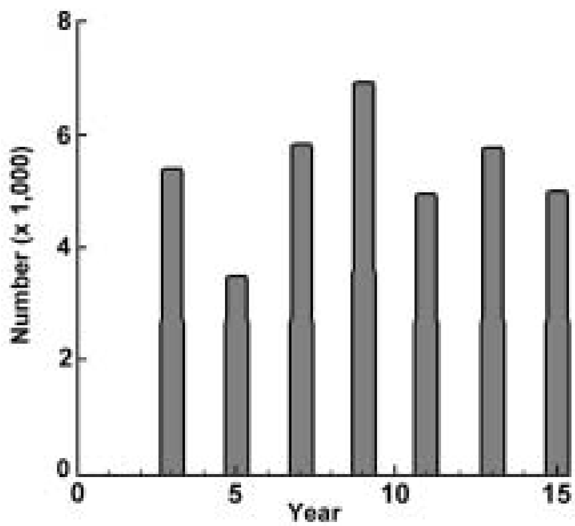


Figure 7.21. Sheep culled when adult livestock survival was increased by 5%.

mortality adds thousands of additional animals that may be culled. Between 4,000 and 8,000 cattle were removed annually when disease was reduced (Figure 7.22). Two to four thousand goats would be culled each year (Figure 7.23) and about 4,000 sheep were culled every few years (Figure 7.24).

Because animals were culled in each of these analyses, livestock populations did not show marked changes; if a population grew above the cut-off, it was reduced and the culled animals tallied. Thus, in this section we show few ecosystem effects, because they were minor. For example, we would expect shifts in the proportions of livestock in each age class as more animals are produced and culled, as was demonstrated. There were also some small changes in the condition indices (e.g., Figure 7.25) and populations of wildlife.

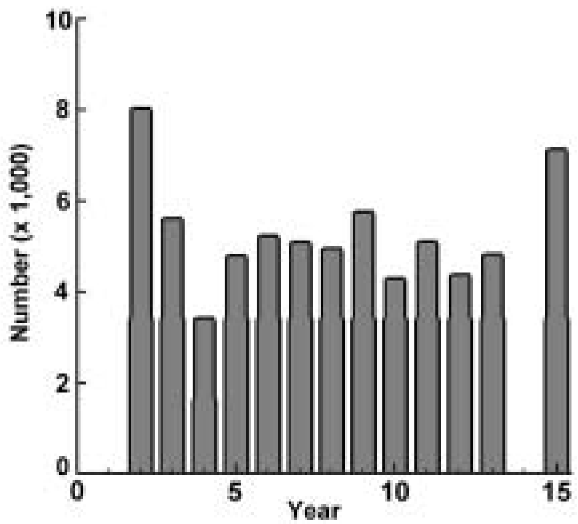


Figure 7.22. Cattle culled when disease associated with high elevation areas and wet areas was reduced by half.

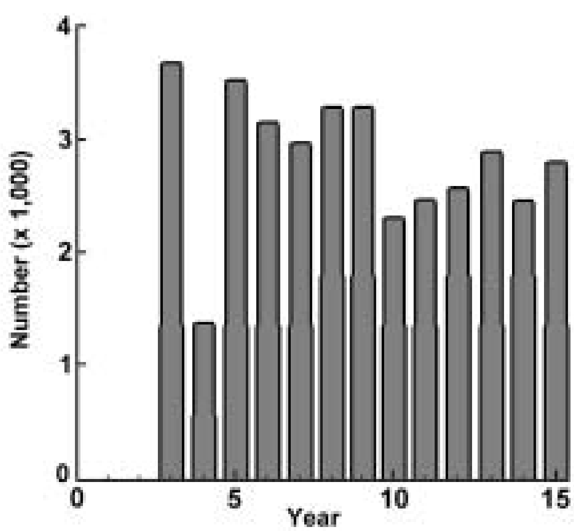


Figure 7.23. Goats culled when disease associated with high elevation areas and wet areas was reduced by half.

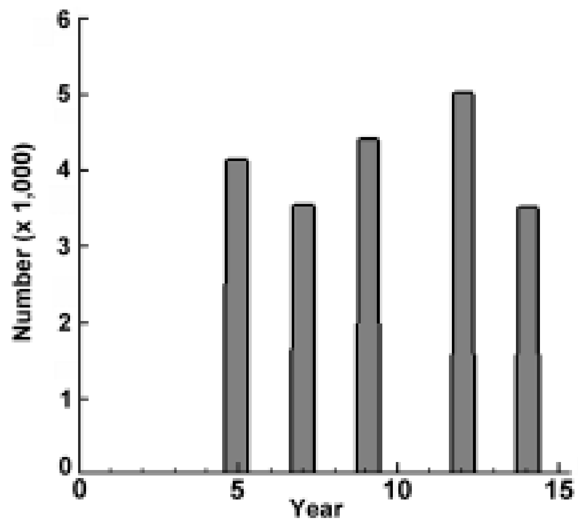


Figure 7.24. Sheep culled when disease associated with high elevation areas and wet areas was reduced by half.

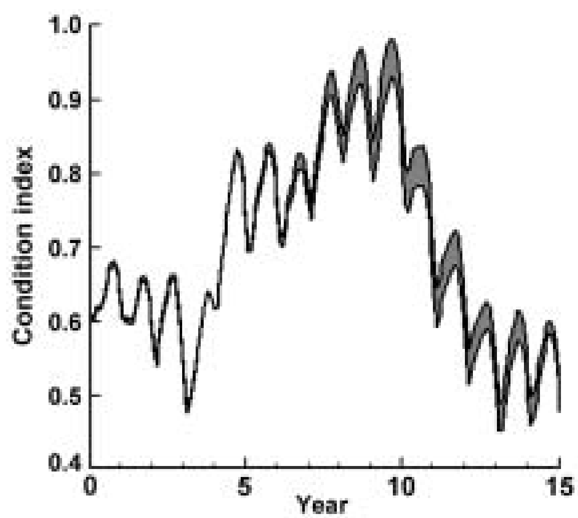


Figure 7.25. The reduction in elephant condition index is highlighted, when disease associated with high and wet areas was reduced by half.

Grazing Access – The Craters

Maasai and their livestock were excluded from Ngorongoro Crater in 1974 (see Runyoro et al. 1995). Today they are allowed to enter Ngorongoro Crater to access water and minerals, but cannot remain to graze. Olmoti and Empakaai Craters are essentially closed as well, although Olmoti is used as a dry-season grazing refuge. Managers and Maasai may wish to know how these limitations affect livestock production and wildlife conservation; IMAS tools can provide some predictions.

In SAVANNA, habitat suitability for animals is calculated based upon forage quality and quantity, slope, elevation, thickets, etc., and then that suitability can be modified by values within maps storing the likelihood of animals occupying sites. In these maps, called force maps, areas assigned a value of 0 will not be used at all by the animal group to which the map applies, whereas areas with a value of 100 may be used freely. Intermediate values lead to intermediate use, assuming habitats are suitable. Many types of management questions can be addressed by modifying the values in the force maps. In the NCA-SAVANNA application, the force maps for livestock contain 0 values for the craters, including Ngorongoro Crater (Figure 7.26), preventing livestock from using the sites. In the experiment, we removed that limitation (Figure 7.27).

When simulated, cattle used the newly available habitat of Ngorongoro Crater, for example (Figure 7.28a versus 7.28b), as did sheep. The grassland habitats in Ngorongoro Crater are not ideal for goats, and so their distributions did not change markedly when craters were made available. Livestock populations did not change markedly however, in-part because of the relatively small grazing areas added by allowing animals to use the craters. In addition, the draft disease model included in NCA-SAVANNA causes more livestock to die if inhabiting wetter, higher areas, like Ngorongoro Crater. Animal groups restricted to Ngorongoro Crater, such as rhinoceros, declined when cattle were present (Figure 7.29).

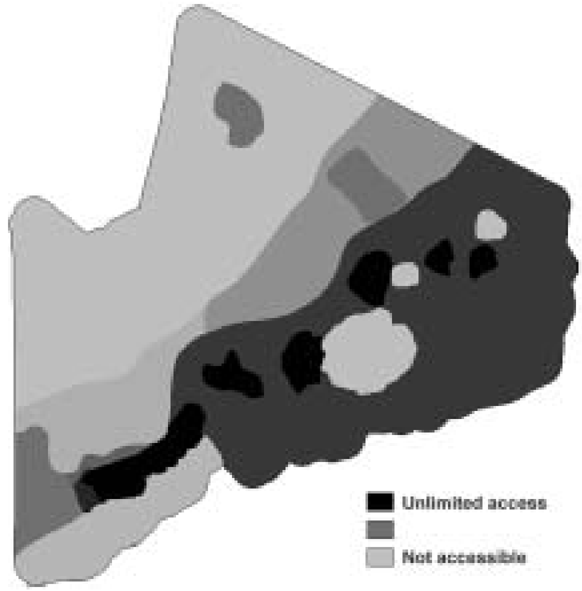


Figure 7.26. The force map for cattle in the wet season, used to inform SAVANNA of restriction on animal movements not necessarily related to habitat suitability.

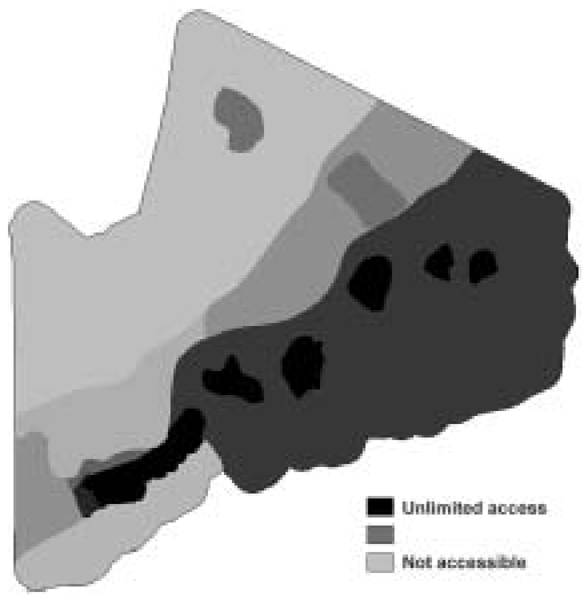


Figure 7.27. An experiment allowing livestock to use the craters may be simulated by altering the force map as shown. Note that the light-colored craters from Figure 7.26 are shaded dark in Figure 7.27.

Grazing Access – Theft

In Aikman and Cobb (1997), the authors describe how Maasai herdsman would not

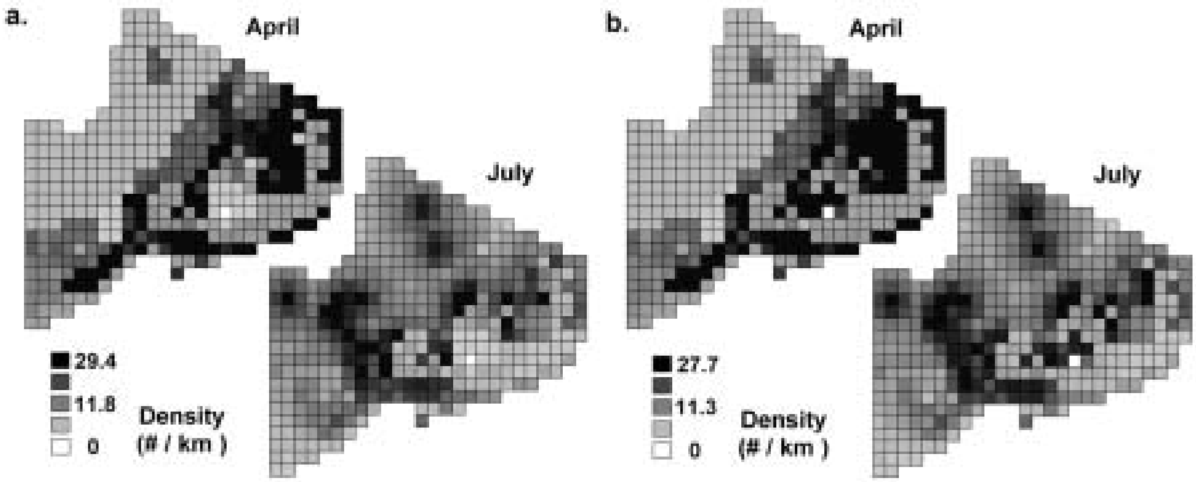


Figure 7.28. Cattle distributions in selected months (for year 3 of the simulation). In the control model (a), cattle were excluded from Ngorongoro Crater, for example. In an experiment (b), cattle made use of Ngorongoro Crater.

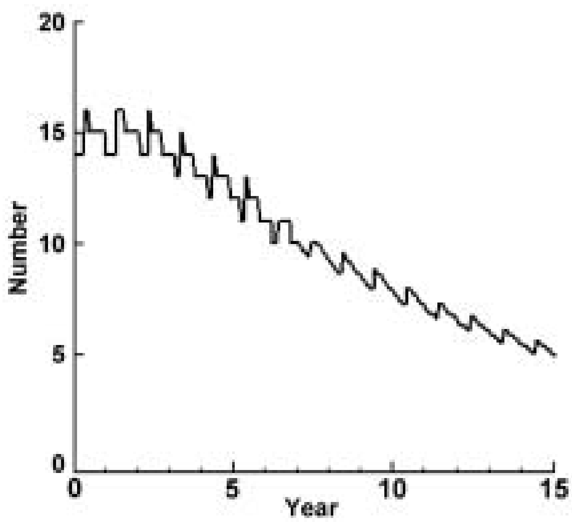


Figure 7.29. The rhinoceros population declined when livestock were allowed to use Ngorongoro Crater.

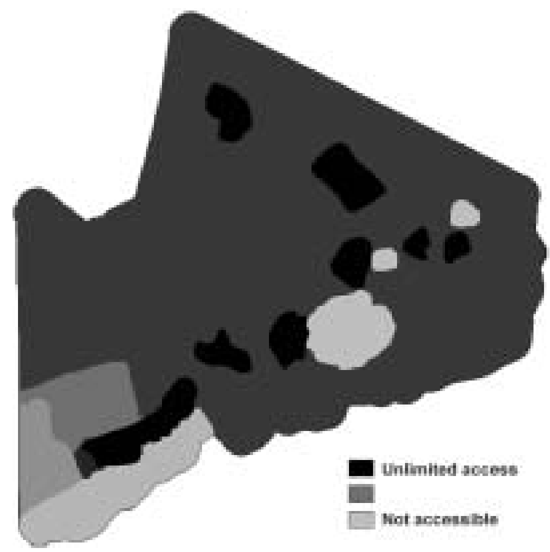


Figure 7.30. The force map for goats in the wet season. The lightly shaded areas in the southwest are sites where livestock-rustling is a threat and are avoided.

endorse repairing water sources in the southwestern portions of NCA because the threat of livestock-raiding by the Wasukuma was too great for the sites to be used. T. McCabe, an expert on Maasai movements within the NCA, confirmed that risk and defined the area of conflict spatially. We then incorporated the relationship into NCA-SAVANNA by reducing force map values in those areas of risk in the control model (e.g., Figure 7.30). In an experiment, we removed the restriction upon grazing in the southwest by altering the livestock force maps (e.g., Figure 7.31).

The results from the simulation suggest that cattle and goats (Figure 7.32) would find the habitats to the southwest suitable. A few hundred goats and about 3,000 additional cattle were supported on NCA when security in the southwest was improved, and the condition indices of the livestock improved incrementally. In the control model, wildlife inhabit the southwest with some relief from competing with livestock. When security is improved and livestock move in, some wildlife

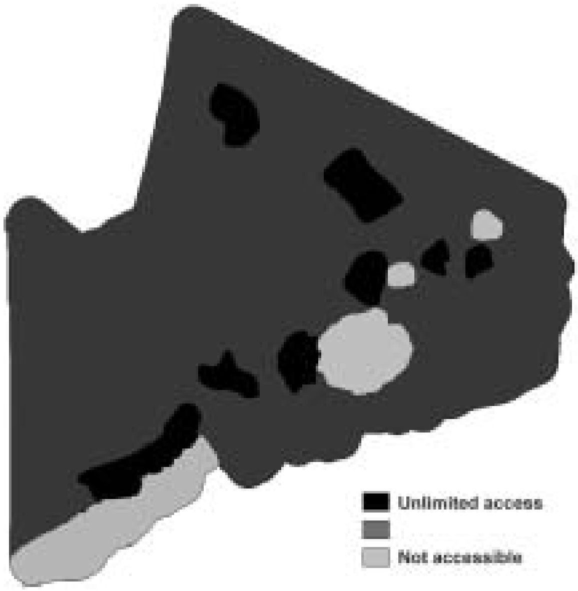


Figure 7.31. Modifying the map shown in Figure 7.30 in an experiment represents improved security, allowing cattle to use the areas of Ngorongoro to the southwest.

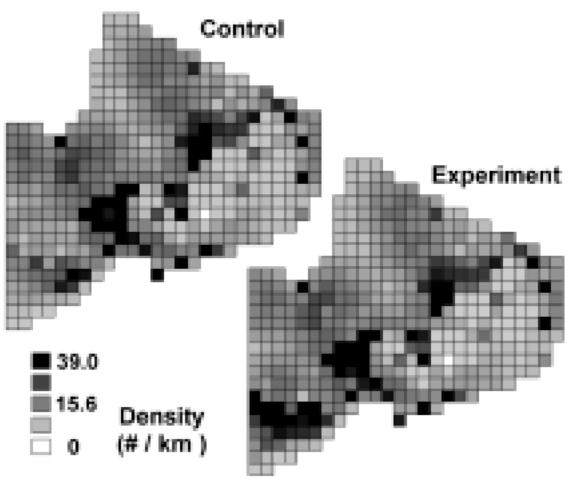


Figure 7.32. When the threat of livestock rustling in the southwest of the study area is removed, goats use the area as shown by the dark shading to the southwest. April of the third year of the simulation is shown.

groups decline. Resident zebra populations decreased by 14%, and elephant populations decreased by 18%. As shown in Figure 7.33, elephants that had inhabited the southwest in the control simulation were excluded in the experimental simulation.

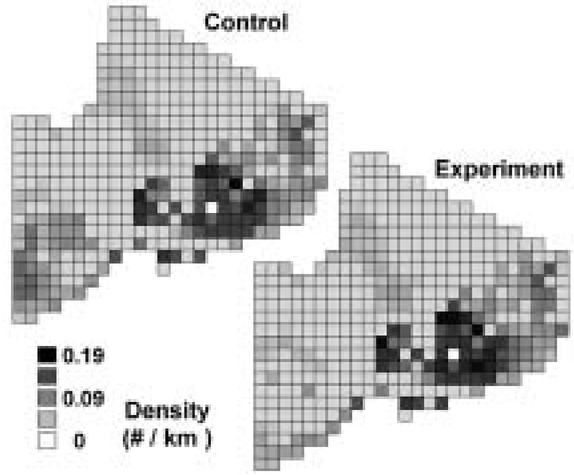


Figure 7.33. When the threat of livestock rustling in the southwest of the study area was removed, elephant densities in those areas declined. April of the third year of the simulation is shown.

Grazing Access – MCF Eliminated

As described in *Chapter 2* and elsewhere, Maasai cattle are not grazed on the short grass plains during the wet season because of the risk of their being infected with the virus that causes malignant catarrhal fever (MCF). Wildebeest move into the plains of Ngorongoro during the early wet season, peaking in April, and give birth to young. These young wildebeest are born with, or soon become infected with, the agent causing MCF in adult cattle. The health of the wildebeest calves is not damaged by the agent, but their nasal and ocular secretions can spread to grasses as they feed. Adult cattle that come in contact with that grass while the agent is still viable can become infected with MCF, with almost 100% mortality.

Of course in practice, we cannot eliminate MCF as the section heading suggests, but using the IMAS tools, we can explore potential repercussions of the existence of MCF by removing it in a modeling exercise. What would be the return on the investment required to create a vaccine for MCF? How important is the avoidance behavior of Maasai herders in preventing cattle deaths? Simulations can provide some estimates as answers to these questions. In practice, the experiment was conducted by altering the cattle force map to remove the wet-season avoidance of short grass plains (Figure 7.34 versus Figure 7.26), and running the SAVANNA simulation. The output from that simulation representing weekly estimates of wildebeest and cattle populations for each cell in the map served as input into our MCF disease modeling program (see *Chapter 9* for details). The same procedure was followed using the NCA-SAVANNA control model and the results compared.

Results from a simulation allowing cattle to use the short grass plains during the wet season confirm that cattle will make use of these thousands of additional square kilometers of grazing lands, regardless of competition with wildebeest (Figure 7.35). Cattle populations continued to grow throughout the simulation, and at the end of the 15 year period, there were 18% (at 132,500) above populations in the control model (112,500). Goat and sheep condition indices declined slightly and their populations declined by 1%. Changes in the populations of wild herbivores were minor (4% or less), but changes in migratory populations of wildebeest were not modeled because their entire range was not included in NCA-SAVANNA. Thus, this application cannot address

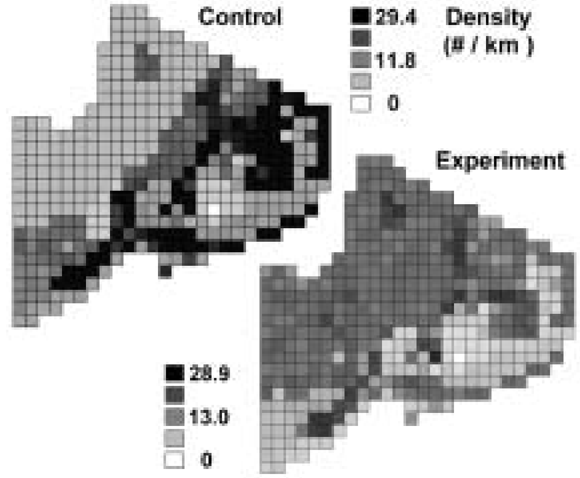


Figure 7.35. Dramatic differences in the distribution of cattle were seen when they were allowed to use the short grass plains in the wet season. April of the third year of the simulation is shown.

Figure 7.34. The wet season force map for cattle was modified in an experiment to allow cattle to use the short grass plains.

what the effects on wildebeest would be of allowing cattle onto the Serengeti plains during the wet season.

In reality, we would expect hundreds or thousands of cattle to die from MCF if the animals were allowed to graze amongst wildebeest calves. The MCF component of the IMAS disease modeling effort suggests the same (Figure 7.36). In the control model, weekly losses to MCF are relatively minor and clustered in the foothills of Ngorongoro. When cattle were allowed to graze in the short grass plains, weekly losses to MCF were much higher (Figure 7.36).

Water sources – Restoration

The NCA includes the driest areas in the Serengeti Ecosystem, in the rain shadows of the Ngorongoro Highlands and Gol Mountains, with 450 mm of rain per year (Campbell and Hofer 1995). Natural water sources are used by wildlife and livestock, with primarily livestock benefitting from additional water sources that have been constructed. Most of the 29 water systems constructed had failed when Aikman and Cobb (1997) conducted their surveys, finding 10 of the

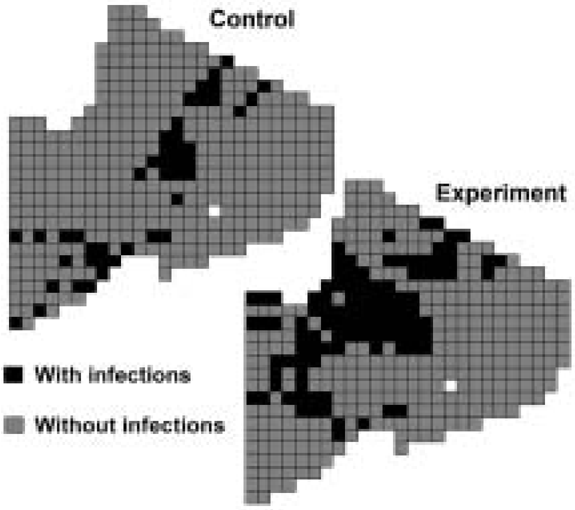


Figure 7.36. Many more cases of MCF were predicted to occur if cattle were to graze amongst wildebeest, without other forms of mitigation. The first week of April of the third year of the simulation is shown.

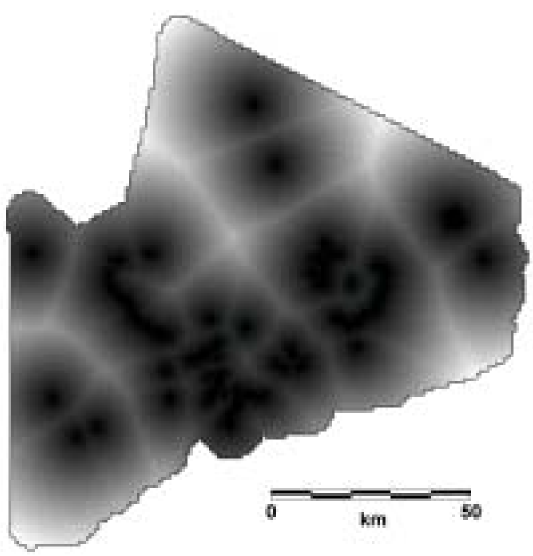


Figure 7.37. The distance-to-water map for the dry season used in the control model. Dark areas are near water, light areas furthur away.

sites working. The Danish International Development Assistance organization is supporting efforts to restore some of those abandoned water systems (C. Sorensen, pers. comm.).

The SAVANNA modeling system incorporates water sources by including distance to water maps (e.g., Figure 7.37). These are used while calculating habitat suitability for animal groups; cells that are too distant from water will receive a lower habitat suitability than those that are near to water, if appropriate for the given animal. Areas that are near to water tend to have high densities of animals and high offtake, and those far from water have low densities and low offtake. Assuming that geographic information system (GIS) software is available, it is a straightforward matter to add or remove water sources in experiments that represent management decisions. Here we restored the 20 water systems Aikman and Cobb (1997) showed had failed. That is, we plotted those water systems in a GIS, added them to the existing suite of water sources, and recalculated the three distance-to-water maps used in NCA-SAVANNA for the wet, transitional, and dry seasons. The resulting distance-to-water maps (e.g., Figure 7.38) represent experiments balancing the costs of restoring water systems against the benefits.

Our simulation results suggested that restoring the water systems of NCA that had failed would redistribute animals across the area (e.g., Figure 7.39), with most of the changes occurring near the center of the study area near Olduvai Gorge. Accumulated offtake of vegetation shows a redistribution as well (Figure 7.40). Only minor

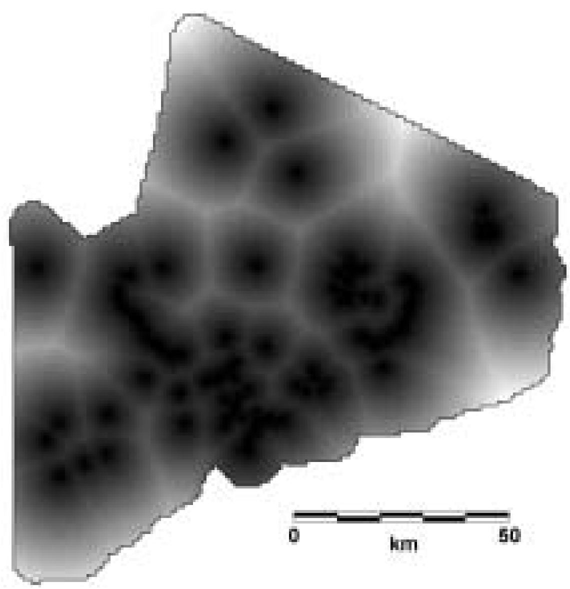


Figure 7.38. The distance-to-water map for the dry season altered by restoring failed water sources. Dark areas are near water, light areas further away.

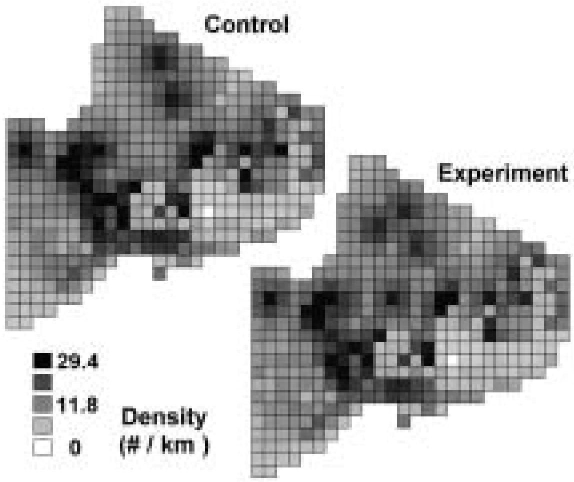


Figure 7.39. The distribution of cattle during July was altered when additional water sources were included.

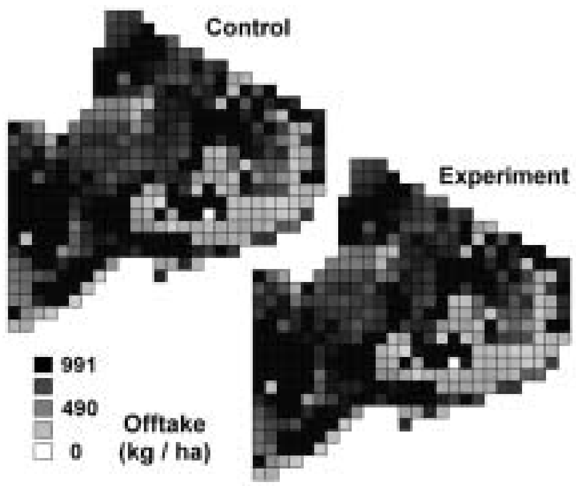


Figure 7.40. Accumulated offtake for the third year modeled shows that the distribution of offtake was altered when there were additional water sources.

changes in wildlife populations occurred in response to additional water sources, with responses specific to the ecology of the animal group. For example, wart hog condition indices improved about 4% with additional water sources due to additional habitable areas available. In contrast, elephant condition indices declined by about 4% because areas that were relatively distant from water, which elephants could use without competing with other animals, were no longer distant from water and had higher densities of animals in general.

Water Sources – Used by Lodges

Because NCA has limited water sources, water use by tourist lodges can be a contentious issue. In NCA, there are lodges along Ngorongoro Crater rim and a lodge near Lake Ndutu in the northwest. To assess potential impacts of water use by the occupants of these lodges, we modified the water source maps used in NCA-SAVANNA, removing water sources that were within 1 km of lodges. Water for Ndutu Lodge is hauled by truck, so the experiment meant modifications to water sources near Ngorongoro Crater (Figure 7.41). When modeled, the change in herbivore distributions was minor, as might be predicted from the small change in the mean distance to water in the maps (10.2 km to 10.5 km). Changes in range conditions and herbivore populations were minor. However, populations of animals that inhabited Ngorongoro Crater did decline, such as browsing antelope (Figure 7.42).

Households and Cultivation

Overall, the human population in a 1999 NCA census was 51,621, and the population increased at more than 3% per year, with some of that increase due to immigration (NCAA 1999; see

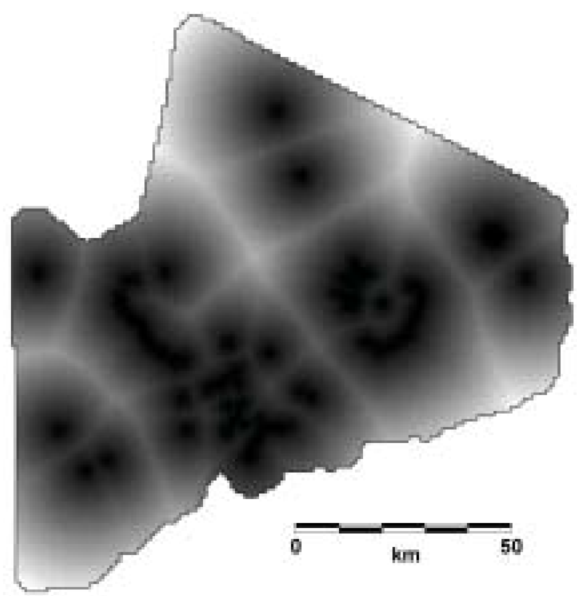


Figure 7.41. The distance-to-water map for the dry season, with water sources within 1 km of lodges removed from consideration..

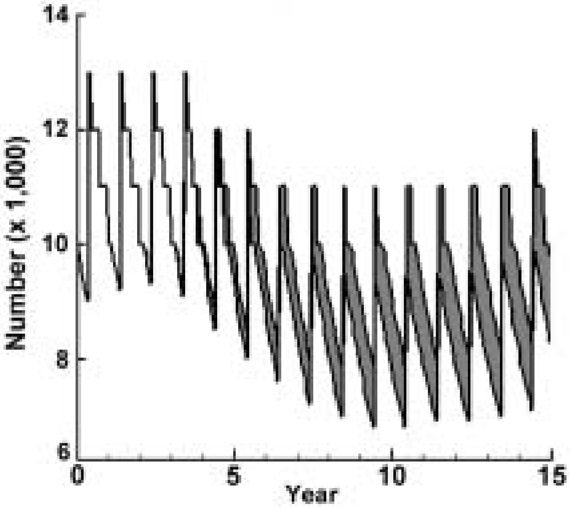


Figure 7.42. A decrease in browsing antelope that inhabit Ngorongoro Crater was seen when water used by lodges was removed from consideration. The difference from the control model is shaded for emphasis.

Chapter 8 for more details). Cultivation was outlawed in NCA in 1975, but was restored in 1992 to improve the nutritional status of the Maasai. Since then, the area cultivated has increased to about 5,000 ha (derived from Smith 1999). Methods to limit the number of people inhabiting NCA have been proposed (NCAA 1999), but in the near-term, we anticipate the population and area under cultivation to continue to increase. We can use the IMAS tools to assess potential effects of human population increase and cultivation on wildlife and livestock.

We modified the SAVANNA model (see *Chapter 6*) to incorporate households and cultivation into the GIS databases. In the modified model, households were placed depending upon their distribution in a 1991 aerial survey of bomas (i.e., groups of households), and cultivated areas were associated with households (Figure 7.43). Cultivated areas were not available to wildlife or livestock. Note that the information reported here is used in the socioeconomic modeling reported in *Chapter 8*, but that chapter includes an additional modeling component (i.e., PHEWS) yielding additional detail. In this chapter, we report simulated effects on wildlife and livestock only.

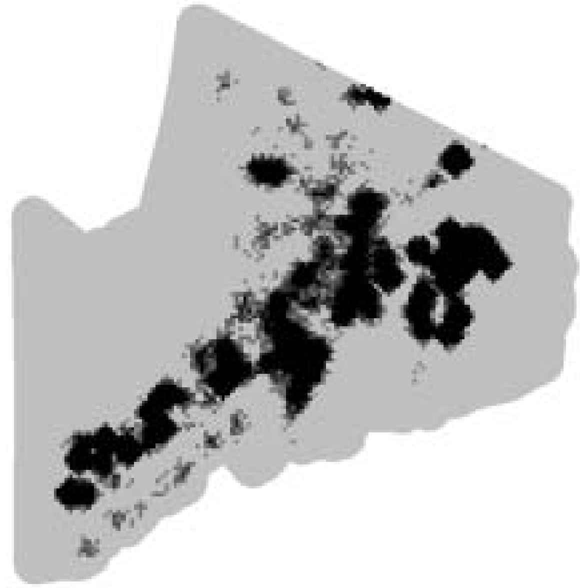


Figure 7.43. A map showing relative densities of households used to guide the placement of new households in NCA-SAVANNA. The map was generated based on boma (i.e., groups of households) densities in a 1991 aerial survey (K. Campbell, pers. comm.).

Households and Cultivation – Growth

Maasai pastoralists generally have an annual population growth rate of about 3% per year (Homewood and Rodgers 1991). We used the IMAS tools to assess the potential effects of such a population growth and a linearly related growth in cultivation on wildlife and livestock. A survey from 1994 showed the average household site (i.e., one man, wives, and children) of 10 people (Natural Peoples World/NCAA census summary data). Therefore, we included 5,000 households in the NCA-SAVANNA experiment, totaling 50,000 people. Three household wealth categories were used in the model, with the average area in cultivation per household at 0.95 ha (Smith 1999), yielding a starting value for cultivation of 4,727 ha for NCA. In analyses, the results after 15 years of population growth were compared to the control model, which did not include households or cultivation.

The simulation results include a simple geometric increase of household and cultivation (Figure 7.44), with households increasing over a 15 year simulation from 5,000, and cultivation increasing from 4,727 to 7,293. Cultivation was associated with households yielding a distribution of cultivation (Figure 7.45) similar to that of bomas (Figure 7.43). Overall, there were few changes in the populations of wildlife or livestock, when the simulated populations after 15 years of human population growth were compared to the control model (Table 7.4).

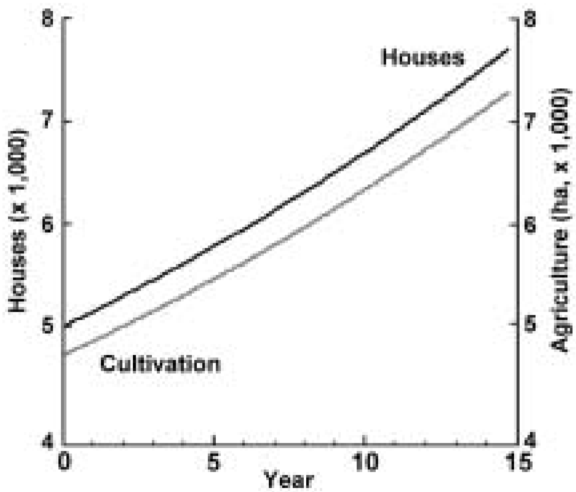


Figure 7.44. The increase in households and cultivation. The information plotted is output from NCA-SAVANNA, but also is a simple geometric relationship with households and associated cultivation growing at 3% per year.

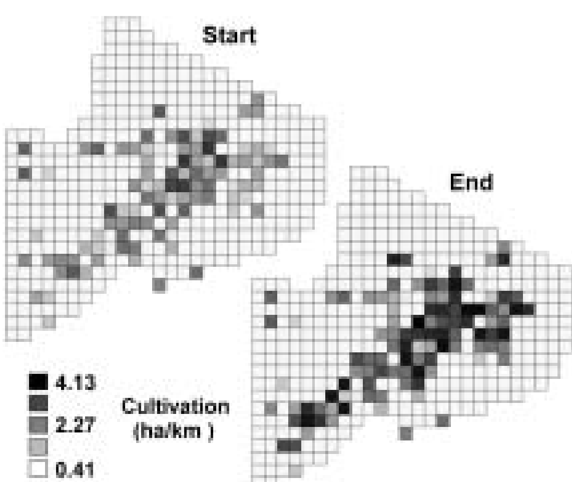


Figure 7.45. The distribution of cultivation in the beginning and at the end of the simulation. Cultivation was distributed based on the distribution of households; those look similar.

Animal group	Change (%)
Livestock	
Cattle	0.00
Goat	-0.57
Sheep	-0.96
Wildlife	
Resident	
Wildebeest	-0.67
Zebra	-1.40
Grazing gazelle	-0.73
Crater	
Buffalo	0.00
Browsing antelope	-5.63
Area	
Buffalo	-2.55
Browsing antelope	-0.96
Elephant	-2.41
Rhinoceros	-1.69
Giraffe	0.00
Warthog	-2.25

Table 7.4. Percentages of change in animal populations when cultivation was compared to the control without cultivation. Changes in migratory animal populations were not modeled.

Households and Cultivation – Cultivation

We have demonstrated that results from the NCA-SAVANNA application suggest only small changes in animal populations in response to a 3% growth in households and cultivation over a 15-year period of growth. We may predict that result, given that cultivation went from about 0.5% of the area at the start of the 15-year simulation to about 0.75% at the end. (Of course, the distribution of that cultivation is important. If it were completely bisecting movement routes, for example, population-level responses would be likely.) To more fully assess the effects of cultivation on animal populations, we conducted a series of analyses, varying cultivation from 0.5% of the area to 5% of the area (Table 7.5) and making that area unavailable to livestock and wildlife. Note that, whereas all of the experimental results

Households	Households (ha)	Coverage (%)
1,000	5,000	0.5
2,000	10,000	1.0
3,000	15,000	1.5
4,000	20,000	2.0
5,000	25,000	2.5
6,000	30,000	3.0
7,000	35,000	3.5
8,000	40,000	4.0
9,000	45,000	4.5
10,000	50,000	5.0

Table 7.5. Simulations used to assess the response of animals to cultivation ranging from 0.5% to 5% of the study area. Each household was assigned 5 ha of cultivation. The area included a 5 km buffer around the 8,300 km^2 site, yielding about 10,000 km^2. The control model did not include cultivation and provided the zero-point in the figures of this section.

described until now had summarized a single simulation, in this experiment we conducted 10 simulations (plus the control, at 0% cultivation) and report the summarized results. This experiement is an example of the many types of secondary analyses that may be conducted using the detailed responses produced and reported by the SAVANNA modeling system.

Results from NCA-SAVANNA simulations suggest that changes in wildlife and livestock (Figures 7.46 to 7.49), which have animals grouped according to general population level. Cattle populations declined by about 15,000 animals at 5% of cultivation (Figure 7.46), whereas goats and sheep had relatively stable populations. Resident wildebeest, which mainly inhabit Ngorongoro Crater, did not decline markedly with cultivation in place, nor did area browsing antelope (Figure 7.47). Resident zebras and grazing antelope, which are grazers inhabiting areas outside Ngorongoro Crater, showed larger declines (Figure 7.47). Buffalo and browsing antelope that inhabit Ngorongoro Crater declined somewhat in response to cultivation (Figure 7.48). The largest

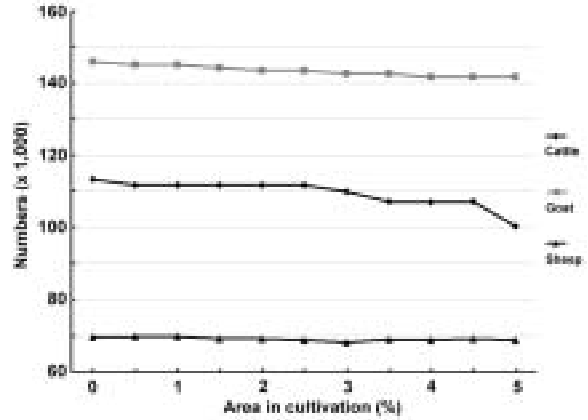


Figure 7.46. Changes in livestock populations in response to increasing areas in cultivation.

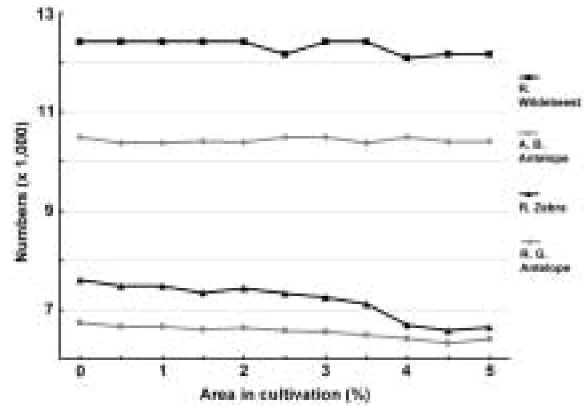


Figure 7.47. Changes in common wildlife populations in response to increasing areas in cultivation.

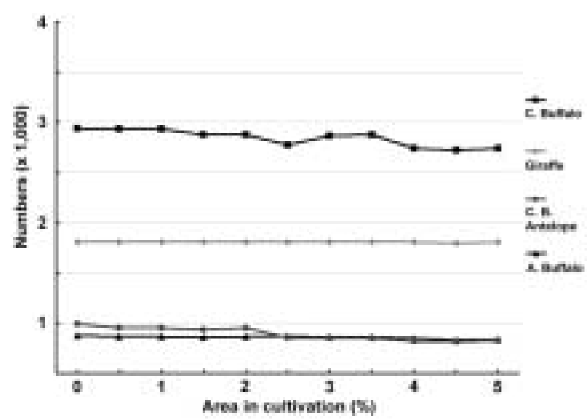


Figure 7.48. Changes in uncommon wildlife populations in response to increasing areas in cultivation.

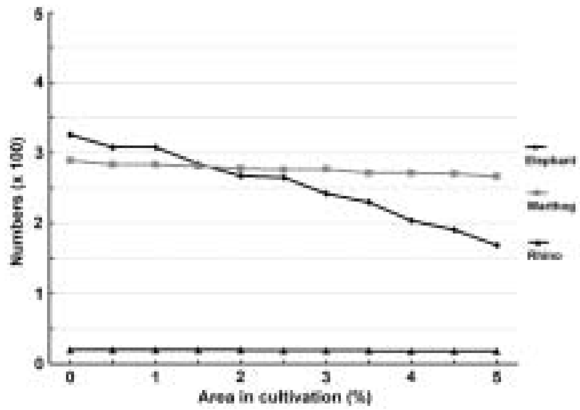


Figure 7.49. Changes in rare wildlife populations in response to increasing areas in cultivation.

change in population occurred for elephants (Figure 7.49), with the population declining to 52% of that of the control model when cultivation was 5% of the area. This decline is due to the spatial overlap in the areas selected by elephants and those used by Maasai as household sites. As cultivation expands in NCA, conflicts between Maasai and elephants may be anticipated.

Southern Kajiado District

We conducted three sets of experiments using the Kaj-SAVANNA application, which are intended to demonstrate the use of ecosystem modeling in Kajiado. The IMAS application in Ngorongoro Conservation Area has demonstrated the flexibility of the modeling system. Here we concentrate on experiments that directly address some long-standing questions about land management in Kajiado. Further, these demonstrations focus upon changes in livestock and wildlife populations, with the understanding that any of the comparisons of range condition shown in the previous sections may be made in Kajiado as well.

Group Ranch Formation

Group ranches were formed in Kajiado District (Figure 7.1) and elsewhere to provide joint freehold title of the land to ranch members and to encourage collective management of the land to yield the maximum benefit to members over the long-term. Kajiado was the site of the earliest experiments in the group ranch concept in 1949, and the District was the first fragmented into group ranches in the 1960s (Ole Katampoi et al. 1990). The group ranch concept was implemented with broad-reaching goals (e.g., range improvement and stability of ownership), but most goals have gone unmet (see *Chapters 1* and *2* for more details). An important concern with the sub-division of Maasai Districts (Figure 7.50) into group ranches has been the fragmentation of grazing resources. Whereas livestock herders may have moved animals over thousands of square kilometers of land to locate forage in the past, now their movements may be limited to the hundreds of square kilometers (or less) of a given group ranch. Because of ranch ownership, herders may be forced to make due with forage on their ranch instead of moving to better pastures elsewhere as they had in the past (Ellis and Galvin 1994). The trend to fragment ownership continues today, with small ranches owned by individuals being created.

To explore the effects of fragmentation of ownership on the carrying capacity of areas within Kajiado, we selected four sites for closer analysis (Figure 7.50). These include a cluster of group ranches collectively known as Dalalakutuk (775 km^2, when represented using 25 km^2 cells), Mbirikani Group Ranch (1,250 km^2, based on the cells modeled), Orkarkar Group Ranch (25 km^2), and an area of Mailua Group Ranches of the same size and shape of Orkarkar, for comparisons. These sites include two main comparisons: productivity, with Orkarkar and Mbirikani being more productive than Dalalakutuk and Mailua; and size, with Dalalakutuk and Mbirikani being large, and Orkarkar and the portion of Mailua used being small. We wish to contrast two scenarios: 1) the relative number of livestock that could be supported on each of the areas when livestock were allowed to move about the entire study area (10,732 km^2), except for fenced areas and Amboseli National Park where livestock are excluded, and 2) the number of livestock that could be supported when they were restricted to the given area or group ranch. For each area in turn, we ran the control model and asked Kaj-SAVANNA to report animal populations for only

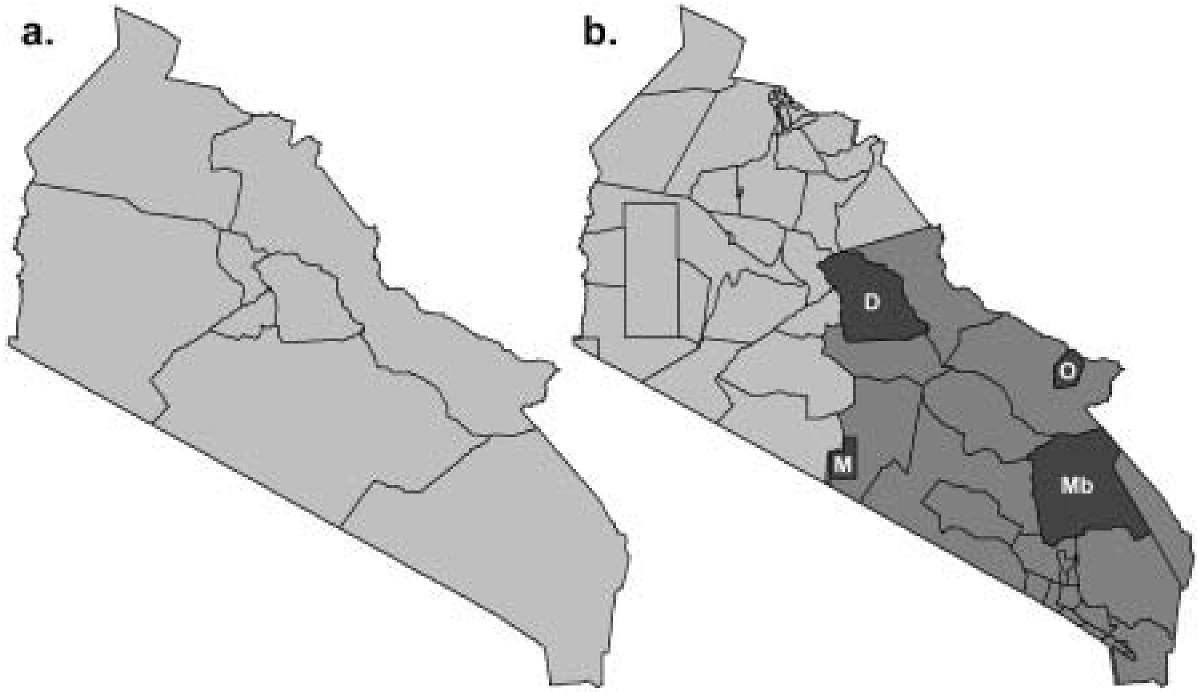


Figure 7.50. Maasai Sections within Kajiado District (a) have been subdivided into group ranches (b). The darker shaded section in Southern Kajiado is the area we included in IMAS ecosystem modeling. The areas we used in analyses include a cluster of group ranches collectively called Dalalakutuk (D), Mbirikani Group Ranch (Mb), Orkarkar Group Ranch (O) and a portion of Mailua Group Ranch, which are heavily shaded. The boundaries shown in (b) combine some ranches and exclude small individual and group ranches. Group ranch boundaries change often.

the area in question. The results of these simulations provided to us the numbers of livestock that occurred on each area, averaged over the entire simulation. We then created force maps for the livestock that confined their movements to a given group ranch, set the population level for livestock to the long-term mean for the group ranch, and repeated the simulation. The results of these simulations provided us with estimates of the numbers of livestock that may be supported on the group ranch alone.

The most straightforward means of assessing the effects of ownership fragmentation was to adjust the population level as described and use force maps to restrict livestock to a given area. There were, therefore, no livestock outside of the area of interest. In this setting, wildlife populations across the study site would be released from competing with livestock, and their populations would increase, altering the wildlife populations on the area of interest and invalidating comparisons. To avoid this confusion, we used switches within the SAVANNA model to stop population changes in wildlife from being modeled; a constant number of wildlife inhabited the study area throughout the simulation. Wildlife distributions may still have been altered in our simulations, but those changes were minor.

The Dalalakutuk region (D in Figure 7.50) is a relatively arid portion of Kajiado, although more productive than the plains along the Tanzanian border. In the Kaj-SAVANNA control model with livestock able to move to the most suitable sites throughout southern Kajiado, livestock remained fairly stable in Dalalakutuk. In Year Five (i.e., 1983), a short-lived increase occurred when animals immigrated from still drier parts of Kajiado because of a drought (upper lines in Figure 7.51, a-c). Populations declined following the drought. When livestock were restricted to Dalalakutuk region throughout a simulation, their populations declined (lower lines in Figure 7.51, a-c). Goats were able to maintain populations better in the shrubby habitats of Dalalakutuk than cattle or sheep (Figure 7.51b versus 7.51a,c). In general and on average, however, Dalalakutuk supported thousands fewer livestock when they were restricted to the site than when the livestock could occupy the most suitable habitats throughout southern Kajiado.

The Mbirikani Group Ranch (Mb in Figure 7.50) is larger and more productive than the Dalalakutuk region, and includes important grazing areas such as swamps and the slopes of Chyulu Hills. In the control model, where livestock were able to select habitats freely from throughout southern Kajiado, livestock tended to increase and then be reduced by drought. In Mbirikani, a dramatic influx of animals into the area occurred during a drought in Year Five (lower lines in Figure 7.52, a-c), moving in from drier portions of Kajiado. In a simulation with a similar number of livestock confined to Mbirkani Group Ranch, the populations showed sometimes dramatic increases (upper lines in Figure 7.52, a-c). Thousands of additional cattle (Figure 7.52, a) were supported on the site through most of the simulation, for example.

Kaj-SAVANNA simulations showed a similar but more dramatic response in the small Orkarkar Group Ranch (O in Figure 7.50) to Mbirikani, as might be expected given that Orkarkar receives more precipitation (Ole Katampoi et al. 1990:19). In the control model, populations almost double during the drought, as animals immigrate (Figure 7.53, a-c). When animals were restricted to the Orkarkar Group Ranch, the population of cattle increased by more than 100% over the 15 year period (Figure 7.53, a). Goats and sheep show more modest increases in populations (Figure 7.53, b-c).

Based upon simulations in Mbirikani and Orkarkar, we may mistakenly conclude that the area to which livestock were confined did not influence the populations. Results from a portion of Mailua Group Ranch (M in Figure 7.50) suggest otherwise. Livestock populations in the control model responded similarly to those in other

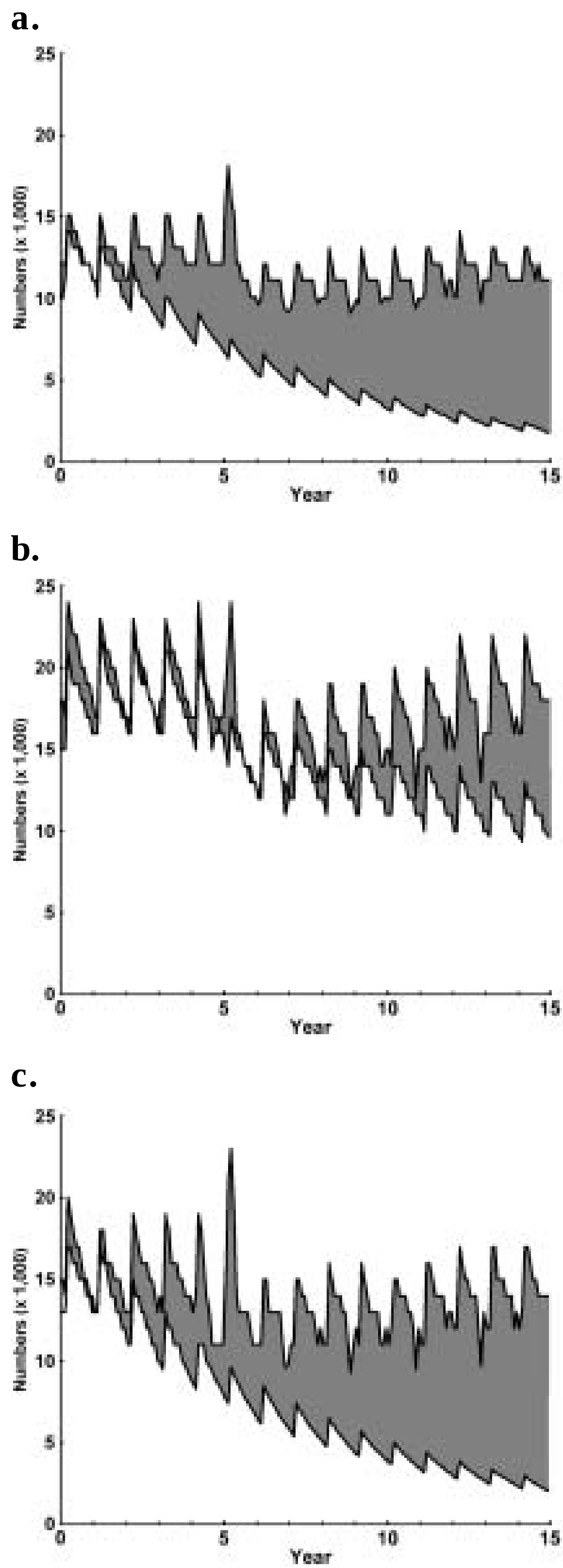


Figure 7.51. Declines in cattle (a), goats (b), and sheep (c) in the Dalalakutuk region when livestock are restricted to the area are shaded.

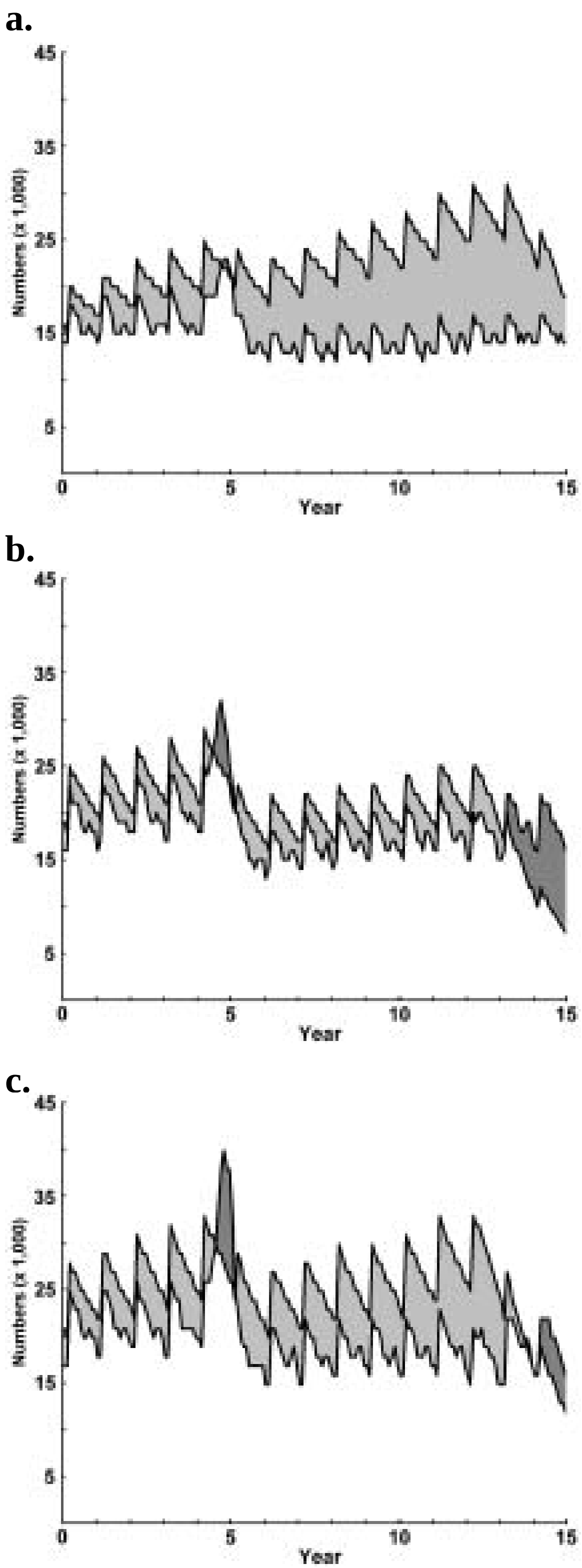


Figure 7.52. Lightly shaded areas show the general increases in cattle (a), goats (b), and sheep (c) in the Mbirikani Group Ranch when livestock were restricted to the area. The few decreases are more darkly shaded.

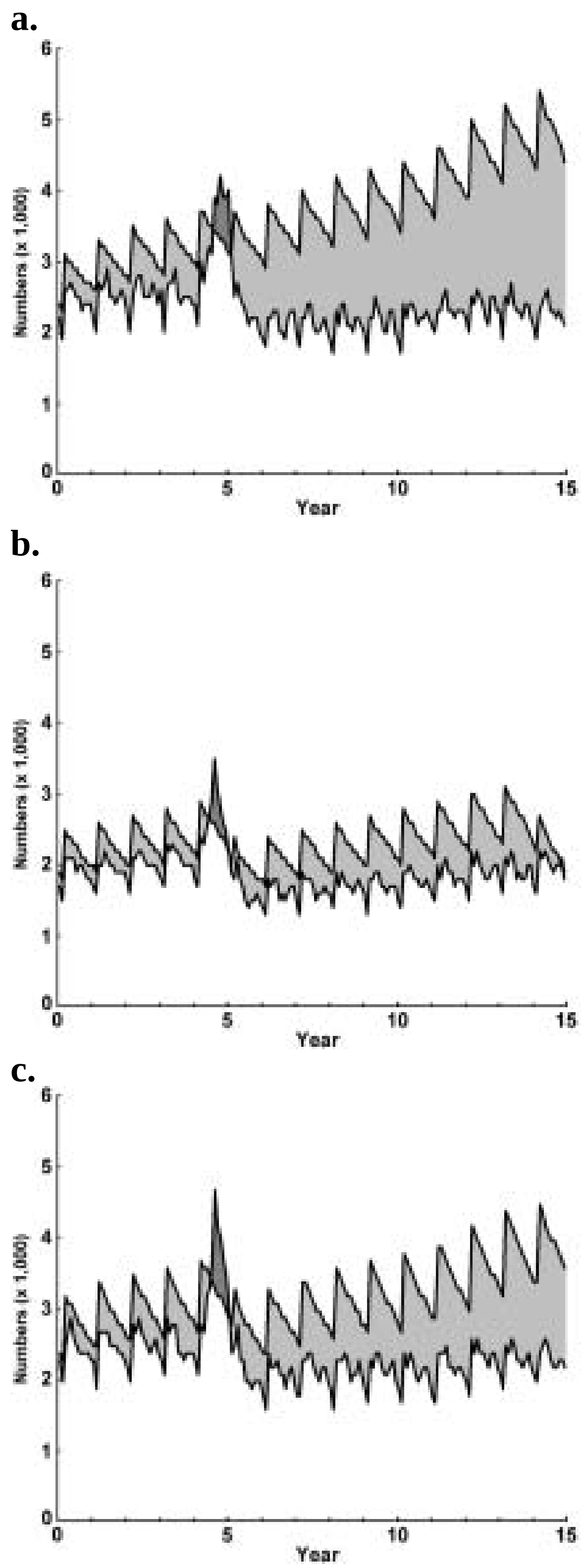


Figure 7.53. Lightly shadedareas show the general increases in cattle (a), goats (b), and sheep (c) in the Orkarkar Group Ranch when livestock were restricted to the area. The few decreases are more darkly shaded.

areas studied. However, when livestock were forced to select habitats from within the small portion of Mailua Ranch rather than all of southern Kajiado, the populations declined to near zero (Figure 7.54, a-c).

The results from this section highlight the importance of site-specific attributes in a setting with fragmented ownership. In some sites (e.g., Orkarkar) with excellent year-round conditions, livestock populations can remain high. In what may be many other sites (e.g., the portion of Mailua of the same area as Orkarkar), livestock cannot be supported on the area year-round. Animals must move to more productive areas during portions of the year when no grazing remains (Ellis and Galvin 1994), and if those alternate grazing sites are unavailable, the populations will decline. In future work, we wish to conduct analyses similar to those described for all ownership blocks in southern Kajiado, sum the resulting livestock populations, and determine if the total that may be supported when ownership is fragmented is smaller than when the entire area is managed as a unit, as we hypothesize.

Importance of Swamps

A series of swamps (e.g., Kimana Swamp including fenced springs; Namelok Swamp; Enkongo Narok Swamp in Amboseli National Park) occur in southern Kajiado (Figure 7.55). The swamps are filled by underground water sources draining from the slopes of Mount Kilimanjaro. In the dry season and during droughts, these swamps can remain wet, allowing grazers to use the sites through otherwise difficult periods. The swamps outside of Amboseli National Park are also the best available lowland sites in Kajiado for cultivation and are being encroached upon. In some cases (e.g., Kimana Swamp), cultivation is moving in from the edges, reducing the size of the swamps and access to wildlife and livestock. In other cases, such as Namelok, the swamp is fenced to exclude wildlife and livestock. Conservationists and managers are concerned that continued encroachment into, and exclusion from, swamps will reduce

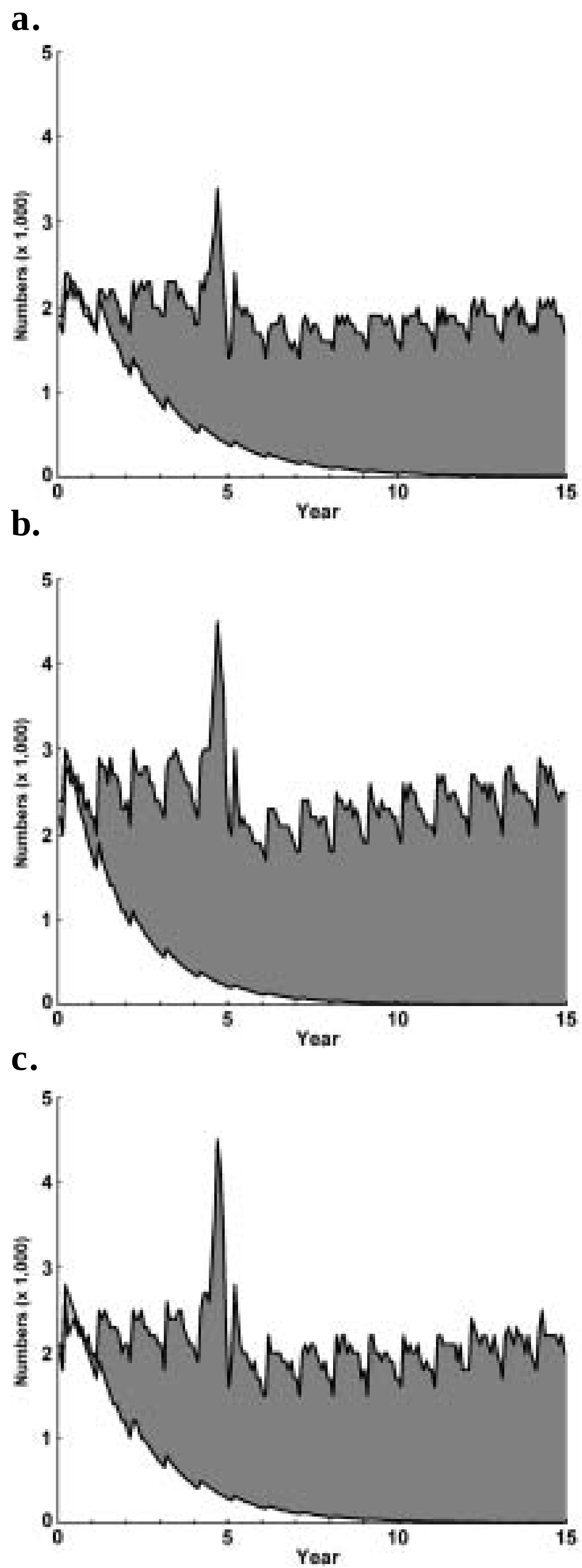


Figure 7.54. Darkly shaded areas show the dramatic decreases in cattle (a), goats (b), and sheep (c) in a portion of Mailua Group Ranch when livestock are restricted to the area. The few increases are more lightly shaded.

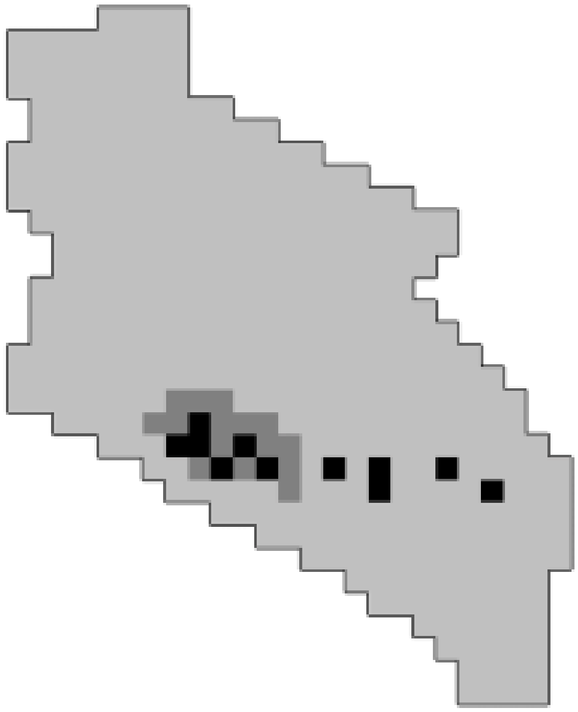


Figure 7.55. The swamps of southern Kajiado, generalized to 5 x 5 km square cells, are shown in black. Amboseli National Park is in a dark shade. Swamps within Amboseli are not available to livestock, and the two swamps to the east of Amboseli are fenced and not available to wildlife. Livestock may use those swamps in a limited way. Access to the two most eastern swamps is not restricted.

wildlife and livestock populations (see *Chapter 2* for more detail).

The swamps of Kajiado present a complex modeling situation. In the Kaj-SAVANNA control model that has been run to-date, patches of landscape were represented by 5 x 5 km cells (Figure 7.55), but the swamps are far smaller than 25 km^2. We incorporated that difference by including upland vegetation in those cells considered swamps, creating mixed-cover cells with upland and wetland (*Cyperus papyrus*) vegetation. Swamps within Amboseli are not available to livestock, and Namelok and Kimana Swamps are fenced, making them unavailable to wildlife. However, the fenced swamps are used by livestock as water sources and for limited grazing, (Jeff Worden, Colorado State University, pers. comm.). Small wetlands to the east are available to wildlife and livestock. These relationships to swamps were incorporated in Kaj-SAVANNA by modifying values within animal force maps.

In this experiment, we made the swamps entirely unavailable to wildlife and livestock. This was done by setting values for swamps in the soils map to zero, which in addition to identifying soils is used by Kaj-SAVANNA to identify the limits of the study area (values greater than zero) and areas to ignore (zero). Plant responses within the swamps may be expected to be unbalanced with all animals removed, so those areas were not included in the results reported.

Results from the simulation varied by animal group in a complex way, but in general, the changes in wildlife and livestock populations were somewhat smaller than we had anticipated, but in the direction we would predict. Changes in livestock populations were small (Table 7.6), as suspected given that livestock had no grazing access to swamps in Amboseli National Park and limited access to the fenced swamps (Figure 7.55). Grazing wildlife most common in the Amboseli region declined when swamps were unavailable, with buffalo declining by 17% (Table 7.6). Elephants increased and giraffes declined. Analysis of detailed output from the simulation shows that elephants were able to increase by altering their diets relative to the control model. Averaged across the year, elephants ate about 6% more unpalatable shrubs than in the control model, their populations grew, and they out-competed giraffes for acacia forage.

Isolation of Amboseli

The grazers of Amboseli National Park range far beyond the boundaries of the park during the wet season, and even in the dry season they range over an area more than three times the size of Amboseli National Park (Ole Katampoi et al. 1990:70). In general, wildlife congregate in or near the park during the dry season, grazing in swamps and elsewhere and using the nearby water sources. In the wet season, many of the animals move to the north and east to areas that re-

Animal group	Differnce (number)	Change (%)
Livestock		
Cattle	-4,000	-2.48
Goat	-5,500	-2.29
Sheep	-10,611	-5.55
Wildlife		
Wildebeest	-617	-3.38
Zebra	-1,356	-7.76
Buffalo	-270	-17.27
Grazing gazelle	141	3.28
Browsing antelope	756	3.65
Giraffe	-265	-6.27
Warthog	6	1.33
Elephant	67	6.81

Table 7.6. Numbers and percentage changes in animal populations when Kajiado swamps were no longer available for grazing or as water sources.

ceive more rainfall (Western 1982). These movement patterns are being disrupted because of the fragmentation of their migration routes and a reduction in the land available to the wildlife. An example already mentioned is the fencing of nearby swamps, once used by wildlife. Cultivation and high livestock densities limit seasonal dispersal to the north. More generally, Maasai are becoming less accepting of wildlife on their lands, especially without monetary reward (Western 1982; see *Chapter 2* for more details).

There are many suggestions and some ongoing experiments intending to improve the plight of wildlife outside of the park boundaries. As examples, local ranchers now benefit financially, to a degree, from tourism (Western 1982) and are reimbursed for livestock killed by wildlife (e.g., Mbogoh et al. 1999 quantifies some reimbursements). An extreme suggestion that attempts instead to contain the wildlife is to fence Amboseli National Park. Fencing the park may indeed seem extreme, but given that South Africa's Kruger National Park has been fenced for almost 40 years, a fenced-in Amboseli is a possibility.

We used the IMAS modeling tools to assess what the effects of fencing Amboseli would be on some of the wildlife populations within the park. Our methods were similar to those used in studying ownership patterns. We restricted the outputs reported by Kaj-SAVANNA to Amboseli National Park and ran a simulation using the settings from the control model. Mean population sizes for Amboseli National Park wildlife were calculated from that simulation. We then forced selected wildlife groups to be restricted to Amboseli National Park. That is, the animals were no longer to select the most suitable habitats from throughout southern Kajiado District, but rather had to select habitats from within Amboseli National Park (Figure 7.55 includes the park in darker shading and the black swamps it contains, generalized to 5 x 5 km cells). The animals in our simulation confined by fencing were wildebeest, zebra, buffalo, giraffes, and elephants. That is, we judged grazing antelope, browsing antelope, and warthogs not to be confined by fences that were likely to be constructed. We conducted two experiments: in one, wildlife populations were maintained at the levels within the control model – in essence, applicable if fencing was put in place with all wildlife congregated on Amboseli; and in the other experiment, populations were set to the mean observed in the control model – applicable if the fence where closed when a typical density of wildlife were on the park. Livestock are not allowed to graze within Amboseli National Park, and so were not of interest in this experiment.

When wildlife populations were as in the control model, and a simulation was run, populations of wildebeest and zebra (Figure 7.56a) and buffalo (Figure 7.56b) declined precipitously. As may be predicted, our simulation suggests that southern Kajiado District would support only a fraction of its current wildlife population if the animals were confined to Amboseli National Park. The park cannot serve as permanent grazing lands for wildlife without population reductions. Conversely, the wet season grazing outside of Amboseli Na-

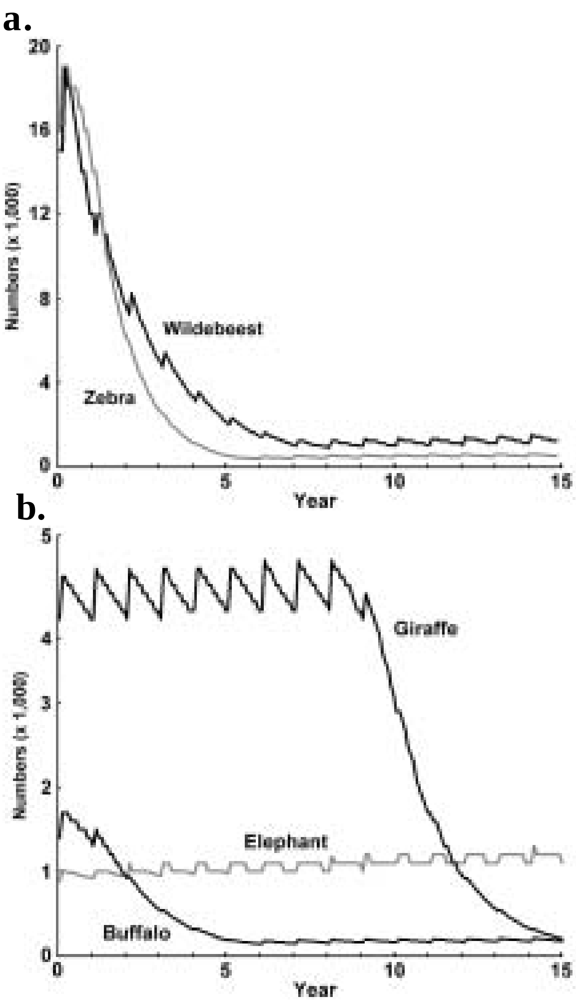


Figure 7.56. Populations of wildebeest and zebra (a), giraffe and buffalo (b) declined dramatically when their control model populations were confined to Amboseli National Park. Elephant populations did not decline (b).

tional Park is important in maintaining large mammal populations and conserving the dry season grazing of Amboseli. In the simulation, elephant populations increase slightly (Figure 7.56b), as do giraffes, until some critical population level is reached, then giraffes decline. Detailed output from Kaj-SAVANNA links this decline to a reduction in their intake of deciduous wood foliage. As in the experiment involving the removal of swamps, elephants in the Kaj-SAVANNA model out-compete giraffes and the other three wildlife populations. We believe elephants persisted in the model because they were not as reliant upon grasses as wildebeest, zebra, and buffalo, and can alter their diets more effectively than giraffes. That said, we adapted the model to the entire southern Kajiado District, rather than Amboseli National Park alone. Caution is, therefore, appropriate in interpreting these results. For example, although elephants may out-compete giraffes, we do not believe the giraffe population would crash as quickly as is shown in Figure 7.56b. Balancing the population dynamics of giraffes in the SAVANNA modeling system is more difficult than for other animal groups.

A more realistic simulation may be where wildlife populations were set to the mean population levels of Amboseli National Park during a control model run. When that simulation was conducted, the decrease in wildebeest and zebra was still large (Figure 7.57a,b), but less dramatic than in Figure 7.56a. Buffalo, elephant, and giraffe (Figure 7.57c) populations changed as they did in the control model, except for a late decrease in giraffes. Although less extreme, the results of this experiment again suggest that the wildebeest and zebra populations of southern Kajiado District would be significantly smaller if confined to Amboseli National Park.

We recognize that the experiments in this section oversimplify the ecological relationships of Amboseli. For example, fencing Amboseli would halt long distance migrations of wildlife (Ole Katampoi et al. 1990) that are likely important in maintaining genetic diversity and subpopulations. Also, stress on animals from being confined to a relatively small area, and the stress of interactions with tourists, have been ignored. However, we believe the IMAS tools have incorporated the principal relationships, such as forage quality and quantity, vegetation dynamics, and wildlife population dynamics.

SUMMARY AND LIMITATIONS

In general, we believe the GL-CRSP IMAS ecosystem modeling tools provide valuable tools to assist land managers in weighing benefits and costs of actions. We do not consider the outputs to be predictions of changes in the literal sense,

a.

b.

c.

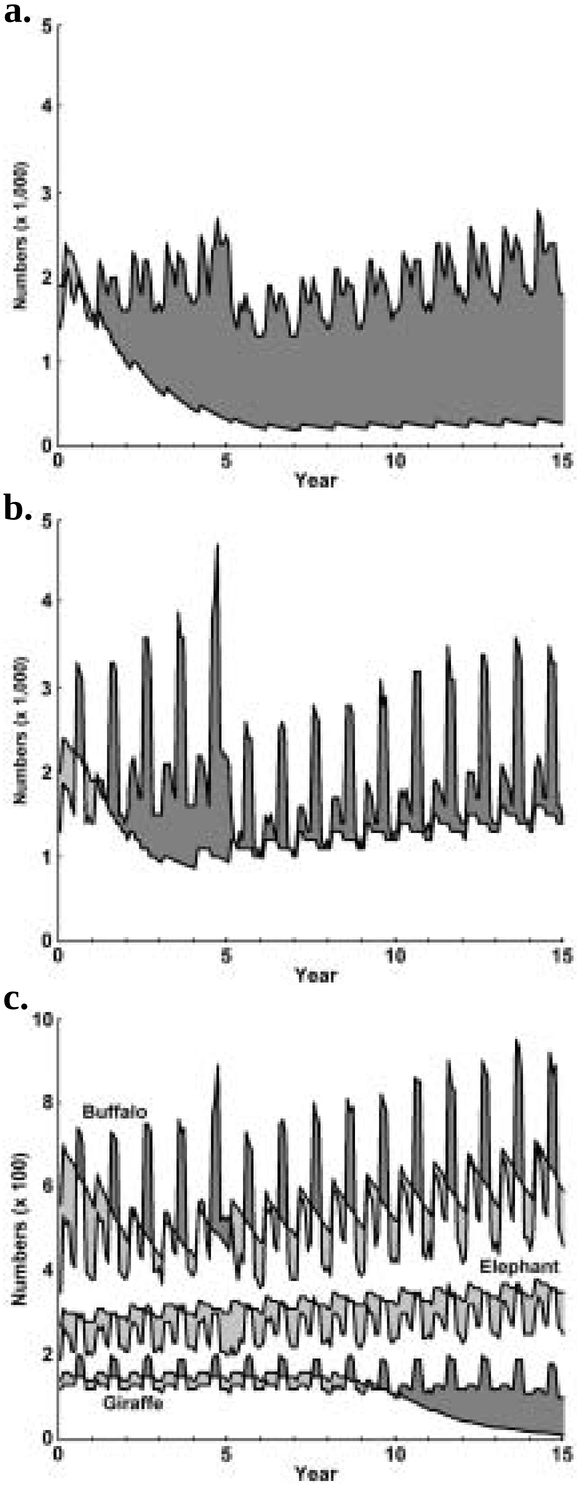


Figure 7.57. Populations of wildebeest (a) and zebra (b) declined relative to a control simulation when initial populations were equal to the mean population in the control model. Buffalo and elephant (c) populations did not change relative to the control. Giraffes declined in later years.

although the SAVANNA model may be used to generate such predictions in straightforward analyses in research settings. Instead, a specific goal of the IMAS effort was to make GL-CRSP IMAS tools available to local ecologists, researchers, and managers to use in their own analyses. With that as a goal, we could not anticipate the myriad of questions that the IMAS system may be asked to address. We do believe, however, that the outputs from NCA-SAVANNA and Kaj-SAVANNA show the relative magnitude and direction of changes correctly.

The system does two additional things that are as important as modeling general responses. First, by their nature the IMAS tools consider many interactions and report many responses. It is difficult for even the best informed managers to keep in mind all of the issues and concerns that must be balanced when faced with a management decision. A manager may consider improving security in southwest Ngorongoro, for example, and include in the thought process the cost of security, effects upon tribal relationships, implications for livestock production, and changes to range condition, but forget to consider implications for elephant populations. The results from NCA-SAVANNA include a long list of measures that might be of interest, which reduces the risk that some important interaction will be go unconsidered. The second benefit from the results of GL-CRSP IMAS simulations is that they provide a common framework from which a contested management decision may be discussed. Neither side in a given argument may agree with the IMAS results completely, but the two sides may begin discussion from a common ground, hopefully leading to a more speedy resolution.

This chapter has introduced a series of experiments addressed using NCA-SAVANNA. As mentioned, a primary goal has been to allow local researchers, managers, and ecologists to conduct experiments themselves. To attain that goal, we constructed a computer interface for the SAVANNA model called SavView which allows Ngorongoro stakeholders to repeat any of the experiments we have outlined, or to modify those experiments as they wish. People may conduct analyses using IMAS tools with just an hour or two of training. See *Chapter 6* for a description of SavView and other GL-CRSP IMAS tools. To-date, we have provided in-depth training in IMAS tools and ecosystem modeling to 26 East African scientists and managers, and have installed IMAS tools in five main locations (see Chapter 10 for more detail).

Chapter 8

Human Ecology, Economics And Pastoral Household Modeling

Kathy A. Galvin and Philip K. Thornton

INTRODUCTION

This GL-CRSP Project was founded on the notion that there is a need to establish a more appropriate and sustainable balance between food security and natural resource conservation in the pastoral regions of East Africa. Field studies and modeling work were designed to quantify the impacts of various problems such as high human population growth, livestock and wildlife diseases, conservation policy, land tenure issues, and agriculture on four objective functions: pastoral welfare, livestock production, wildlife, and ecosystem integrity. In this chapter we summarize some of the important field study and modeling results that have implications for pastoral welfare.

Human ecological research and modeling have been focused on two sites; the Ngorongoro Conservation Area, Tanzania and Kajiado District, Kenya, two areas with Maasai pastoralists living with a diverse wildlife population. In both cases, the Maasai pastoral strategies and interactions with wildlife are different and for different reasons. We explore here the Maasai situation and discuss scenarios of human welfare with the use of PHEWS, the Pastoral Household and Economics Welfare Simulator.

NGORONGORO CONSERVATION AREA

Human ecology has been the focus of interdisciplinary research in the Ngorongoro Conservation Area (NCA), Tanzania, where Maasai pastoralists live with a diverse and concentrated wildlife population. The NCA harbors one of the most spectacular and beautiful landscapes in Africa. Volcanic peaks of the Ngorongoro highlands rise steeply to over 10,000 ft. above Olduvi Gorge, the Rift Valley and the Serengeti Plain. The landscape and vegetation diversity supported across this escarpment is startling, with tropical mountaine evergreen and bamboo forests at high elevations and shortgrass plains at the base levels. Between the mountaine forest and the plains are woodlands, bushlands and grasslands of a vast variety of forms and composition (Herlocker and Dirschl 1972). The centerpiece of the NCA is Ngorongoro Crater, the 300 km^2 caldera of an extinct volcano. The crater has several water sources and its grasslands support a year-round population of herbivores and predators, which is seasonally supplemented by migrants (Moehlman et al. 1997). Herbivores include wildebeest, buffalo, gazelle, zebra, eland, elephant, rhinos and others. Until very recently, the crater supported the most dense population of predators (mostly lions and hyenas) known in Africa.

In addition to the wildlife, the NCA supports Maasai pastoralists and agro-pastoralists. In 1959, when the Maasai were removed from the Serengeti, there were approximately 10,000 Maasai resident in the NCA; over the ensuing forty years, the population has expanded to about 50,000 Maasai. Land use has intensified and most Maasai have become agro-pastoralists, cultivating small plots of maize, beans and other products (Kajazi et al. 1997). Agriculture was prohibited between 1975 and 1991; however, since 1991 the Maasai have been permitted to conduct limited cropping. Current conservation policies limit the amount of area that can be cultivated and outlaw grazing in some parts of the

NCA (McCabe, in press). Thus, as the human population has expanded, land use and conflicts have intensified, the Maasai sensing that their welfare and economic status were declining.

Yet, the Maasai are still dependent on grazing for their livestock as the mainstay of their livelihoods. During good years, there is enough forage for livestock and wildlife alike, but drought is not uncommon. The year 1997 was an extremely dry year, followed by the very wet el Niño event of late 1997 and 1998, followed by a very dry 1999 (Galvin et al., in press). In drought, many people and their animals migrate into the NCA from the north and south making the NCA a crowded place for people, livestock and wildlife (McCabe 2000).

Research

In a long-term study, we have examined Maasai pastoral well-being as measured through land use, household economy, health, and nutritional status. We examined the claims of the Maasai with respect to the impact of conservation policy on their land use and livestock holdings, their nutritional status and income levels. This research was supported, in large, by a NSF funded research program.

Land Use

The pattern of movement of the Maasai in the NCA throughout most of the 20th century was typical of many Maasai communities in Kenya and Tanzania. It involved remaining in the highlands for most of the dry season and moving down to the plains during the wet season. The short grasses of the plains are more nutritious than the grasses in the highlands and access to this resource was considered extremely important for cattle to recover condition lost in the dry season. In the NCA, there are few sources of water in the lowlands, and people and livestock would return to the highlands in the months of May or June as the plains dried out. In particularly dry years, the Maasai of the highlands would often move their cattle into the northern highland forest in the late dry season; glades in the forest provide cattle with access to grass not found anywhere else in the highlands during dry years.

This pattern changed following the irruption of the wildebeest during the 1960s and 1970s. The wildebeest population increased from approximately 240,000 to 1.5 million animals. The wildebeest migrate into the NCA and the Serengeti during the months of January-March and deliver their calves in the short grass plains. The dramatic increase in wildebeest numbers increased pressure on the forage resources of the plains, but what caused the most problems, from the Maasai viewpoint, was the increased chance of their cattle contracting malignant catharral fever (MCF). MCF is a viral disease that is benign in wildebeest, but nearly 100% fatal in cattle. Nearly all wildebeest calves are infected and remain so for approximately three months. The disease is transmitted through ocular and nasal secretions of the calves. Before the irruption, the Maasai could keep their cattle away from the wildebeest herds. However, following the increase in wildebeest numbers, the only way that the Maasai could ensure that their cattle would not contract the disease was to avoid the plains once the wildebeest began to calve. Thus, the mobility pattern that emerged involved people and livestock moving onto the plains shortly after the rains began and remained there until the wildebeest began to calve. At this time, the cattle returned to the highlands while small stock remained on the plains. The cattle remained in the highlands until either the wildebeest moved away or their coats turned from brown to black (around three months). Most of the cattle would then move back onto the plains until either the forage or water was limited.

This pattern is now altered in very dry and in very wet years. The year 1997 had a severe drought and 1998 was an el Niño year. The drought of 1997 forced people to remain longer in the highlands than they would in a normal year. In the highlands (Olirobi area, Nainookanooka), people and livestock did not stay as long in the lowlands as they normally do. During the dry season some people and livestock were forced to move into the Northern Highland Forest and the Olmoti Crater. The use of forage resources in Olmoti and in the forest prevented major losses to starvation, and people seemed to have been able to cope with this drought without major problems. Some people who live in the lowlands were forced to radically alter their mobility patterns, spending far more time than usual in highland locations. There were some problems with wildlife as people moved into forested areas, and many crops failed due to the lack of adequate rainfall. In addition, the NCA is a drought refuge and many people from north of the NCA migrated into the highlands areas. People from as far away as Kisongo, near Arusha, also migrated into the NCA (McCabe 2000).

The mobility pattern of the people and livestock in the Endulen area did not change much. They generally only move short distances from their homesteads in the wet seasons and remain close to home in the dry season. The major problems were caused by a large number of people and livestock moving into the area from north of the NCA and from the Olbalbal area. It was reported that the cattle were emaciated by the end of the dry season, but no major losses were reported. People said that human nutrition was low due to the fact that the livestock were not giving much milk, crops had a very bad year, and the price for selling livestock had dropped dramatically. In contrast, people and livestock from the Olbalbal area drastically altered their normal mobility patterns in this very dry year. About one half of the population took their livestock to the Endulen area during the dry season, while the other half migrated up into the forests on Olmolti Mountain. Both groups suffered major losses to their livestock. For the animals that went into the forested area, problems with wildlife were a major concern, while tick- borne disease caused many deaths among the livestock that went into the bush country near Endulen.

The year 1998 was a very difficult year for people living in the NCA. Because of the unprecedented amount of rain, the crops in the area failed and there were major outbreaks of rarely seen livestock diseases and malaria. The forage resource was at an all time high, so livestock could recover condition as long as they were able to avoid disease. People from the highlands stayed near their homesteads for longer periods of time than normal. When the heavy rains began, people and livestock moved down onto the plains, but many people contracted malaria there. It was decided that there was enough forage for the year in the highlands and both people and animals moved back to their homesteads a couple of months after moving to the lowland plains.

There was quite a bit of tick-borne disease among the livestock in Endulen. Two new diseases, lumpy skin disease and contagious bovine pleuropneumonia, also broke out. There were fairly heavy losses because of all three of these diseases. The 1998 year was very stressful for people and livestock in the Olbalbal area. Most of the crops failed due to excessive water, and a majority of the people came down with malaria. In addition to tick-borne diseases, lumpy skin disease also exacted a significant toll on the livestock in this area (McCabe 2000).

Maasai Economy

In 1991, research on the Maasai economy began by examining the claims of the NCA Maasai with respect to the impact of conservation policy on their land use and livestock holdings, nutritional status, and income levels. We hypothesized that conservation policy, through its limitations on land use, might have a detrimental affect on Maasai well-being as measured through household economy, health, and nutritional status. Our early research established that a large percentage of the NCA Maasai could not support themselves, but were supported, in part, by wealthier friends and relatives. Overall nutritional status was low and all NCA Maasai were in a chronic state of undernutrition (Galvin 1994, 1995, 1997, Galvin et al. 1994a). Our research supports Maasai claims of economic difficulties, but we were not able to confirm that the causes of their problems were rooted in the policies of the Ngorongoro Conservation Area Authority (NCAA). It is plausible that many of the problems experienced by the NCA Maasai are typical of pastoral populations elsewhere in the region or more generally, throughout Africa (Galvin 1992, Grandin et al. 1991). With this in mind, we conducted a comparative study of human welfare between the NCA and the adjacent Loliondo District where conservation policies are less restrictive on Maasai land use. Cultivation is practiced by most households in the Loliondo Game Controlled Area (LGCA), and there are few restrictions on grazing and agriculture, unlike the case in the NCA.

Analyses on livelihoods support the notion that the Maasai in both the NCA and LGCA are agro-pastoralists (McCabe 1997). This has occurred in the NCA only since 1991 as agriculture was banned before this time. The prime motivating factor involved in the diversification of livelihood strategies, specifically the adoption of cultivation, is to reduce the number of livestock sold to provide a pastoral family with non-livestock foods (mostly maize) and other necessities. However, we compared the economic state of the Maasai in the NCA with their neighbors just north of the NCA and ascertained that Maasai in the NCA are not as well off in a number of measures of well-being relative to Loliondo Maasai.

Figure 8.1 shows livestock to human ratios for the LGCA and the NCA as measured by TLUs (Tropical Livestock Units) per person. In our sample, LGCA Maasai have more than three times as many TLUs per person (Θ= 10.3) as the Maasai who live in the NCA (Θ= 2.8) (p< 0.0009). Moreover, LGCA Maasai have, on average, agricultural plots three times the size (Θ= .3 acres/person) of the NCA Maasai (Θ= .1 acres/person) (p=0.002) (Figure 8.2). Figure 8.3 shows the livestock/human ratios arrayed against the acreage per human ratios. The majority of the NCA households are clustered together and 87% of them have below the theoretical minimum of 6 TLUs per person needed for food security in pastoral populations (Brown 1973, see Galvin 1992 and Homewood 1992 for further discussions on TLUs among pastoralists). The figure shows that a much lower percentage (42%) of LGCA households are below this minimum (Lynn 2000).

The number of people in the household includes the head of the household, his wives and their children. Households in the NCA are significantly larger on average, with a mean of 22 people, while for LGCA the mean is 15

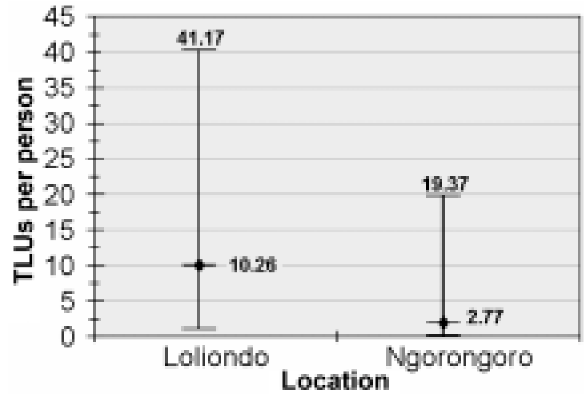


Figure 8.1. Livestock to human ratios (TLUs per person) for the LGCA and for the NCA.

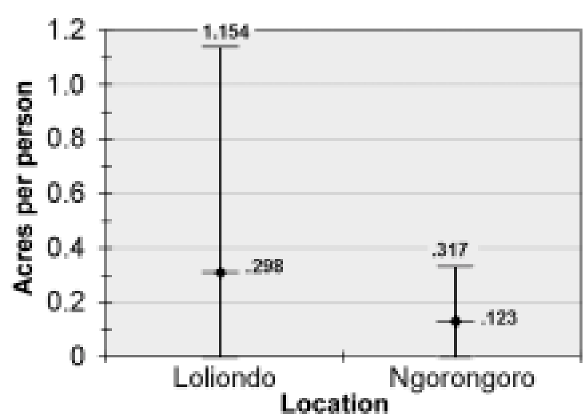


Figure 8.2. Acreage to human rations (acres cultivated per person) for LGCA and for the NCA.

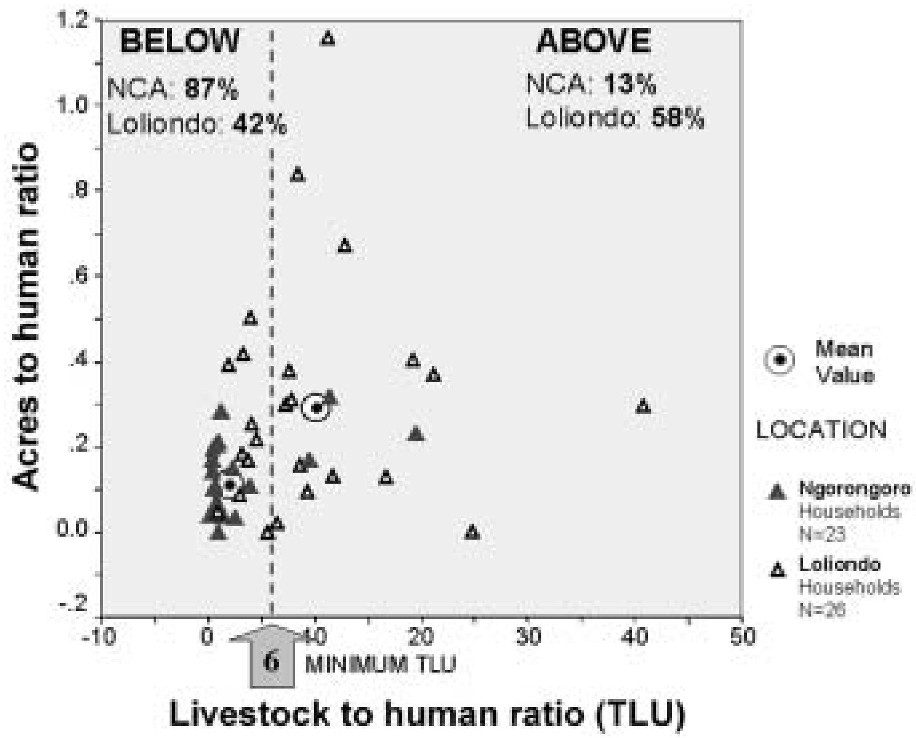


Figure 8.3. Livestock to human ratios compared to acreage to human rations with an estimate of the minimum number of TLUs needed per person for food security.

(p<0.008). A census (NCAA 1993) of the entire NCA reported an average of 8.2 people per household. Our study shows almost three times as many people per household as in the 1994 study. This could be related to our smaller sample size; however, rural population increases may be a factor, as there has been significant emigration to the NCA since the ban on cultivation was lifted (McCabe et al. 1997). Also, anecdotal evidence suggests that health care has improved in accessability and effectiveness during the last several years and may affect child morbidity and mortality (Endulen and Wasso, hospital doctors, personal communication).

Livestock sales were higher in the NCA than in LGCA. The mean number of cattle sold in Loliondo as a percentage of the total herd size was 3.7%; in the NCA it was 8.2% (Table 8.1). The same pattern exists for sheep and goat sales (Table 8.2). Households in Loliondo are generally located further from the livestock markets than those in the NCA, which may partly account for the higher sales in the NCA. In addition, discussions with pastoralists suggest that people sell diseased livestock, and households in the NCA appeared to have more diseased animals than those in Loliondo. Agricultural yields also revealed differences between the two regions. Whereas there was tremendous variability in agricultural yields (Table 8.3), yields per person were generally

Location	Mean (%)	SD	P	N
Loliondo	3.7	2.3	NS	14
NCA	8.2	7.5		15

Table 8.1. Cattle sold per household, as a percentage of the total herd. SD - standard deviation; P - P value; N - number of households surveyed.

Location	Mean (%)	SD	P	N
Loliondo	3.8	11.1	NS	16
NCA	7.4	9.2		21

Table 8.2. Goats and sheep sold per household, as a percentage of the total goat and sheepherd. SD - standard deviation; P - P value; N - number of households surveyed.

	Location	Mean (%)	SD	P value	N
Per acre	Loliondo	484.8	422.3	NS	15
	NCA	476.3	365.0		5
Per person	Loliondo	190.8	277.4	NS	12
	NCA	86.2	113.5		4

Table 8.3. Maize and beans harvested in 1997 and 1998. SD - standard deviation; P - P value; N - number of households surveyed.

about twice as high in Loliondo as those in the NCA.

The research demonstrated that Ngorongoro (NCA) Maasai are indeed economically worse off than their counterparts in the adjacent LGCA as measured in terms of the amount of agricultural land cultivated by households in each area and the number of livestock per human in each area. Although we had hypothesized that such a difference (if found) would be due to NCA policy restrictions, we also tested the effects of different ecological zones on these economic indicators. We found that although there were differences in human/livestock ratios among different ecological zones (lowlands, midlands, highlands), the differences between locations (NCA vs LGCA), overrode ecological zones variations. The same was true for area cultivated per person.

We also examined Maasai settlement and land use patterns among ecological zones within locations and across locations. Three settlement-land use patterns were discerned: Type A (sedentary); Type B (sedentary boma with seasonal herd movements); Type C (seasonal boma and herd movements). Type B patterns were most prevalent in LGCA, whereas Type C were most prevalent in NCA. Type B households had the longest annual travel distances, whereas Type C households had longer one-time movements (to seasonally temporary boma sites). However, daily distances were significantly shorter for Type C than Type B households. So while NCA households moved longer distances in response to seasonal changes, they were less mobile on a daily basis than LGCA households (Lynn 2000).

When comparing the two regions, we see clear patterns, but within each area there was considerable variability in various economic indices. For example, we look here at the large variability in livestock mortality, livestock sales and slaughtering within the NCA. Table 8.4 shows that for various locations within the NCA, the main cause for death was tick-borne disease. In Endulen, most of the death resulted from East Coast Fever (ECF) and Ormilo (about equally divided). There were also small numbers of deaths from contagious bovine pleuropneumonia and seven cattle were killed by lions. In Nainookanooka, the deaths were related to lack of forage in the dry season (46%) with the rest being caused by ECF. The reasons

		Cattle	Died	Sold	Slaughtered	Total Loss
Endulen	N	3089	235	76	12	323
	%		7.6	2.5	0.3	10.5
Nainookanooka	N	705	87	56	15	148
	%		12.3	6.5	2.2	21.0
Total	N	3794	322	122	27	471
	%		8.5	3.2	0.7	12.4

Table 8.4. Cattle offtake.

given for sales are as follows in rank order: clothes, food, taxes, grain, livestock, drugs, and hospital bills. The data for mortality and sales for small stock is less reliable than for cattle as people tend not to remember what happened to small animals as well as they do cattle (Table 8.5) (McCabe 2000).

The effects of livestock production and losses, and agricultural production influences household income in the two regions (Table 8.6) (Smith 1999). In both locations, livestock sales were the most important source of income, followed by crop sales. However, NCA households report crop sales as being almost three times as important as for households in Loliondo.

Maasai Nutrition

Comparison of nutritional data among the NCA Maasai with those living in Loliondo where conservation policies are much less restrictive should illuminate whether the problems experienced by the NCA Maasai are typical of pastoral populations in the region or whether differences between the two regions are due, in part, to conservation policy and the attendant reduction in human economic welfare as argued by the NCA Maasai.

Anthropometric measurements were taken on individuals in the LGCA and in the NCA. Measurements of height, weight, upper arm circumference (UAC) and tricep skinfolds (TSF) were taken on individuals depending on their age (WHO 1995). We analyzed the effect of years and regions (LGCA vs. NCA) on the anthropometry measures. ANOVA was used to detect annual differences between NCA Maasai nutrition in 1998 and 1999.

The results of comparing nutritional indices among NCA children in 1998 and 1999 showed that there was no effect of year on height of children, but weight differences were significant at the $p = 0.02$ level (0= 25.9 kg for children in 1998 and 0= 23.4 kg for children in 1999). Adult male and female Body Mass Index (BMI) scores (a measure of leanness), UACs and TSFs for NCA Maasai in 1998 were not different than those in 1999.

Figure 8.4 shows that, in general, girls and boys in Loliondo tended to weigh more than their NCA counterparts; however, the differences were not significant. Among two- to five-year old boys, the difference in mean weight was on the order of 15%; among the six- to thirteen-year olds, the difference was 17% and among the adolescents, it was 4%.

a.

		Goats	Died	Sold	Slaughtered	Total Loss
Endulen	N	546	0	0	0	0
	%					
Nainookanooka	N	1225	0	0	21	21
	%				1.7	1.7
Total	N	1771	0	0	21	21
	%				1.2	1.2

b.

		Goats	Died	Sold	Slaughtered	Total Loss
Endulen	N	320	0	0	0	0
	%					
Nainookanooka	N	270	0	12	21	41
	%			4.4	1.7	15.2
Total	N	590	0	12	21	41
	%			2.0	1.2	6.9

Table 8.5. Small stock offtake, including goats (a), and sheep (b).

a.	**Rank order of importance**					
	1	**2**	**3**	**4**	**Total**	**Importance**
Loliondo	(1.0)	(0.5)	(0.25)	(0.125)	**value**	(%)
Livestock sales	24	8			28.0	88
Crop sales		2	1	1	1.4	5
Animal medicine	1				1.0	3
Plow labor		1			0.5	2
Milk sales			2	1	0.4	1
Beadwork			1		0.3	1
Livestock skins				1	0.1	0
Total	**25**	**11**	4	3	31.7	100

b.	**Rank order of importance**					
	1	**2**	**3**	**4**	**Total**	**Importance**
NCA	(1.0)	(0.5)	(0.25)	(0.125)	**value**	(%)
Livestock sales	14	8	2		18.5	83
Crop sales	1	4		1	3.1	14
Honey sales			2		0.5	3
Mile sales				1	0.1	0
Total	15	12	4	2	22.2	100

Table 8.6. Sources of income and their relative contribution to the household economy.

The mean BMI score for all adult women from Loliondo is 19.4 whereas among women in Ngorongoro, it is 18.5. Loliondo men's mean BMI score is 19.7 versus 18.7 for men from the NCA. BMI scores were significantly different among the 18-29.9 year old women ($p<0.01$). The other age-specific values were not significantly different. Loliondo men's BMI scores for specific age groups also tended to be greater than those of men from Ngorongoro, but the differences are non-significant. Adult TSFs were significantly different by region for women ($p< 0.0001$) and for men ($p< 0.0009$) (Figure 8.5).

Summary

The Maasai of Loliondo clearly have more resources available to them than do the Maasai in the NCA, as measured by livestock holdings and agricultural plot size. The reason for the differences in area cultivated is a direct result of NCA Authority limitations on agricultural plot size in the NCA (McCabe et al. 1997). The issue is more complicated where livestock are concerned. There are policy restrictions on grazing in the NCA, but these restrictions are not so severe as to account for the vast differences in livestock holdings. However, in the NCA, the wildebeest migration excludes Maasai livestock from important wet-season forage resources preventing the traditional transhumant migration of livestock, i.e.,

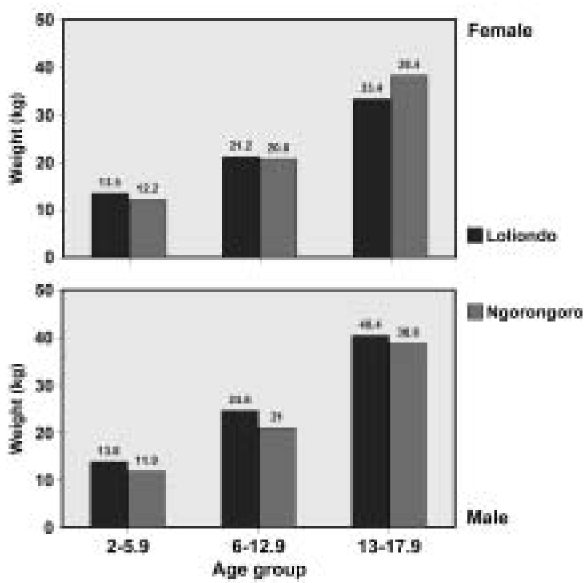


Figure 8.4. Weights of children in the NCA and in LGCA.

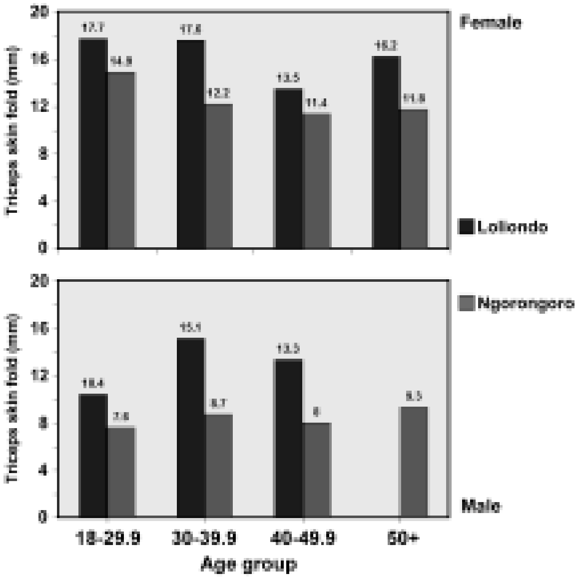


Figure 8.5. Measures of triceps skin folds of adults in the NCA and in LGCA.

moving into the highlands during the dry season and using the plains during the wet season. This is because wildebeest calves transmit malignant catarrhal fever to cattle, a fatal disease. In the past, the Maasai apparently harassed the wildebeest away from plains areas grazed by cattle, or fenced water holes, denying water to the wildebeest (McCabe et al. 1997). This is no longer possible within the NCA, although such actions could be used in the LGCA. Thus, livestock nutrition in the NCA is constrained by lack of access to the wet season range, and other disease problems (such as East Coast Fever) are exacerbated because cattle are confined to the highlands during the wet season. Reduced nutrition and increased disease incidence combine to limit production, reproduction, and early survival of NCA cattle (Machange 1997).

Households in the NCA are larger than in the LGCA. More livestock and agricultural produce are sold in the NCA than in LGCA. This occurs even though production is lower in the NCA than in the LGCA. It is likely that livestock and crops are used to make up for food shortfalls; we know that most expenditures go to purchasing food (Smith 1999). The Maasai children from Loliondo tend to have higher anthropometric measures than children from the NCA. But children in Ngorongoro tend to be better buffered from nutritional stress than are adults; a pattern common among pastoral populations (Galvin 1992, Galvin et al. 1994b). Adults of Loliondo also tend to show higher nutritional status (BMI scores). TSF measurements were also significantly higher among Loliondo women and men than among adults in Ngorongoro. These results suggest that conservation policy, among other things, affects resources available to the NCA Maasai and this may influence nutritional status of the population, especially in adults.

These comparisons demonstrate that the Maasai of Loliondo are better off than the NCA Maasai. Some of these differences (e.g., crop acreage) are clearly attributable to conservation policy. However, population density is greater in the NCA (6.0/km^2) than in the LGCA (3.9/km^2 with the use of population numbers from the 1988 Tanzanian census) which also affects access to resources. Whereas landscape variation did not seem to affect the differences, other factors such as distance to markets and health care may also contribute to variations in human welfare and resource access.

Our research has demonstrated that conservation and development policy must be carefully crafted for application in multiple use areas like NCA, the Greater Amboseli Ecosystem, and other places where wildlife conservation, livestock development and enhancement of human food security and welfare are all goals. Although there has been a lot of optimism for the future of community-based conservation, our results show that this optimism may be premature. We expect that optimization of multiple goals is not possible in most instances, and either conservation values or human development will suffer if this multiple-optimizing viewpoint prevails. Rather, policies and management of multiple use areas should seek compromises which can be accepted by the relevant stakeholders. At the NCA, for example, it is becoming more and more obvious that current policies are not sustainable. Something must change, and it is likely that if NCA is to remain a multiple use area, then compromises in both conservation and human expectations will be required.

How can the situation in the NCA be modified to improve human welfare and maintain conservation value? Data from the research have been combined in the IMAS to address a number of human welfare questions.

Modeling

PHEWS, the socio-economic household model for Ngorongoro Conservation Area, has been completed and tested, and is fully integrated within the Savanna Modeling System. A set of scenarios was drawn up that PHEWS and Savanna together would be used to investigate, and were run and analyzed. PHEWS was also to be adapted for Kajiado in Kenya (the second project site), a much more market-orientated production system. Work has progressed on this, primarily on the fieldwork needed to parameterize the model.

Early in the project, perhaps the major design criterion to be elucidated for the development of this model was that a rule-based approach should be used. Two factors in particular influenced this decision: the low level of market integration in NCA, meaning that standard economic models were unlikely to be appropriate, and the recent building and testing of simple, top-down models that seemed to offer substantial benefits with respect to the simplicity of the model processes and relatively short development time, while still providing useful information to the modeler and other users.

Thus, the general modeling approach taken is to use a small set of rules that govern the operation of the model, and then use the revealed characteristics of the model through simulations to adjust some of the key model parameters so that reasonable behavior of the model is obtained.

We hypothesized that there is a quantity T of Total Livestock Units (TLUs) per person that characterizes pastoral systems. While it is not immediately clear what this value of T is, the idea is that T increases to levels at which the operator becomes a commercial beef rancher, and decreases to the point where agro-pastoralism commences (at 0 it defines agriculture). The rules in the household model reflect the management decisions that are taken to aim at this target TLU per person, which may vary with wealth levels. If there are excess animals, these can be sold for cash. If there is a deficit, then animals can be bought, if there are resources to do so.

We also hypothesized a hierarchy of goals at the household level. First, the household has to meet its food requirement. If there is a shortfall, then this is made up by recourse to various options, including the selling of an animal, if necessary. Second, the household is assumed to manage for T in terms of investment and disinvestment decisions — these types of livestock purchases and sales can be considered different to the meeting of household food requirements. Third, there is discretionary consumption; after the first two goals have been dealt with, with consequent impacts on the cash reserves (purchase of food, for example), there may be a certain amount of cash left over for spending on various items.

Considerable field work had been undertaken in NCA, planned in part to generate information with which to test these hypotheses within a simple model framework. Once tested and applied in NCA, the plan was to use the same basic structure for the Kenyan case study area, Kajiado, using data collected from surveys and existing secondary sources.

One of the very attractive features of the Savanna Modeling System (SMS) is the ability to map outputs spatially and to be able to assess how spatial outputs change over time as well. A set of socio-economic outputs from PHEWS has been defined, and can be accessed by SMS for mapping. These spatial output variables are shown in Table 8.7. Modeled households are located in the landscape of NCA in a random fashion, depending on an underlying probability map for household location (Boone and Coughenour 2000). Spatial variation arises because of two factors: differences in household density per pixel, and differences in the relative preponderance of rich, medium and poor households in NCA. Given data shortages, we hypothesized, following Smith (1999) and Lynn (2000), that NCA could be divided up into three distinct areas based essentially on elevation: lowlands, midlands and highlands. It has been observed (Lynn 2000) that the relative occurrence of poor, medium and rich households in each of these areas is different, although detailed data on these changes are not yet available. Thus, we hypothesized a set of relative household occurrences based on the following:

- We classified 73% of the pixels in NCA as lowlands, 9% as midlands, and 18% as highlands;
- The weighted average of household type needed to match the typical household;
- Estimates were based on observations in the field.

As a result, we estimated that:

- In the lowlands, 39% of households are poor, 40% medium, and 21% rich;
- In the midlands, 29% of households are poor, 44% are medium, and 27% are rich;
- In the highlands, 22% of households are poor, 38% are medium, and 40% are rich.

In mapping output from PHEWS, output variables are weighted per pixel using these relative household occurrences, depending on where the pixel lies (lowlands, midlands or highlands).

Overview of Results

The activities of this modeling effort concentrated on two of the case study regions: Ngorongoro Conservation Area (NCA), northern Tanzania, and Kajiado District, southern Kenya, areas with very different specific problems, but that share common problems relating to pastoralism, wildlife conservation, and agriculture. The socio-economic household-level model was constructed and calibrated for NCA, and a range of scenarios were simulated. The model, named PHEWS (Pastoral Household and Economic Welfare Simulator model) produced results to show that all households depend on outside sources of calories. Pastoralist welfare in NCA, even with small amounts of agriculture allowed, is not internally sustainable at current human population levels. If realistic population growth rates are imposed for the next 15 years, then the household food security situation would deteriorate markedly. The model suggests that the introduction of agriculture in 1991 in NCA occurred at a time to make a substantial improvement in householders' welfare by reducing the dependence on "outside" grain at a time of rapid population growth. By the late 1990s, these welfare gains would have been overtaken by human population growth rates in excess of 6% per year. From a household welfare perspective, banning agriculture is not an option; poor households would be dependent for nearly one quarter of their calories from gifts and relief. Doubling the area of agriculture per household was shown to have a highly beneficial impact on the food security of poor and medium households. This doubling would still amount to only 0.6% of the land area of NCA. If pastoralists are to continue as part of the landscape of NCA, then allocating increased amounts of agricultural land seems an effective mechanism for improving household food security for the less well-off.

The model also shows that the NCA pastoralists are susceptible to drought; in the immediate term, household food security is severely compromised, but there is also the longer-term impact on livestock numbers where they have to be built up in the aftermath of drought. The model also indicates that various productivity-increasing interventions can have beneficial impacts on household welfare.

The NCA Control Model: Results from a Scenario Analysis

Boone and Coughenour (2000) describe the control model; the idea of which is to model

File	Variable	Temporal or spatial output
DIETP/M/R	• Household energy requirements, kcal • Milk consumed, proportion in diet • Maize consumed, proportion in diet • Meat consumed, proportion in diet • Sugar consumed, proportion in diet • Maize bought, proportion in diet • Relief consumed, proportion in diet	Temporal
HOUSP/M/R	• Cash reserves, Tz Sh • Own maize available, kg • Other crops available, kg • TLU welfare ratio • Cash welfare ratio • Actual TLUs • Adult Equivalents	Temporal
CASHP/M/R	• Cash reserves, Tz Sh • Net income, Tz Sh • Livestock purchase flag • Livestock sales flag • Crop sales, Tz Sh • Milk sales, Tz Sh • Other income, Tz Sh • Livestock sales, Tz Sh • Surplus milk sales, Tz Sh • Tea expenditure, Tz Sh • Livestock purchases, Tz Sh • General household item expenditure, Tz Sh • Maize purchases, Tz Sh	Temporal
ANIMP/M/R	• Cattle number in household herd • Percent female cattle in household herd • Percent adult cattle in household herd • Goat number in herd in household herd • Percent female goats in household herd • Percent adult goats in household herd • Sheep number in herd in household herd • Percent female sheep in household herd • Percent adult sheep in household herd	Temporal

Table 8.7. List of output variables generated by PHEWS that can be graphed in SMS. Spatial data that may be mapped includes household density, agriculture, net income, diet relief, household maize availability, tropical livestock units per adult equivalent, household's own food availability, cash box, and human population density.

Ngorongoro as it is now. The control model was used to calibrate the PHEWS module. Ecologically, the outputs of the control model are quite stable; animal populations rise and fall annually and in response to longer-term weather patterns of below- and above-average rainfall, but basically the system is relatively stable. For calibrating PHEWS, the object was to end up with similar stability in terms of household welfare and herd numbers. The control run was undertaken with no population increase imposed and with the values of a number of other inputs stable.

Summary results for the NCA control run are tabulated in Table 8.8. The first six rows of the table show the total percentage makeup of diet for the three household types.

The data of Smith (1999) and others show clearly that the diets of the Maasai in NCA do not vary much depending on household wealth. Assuming that gifts/relief (the portion of the diet that cannot be produced by the household from animals or crops, and that cannot be bought with cash) are in milk, then the dietary figures from the control run indicate that NCA diets are made up of about 12% meat, 29% milk, and 56% grain, which accords well with the approximate 10:30:60 proportions for meat, milk and grain that other researchers have found (Homewood and Rogers 1991, Bekure et al. 1991). A major indicator of household welfare lies in the percentage of gifts or relief. As might be expected, this changes sharply, depending on household wealth, from 13% of all dietary energy in poor households to zero for rich households. The problems that poor and medium households have are not surprising, given that these households have 1.07 and 1.65 TLUs per Adult Equivalent (AE), on average. Even the rich households have only 4.40 TLUs per AE, which is well below the threshold of 6-8 that is often cited as a necessary requirement for sustainable pastoralism (Dahl and Hjort 1976, Galvin et al. in press).

The need for poor households to receive gifts or relief is highly seasonal, as might be expected. Results for the average monthly relief figures for poor and medium households indicated that such households are clearly at serious risk of food insecurity during certain months when the household's own resources can provide 60% or less of the energy requirements of the household members. Interestingly, there was an interaction between the time when households are most affected and household type. Poor households were, on average, particularly badly affected in December, January, and February, while medium households were more affected in August, November, and December. Medium households had larger herds and more area in crops compared

Variable	Poor	Medium	Rich
Total milk consumed (% in diet)	13.1	20.1	29.0
Total own grain consumed (% in diet)	16.2	12.5	17.1
Total meat consumed (% in diet)	11.8	11.9	11.5
Total other, including sugar (% in diet)	2.9	3.0	2.9
Total bought grain consumed (% in diet)	42.5	44.1	39.6
Total gifts/relief (% in diet)	13.4	8.4	0.0
Total income from selling (Tz Sh, 000)	498	686	2,826
Cash used to buy food (Tz Sh, 000)	1,098	1,951	2,108
Average cashbox per month (Tz Sh)	9,504	11,131	132,453
Cashbox sd per month (Tz Sh)	7,389	10,602	44,862
Own food available (%)	41.1	44.5	57.6
Average TLUs per adult equivalent	1.07	1.65	4.40

Table 8.8. Summary output for the control run over 15 years for the three household types.

with poor households, but they had more people than poor households (about 12 AEs compared with 7) and thus, greatly increased monthly caloric requirements.

The results also highlighted differences in income and cash used to buy food by household type (these are totals over the 15 years of the simulation run). The average size of the cash box per month is shown in row 9 of Table 8.8. The standard deviation of these figures by household type showed huge variability for poor and medium households alike. The CV is close to 100%, again underlining the vulnerability of such households to cash shortages and thus, to food shortages as well. Again, as might be expected, the results showed that the richer the household, the greater the percentage of food available from the household's own resources, although even rich households were dependent for 40% of their calories on outside sources.

It must be remembered that these results apply in a reasonably steady-state situation. Assuming that the calorie transfers via gifts and relief are actually occurring, then the control run describes a reasonably stable situation. The results for evolution of rich household herd sizes demonstrated substantial seasonal variation, but the overall trends in livestock numbers per household are fairly flat. This is not surprising given that total numbers are cyclical, but stable (Boone and Coughenour 2000) and that the number of households is constant. Similarly, if the two ratios, actual TLUs per AE and cash income per month per AE, or the two welfare ratios (these as a proportion of the household's desired numbers of TLUs and cash income) are plotted over time, no trends were apparent for any of the household types. In a typical simulation year, poor households in the control run were selling two or three goats for cash, medium households are selling three goats and a steer for cash, while rich households were selling three or four steers during the year for cash.

As an example of the spatial output that can be produced using SMS, maps of model output were produced which showed that household density in NCA for the first four months of the control run. The maps were identical, as there is no population growth in the control run. In sum, the results from the control run for the household model showed reasonable stability over a 15-year period, but sustainability of households and household welfare for the less well-off are still dependent on gifts and/or food relief. All households depend on "outside" food calories, which have to be purchased.

The number of TLUs per AE for all household types was very low, and poorer households were very food- and cash-insecure. The control run shows clearly that pastoralist welfare in NCA, even with small amounts of agriculture allowed, is not even remotely internally sustainable at current human population levels. Even the basis for looking at a range of alternative scenarios, therefore, is of real concern. A range of other scenarios were run using Savanna and PHEWS. Details of the model can be found in Galvin et al. 2000 and in Thornton et al. In press

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KAJIADO DISTRICT

Research

The situation in the second case study site, Kajiado in Kenya, is very different from the case of NCA. The land tenure reform program implemented in Kajiado District from as early as 1962, in which group and commercial ranches were established, set the stage for the development of conflict between wildlife and pastoral livestock. The Land Adjudication Act of 1968 launched the process of conveying common and undivided land titles in the ranches to the members of the group, paving the way for a development program to convert the subsistence pastoralism on these ranches to commercial ranching (Davis 1999, 2000). Pastoralists were able to move about to avoid concentration of wildlife in their grazing areas at certain seasons in order to minimize transmission of diseases from the wildlife.

However, the assignment of property rights to discrete land rights has circumscribed such movement and reduced the flexibility with which pastoralists can use nomadic movement to minimize wildlife-induced losses.

The group ranch program had the objective of increasing the off-take of pastoral livestock for commercial sale and thereby meeting the objective of satisfying the beef demand of urban markets and also commercializing livestock production for the benefit of the pastoralists. However, the group ranch program has not fared well. Hardly any of the objectives for which it was established have been attained (Munei 1990). This is because the group ranches do not operate as economic organizations, but merely as commercial land units with a shared title deed by many individuals who carry on their livestock production activities individually. The essence of the group ranch is the joint acquisition of ranch capital inputs such as dips and boreholes. This would bring the pastoralists together in contributing to the establishment of these capital goods as well as in contributing to maintenance costs. But this aspect of group ranching is dormant. Most group ranches never managed to acquire these inputs and in those group ranches where they have acquired the inputs, many are rusting away from non-use. The individuals prefer to use hand pumps rather than communal dips, and to dig wells rather than jointly maintain and use a borehole.

Without the sharing of acquired inputs, the group ranch implies merely joint ownership. The focus of individuals in group ranching then becomes land ownership. Conflicts have arisen and proliferated over membership of a group ranch, and therefore, over entitlement to a share of the group ranch, as well as over the actual use of group ranch resources, such as grazing and water. The group ranches that have not been subdivided are generally those that have pending court cases concerning disputes over land ownership. There are also a few group ranches that have not been subdivided either because they are too dry (those in Magadi division, for example) or because there are some wildlife tourism benefits anticipated. Otherwise, the unmistakable trend for group ranches in the district is a movement towards privatization through subdivision. Table 8.9 shows the status of the subdivision of group ranches by September 1999. Twenty-nine group ranches have been completely subdivided such that the owners have obtained individual title deeds. In total, these group ranches account for 51% of all group ranches and 35% of the group ranch area. However, when these are added to another eleven group ranches in the process of subdivision, the extent of group ranch privatization becomes clear. There are thus 40 subdivided group ranches, constituting some 70% of all group ranches and 59% of group ranches moving into private ownership and control. Only 17 group ranches remain intact, constituting 30% of all group ranches and covering 41% of the group ranching area (Mbogoh and Munei 1999).

In the 1980s, Maasai group ranches began to initiate wildlife and tourism projects. At the same time, Maasai were rapidly changing from subsistence pastoralism to an economy of

Group ranches		**Completely subdivided**	**Partially subdivided**	**Not yet subdivided**	**Total**
Number	(n)	29	11	17	57
	(%)	50.9	19.3	29.8	100
Total area	(ha)	552,734	384,517	653,409	1,590,660
	(%)	34.7	24.2	41.2	100
Average area	(ha)	19,060	34,956	38,436	

Table 8.9. Status of group ranch subdivisions in Kajiado District, 1999.

farming, salaried employment, and commercial livestock ranching. Changing land use is currently transforming the entire economy of Amboseli from a mixed wildlife-livestock system to a primarily agriculture-based system. The proximity of wildlife, farm fields, and ranching is a cause of constant conflict. There are great uncertainties about the spread of fencing from shambas and small stock pasturage to wholesale areas, the subdivision and spread of cultivation to submarginal areas, wildlife becoming a commercial reality for the ranchers, the governments's ability to stem corruption, guarantee property rights and recover the Kenyan economy (Davis 2000). The Maasai production systems are very much in a state of flux. As in NCA, food security is still an issue of great concern, but the market orientation of these systems is generally widespread.

Relatively little is known, however, concerning the economics of ranching in Kajiado in recent times. The studies of Bekure et al. (1991) and Munei (1990) provide much useful detail, but up-to-date information on the economics and competitiveness of ranching is generally absent (Mbogoh 1999). For this reason, work on the Kajiado case study concentrated on assembling the information that would be needed for redefining parts of PHEWS and for calibrating it for the more commercially-orientated production systems found there. It was clear that some of the decision rules in PHEWS would need considerable revision from the NCA situation. Livestock purchasing and selling decisions in Kajiado, for example, may be made for very different reasons compared with NCA, and the type of model needed to simulate such decisions is likewise going to be somewhat different.

As part of the socio-economic sub-component of the CRSP project, two surveys were carried out in Kajiado to generate data for the socio-economic modeling effort. In addition, a 15-month PhD socioeconomic research project is underway. In the first survey of the wildlife, livestock and human interaction in Kajiado District focused on the case of the Amboseli National Park wildlife dispersal areas encompassing the Kimana and Mbirikani Group Ranches (Mbogoh and Munei 1999).

The first survey found no evidence of severe competition for available resources between livestock and crop production in both Mbirikani and Kimana Group Ranches. On the contrary, there appears to be some degree of complementarity. Manure from cattle and livestock keeping finds use in crop production. Livestock and cropping enterprises give relatively high rates of return to capital, and most of the pastoralists and agro-pastoralists are able to derive their livelihood from the two enterprises.

The second survey was carried out in July 2000 in an attempt to concentrate on the more highly commercial ranching operations found in the Kajiado District. In summary, all respondents were married male adult ranchers (in Maasai culture, ranching is a male activity). While ranching was the main economic activity, 57% engaged in other economic activity in addition to ranching. Some 23% of the sample attempt to produce crops within their land holdings whenever rainfall permits. Most ranchers keep cattle (mostly local breeds), sheep and goats. Over 70% of the herding, milking, and other livestock-related labour is hired, the rest being provided by family members. All respondents control ticks and give veterinary drugs (commonly antibiotics) to their cattle. Respondents had invested quite widely in a range of facilities, such as water boreholes, cattle crushes and dips, fencing and water tanks. Most had also invested in residential and workers' housing. Only 12% of ranchers had taken credit over the last five years. Most were for steer purchasing and fattening. Respondents cited high risk, high interest rates, and the logistical difficulties of getting credit as the major reasons for not taking more credit for ranch development.

Preliminary analysis indicates a mean annual profit per ranch of some KSh 205,000 (US $2,600) for all respondents, but there are large variations depending on ranch size. For those with less than 240 ha, for example, reported average total revenue barely covers average annual costs. Full survey results and analysis are presented in Mbogoh and Munei (2000).

The PhD research project is focused on the issues of how pastoral welfare, livestock production, and human-wildlife interactions are impacted by larger-scale environmental and political economic factors which characterize the greater Amboseli ecosystem (BurnSilver in progress). Research efforts revolve around the following three core questions:

1. What are current Maasai land use patterns across a gradient of ecological and human induced infrastructural heterogeneity?
2. How is the traditional strategy of pastoral mobility modified within the constraints imposed by current land tenure arrangements and household level choices of economic strategies?
3. What is the relationship between levels of pastoral welfare and the quantity/quality of human-wildlife interactions and Maasai land use patterns as reflected in economic strategies and spatial scale of land use?
   a) What are the economic strategies of Maasai households across different regions of the study area? To what extent are economic intensification and diversification occurring, and is there a spatial component to these economic strategies within the Amboseli Basin?
   b) What are the implications for Maasai productive strategies at the household level?
   c) Do these processes have implications for human-wildlife interactions within the Amboseli region?

Six study areas have been chosen as focus areas for the study. These six areas fall within four Maasai Group Ranches: Mbirikani, Olgulului/Lolarashi, Eselengei, and Osilalei. As well as falling along a climatic/vegetation gradient, the study areas represent a range of land tenure types, levels of market access, and available combinations of resource/economic infrastructure- all variables that interact to affect the land use strategies pursued by pastoralists within the wider Amboseli ecosystem. As well, these group ranches essentially form a ring around Amboseli National Park, and as such, contain the seasonal dispersal areas for much of the region's wildlife.

A general settlement survey of all bomas (Maasai compounds) within the six study areas was carried out in order to begin to address question number one described above. Data gathered included settlement location, number, and identities of elders within each settlement, economic activities (i.e., livestock, agriculture, employment and business activities), as well as the spatial distribution of all economic activities across the landscape. Table 8.10 and Plate 2b illustrate the broad land use patterns of Maasai producers across the study areas. These results represent land use at the scale of the settlement. The type and presence or absence of water resources is clearly a deciding factor in the land use and economic decisions taken by pastoralists in this area. Fully, 79.9% of all settlements are engaged in some form of agriculture; however, the type of agriculture ranges from rainfed (in Osilalei and Eselengei areas) to swamp-based irrigation (in the Southern Mbirikani study area), and extending south onto the rainfed slopes of Kilimanjaro at Loitokitok. The number of households in the Osilalei and Eselengei study areas, which are carrying out rainfed agriculture, illustrates that at the high end of the precipitation gradient defined by the Amboseli study zone, agriculture currently is considered to be a worthwhile economic diversification strategy by pastoralists. However, how successful a productive strategy this is over consecutive years remains to be seen. Even in areas with levels of precipitation not sufficient for rainfed agriculture, pastoralists are taking steps in order to guarantee themselves access to agricultural resources. Column 1 of Table 8.10 indicates that some pastoralists in particular areas (primarily Northern Mbirikani and Meshenani Ridge) are using a "two-boma system," in which households are split into multiple functioning units that straddle both an agricultural area (like the swamps or Loitokitok) and a dry pastoral area (like N. Mbirikani, Lengism, and Meshenani). This strategy of s*patial* economic diversification is an interesting phenomenon, and it remains to be seen if particular labor and capital requirements are necessary in order to make the strategy possible for individual households.

Both Plate 2b and Table 8.10 illustrate that a significant proportion of pastoral households across the Amboseli study zone are taking part in some form of employment and/or business activities. Business activities range from grain grinding, small shops, and cattle trading to buying and selling of vegetables and other commodities. Employment activities are centered around two major types of activities: 1) work in Nairobi/Malindi, and 2) employment linked with the wildlife and tourism sector. Preliminary analyses indicate that up to 55% of all employment across the six study areas is linked with wildlife and/or tourism.

This research project is employing data gathering tools at multiple levels in order to identify the processes at work which underlie the broad scale patterns presented above. Multiple entry household surveys are being carried out with a small sample of 38 pastoralist households across the six study zones. Preliminary analysis show that average TLUs per adult equivalent for each study area range from a low of 5.5 in Mbirikani South to a high of 10.23 for Meshenani (Table 8.11). The high and low results for these two areas in particular makes sense in view of the fact that large-scale land use patterns indicate a high dependence on livestock on Meshenani Ridge and a lower absolute dependence on livestock in the agro-pastoral area of the swamps.

	Land use types									
Study areas	Two bomas	Livestock only	Livestock Business Employment	Livestock Irr. agric.	Livestock Rain agric.	Livestock Agric. (Loitokitok)	Livestock Irr. agric. Bus. / Employ.	Livestock Rain agric. Bus. / Employ.	Livestock Agric. Bus. / Employ.	Total bomas
Osilalei	(0)	(0)	(0)	(63)	(77)	(0)	(2)	(0)	(0)	
	0.0	0.0	0.0	44.3	54.2	0	1.4	0.0	0.0	142
Eselengei	(3)	(1)	(5)	(4)	(14)	(0)	(3)	(19)	(1)	
	6.4	2.1	10.6	8.5	29.8	0.0	6.38	40.42	2.1	47
Lengisim	(4)	(2)	(15)	(1)	(1)	(1)	(2)	(4)	(0)	
	15.4	2.4	57.69	3.9	3.9	3.9	7.7	15.4	0.0	26
Meshenani	(12)	(24)	(7)	(4)	(0)	(2)	(0)	(1)	(5)	
	27.90	58.8	16.28	9.30	0.0	4.7	0.0	2.3	11.6	43
Mbirikani	(40)	(1)	(20)	(4)	(1)	(5)	(33)	(4)	(3)	
North	56.3	1.4	28.2	5.63	1.4	7.0	46.5	5.63	4.2	71
Mbirikani	(19)	(4)	(4)	(43)	(0)	(2)	(36)	(0)	(1)	
South	21.1	4.4	4.4	49.8	0.0	2.2	40.0	0.0	1.1	90

Table 8.10. Land use types across the study zones. *The first number in each cell (in parentheses) denotes number of bomas with specified land use type (column); the second number denotes the percent of respondents within that study area (row) using that land use type.

Study Area	Mean	N	SD
Selengei	5.23	6	3.363
Lengisim	9.99	6	9.553
Meshenani	10.24	7	5.840
Mbirikani North	6.32	8	4.287
Mbirikani South	5.52	7	1.960
Osilalei	NA	NA	NA
Total	7.42	34	5.582

Table 8.11. TLUs per average adult male equivalent/household. N - number of households; SD - standard deviation.

Anthropometry and Diet Intake

In cooperation with the District Hospital in Kajiado Town, the Lengism Mission Hospital, and Dr. Risa at Loitokkitok Hospital, anthropometric measures of nutritional status were taken on almost 1000 Maasai during May and June 2000 and within each of the six study areas. In addition, a number of diet intake surveys were conducted in June and July 2000 for Maasai women and their children.

The nutritional status information and household diet data, along with the economic data provide information on human economic status and human welfare under current circumstances. This information will be used in the PHEWS modeling system to project the effect of changes in policy, management, economic, or ecological conditions. For example, if policy or management decisions are contemplated that suggest an increase or decrease in the flow of income or food energy, we can, based on the current nutritional status indicators, suggest the impact of these decisions on human welfare and food security.

Summary

Land tenure changes associated with, first, the development of group ranches and then, processes of privatization have resulted in very different wildlife-livestock interactions for Kajiado than for the NCA. The implications for human welfare may not be that different, however. We do not know the answer at this time. It is clear that diversification of livelihoods in both space and activities has resulted in multiple land uses in Kajiado. Yet there is still a great dependence upon livestock. As was the case for the NCA, it is clear the conservation and development policy must be carefully crafted for application. It is likely that optimization of several goals such as wildlife conservation, livestock development, and enhancement of human food security and welfare is not attainable. Rather, compromised policies and management are going to have to be the rule.

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Chapter 9

Animal Disease Risk and Modeling in East Africa

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INTRODUCTION

Diseases of wildlife and domestic animals in East Africa not only affect animal populations and but also have economic, social, and political implications. Therefore it is important to include disease as a component of Integrated Management and Assessment System and to consider the impacts of disease in the generation of management alternatives for the ecosystem. This requires development of disease submodules within SAVANNA. Prior to developing the disease submodules, it is important to obtain information on the occurrence and distribution of important diseases within the affected animal populations. In this project, two general approaches were employed to obtain the necessary background information: 1) field disease risk assessments, as described for the Ngorongoro Conservation Area (NCA) below, and 2) use of published data and reports. Based on criteria such as morbidity and mortality and economic or ecological impact, 3 diseases were prioritized for initial emphasis: malignant catarrhal fever, rinderpest, and East Coast fever. For each of these diseases, it was necessary to either obtain data or make assumptions concerning species affected by the disease, its impact on the host population, development of immunity or resistance in each species, shedding, survival and transmission of the causative agent, the role of invertebrate vectors, and the application and economics of current disease control measures. Following development of the disease submodules, linking points and the nature of interaction with other submodules of SAVANNA were identified and characterized, including forage production, bioclimatology, animal nutrition, animal migration, animal distribution and contact, and animal population demographics.

DISEASE RISK ASSESSMENTS

Ngorongoro Conservation Area, Tanzania

The NCA is an 8,300 sq km area supporting various numbers of wildlife species and livestock. It can be divided into six land use zones based on rainfall, vegetation, and topography. Several factors including the availability of pasture, water, and salts influence the annual livestock grazing patterns in the NCA. The presence of ticks and tick-borne diseases and the potential for transmission of malignant catarrhal fever are major determinants of livestock grazing patterns, and a possible source of conflict between pastoralism and wildlife conservation (see *Chapter 2*). Participatory rapid appraisals (PRA) to determine the priority diseases of livestock, the animal health constraints to livestock productivity and the community perception to wildlife as a potential source of diseases of livestock were conducted. In 1998, the pastoralists identified East Coast fever (ECF), ormilo (turning sickness), malignant catarrhal fever (MCF), anaplasmosis, contagious bovine pleuropneumonia (CBPP), blackquarter, lumpy skin disease and anthrax as the most important diseases affecting cattle, sheep and goats (Tables 9.1 and 9.2). Since 1984, the incidence of tick-borne diseases including ECF and ormilo increased drastically and the average mortality rate associated with the two tick-borne diseases was 18% in adults and 52% in calves under 12 months of age. Analysis of PRA data was useful in documenting the seasonal and geographic occurrence, as well as the currently used means of control of these diseases. The risk of direct disease transmission from wildlife to livestock was primarily associated with the wildebeest. Disease incidence varied with the species and location (Figure 9.1), but, because of animal movements, virtually all livestock were considered to be at risk from all diseases present in the NCA. This information on disease interactions formed a baseline for development of the disease model for the IMAS.

The investigations on wildlife/ livestock disease interactions in the NCA revealed that some wildlife diseases and several livestock diseases constrain pastoralism and cause conflict between livestock production and the conservation of natural resources. The lessons learned in the study include:

1. During discussions with key stakeholders and community members during participatory rapid appraisals, the following diseases of livestock were identified as posing serious constraints to livestock production in the NCA: ECF, Ormilo, MCF, CBPP, calf pneumonia, anaplasmosis, anthrax, and blackquarter were the priority diseases requiring urgent intervention because of the high mortality rates they cause in livestock. An average mortality rate of 52% for calves below the age of one year was reported. This high mortality rate in itself could be responsible for the serious decline of cattle populations that has been observed in the NCA for a number of years. Tick-borne diseases, principally ECF, were listed as responsible for the high calf mortality. During the study, it became apparent that there is very little information, if any, on cause-specific morbidity and mortality data on nearly all the livestock and wildlife diseases in the NCA.

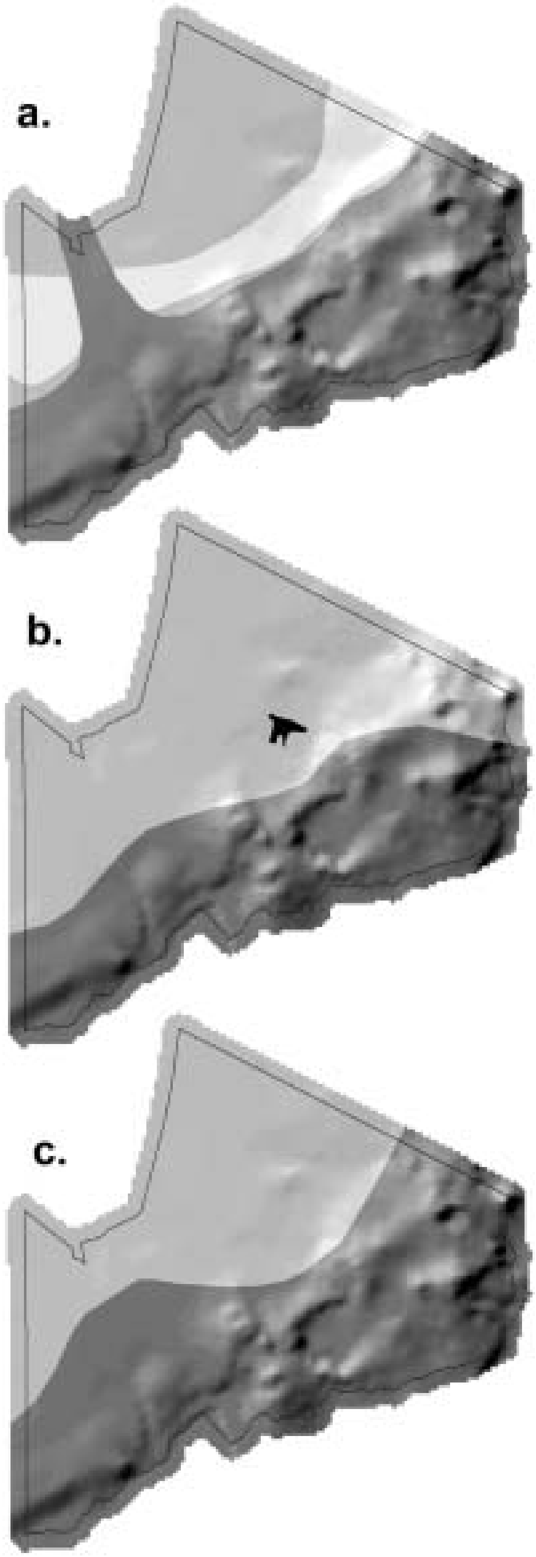

Figure 9.1. Disease risk in Ngorongoro Conservation Area, Tanzania. The sources of transmission or diseases are: a) buffalo (darkly shaded) and malignant catarrhal fever (lightly shaded), b) anthrax (black) and East Coast fever (darkly shaded), and c) *Rhipicephalus appendiculatus*. Adapted from Rwambo et al. (1999).

2. The annual removal of livestock from the short grass plains during the wet season to the intermediate and highland areas in avoidance of exposure to MCF virus being secreted from two to four months old wildebeest calves exposes livestock to high risks of transmission of tick-borne and infectious diseases. We were surprised to note that the community does not associate buffalo as a source of livestock disease, particularly as a source of ECF.

3. Although the disease risks are not evenly distributed in the NCA, the frequent migration of livestock in search of good pasture, water, salts, markets and in avoidance of specific diseases invariably leads to livestock being at risk of exposure to all the wildlife and livestock diseases (Table 9.3). The situation is worsened by the concurrent migration of various wildlife species in search of pastures, water, and salts. However, the risk of the transmission of selected animal diseases including MCF, trypanosomosis, anthrax and blackquarter is confined to geographically defined areas where risk can be mitigated by avoidance, albeit at the expense of availability of good grazing (Table 9.4).

4. The concentration of livestock and wildlife in the available pastures is a potential source of conflict between pastoralism and natural resource conservation. The available

	DISEASE	OLBALBAL	ENDULEN	NAINOKANOKA
1	East Coast fever	●	●	●
2	Anaplasmosis	●	●	●
3	Ormilo	●	●	●
4	Anthrax	●	●	●
5	Pneumonia	●	○	○
6	Eye infections	●	●	○
7	Skin infections -mange	●	○	●
8	Acute diarrhoea	●	●	○
9	Malignant catarrhal fever	●	○	●
10	Rinderpest	●	○	●
11	Foot-and-mouth disease	●	●	●
12	Contagious bovine pleuro-pneumonia	●	●	●
13	Contagious caprine pleuropneumonia	●	○	●
14	Bloat	●	●	○
15	Helminthosis	●	●	●
16	Coccidiosis	●	○	○
17	Blue tongue	●	○	○
18	Haemorhagic septicemia	●	●	○
19	Trypanosomosis	●	●	●
20	Blackquarter	●	●	●
21	Lumpy skin disease	●	●	○
22	Babesiosis	●	●	○
23	Foot rot	●	●	●
24	Heartwater	●	●	●
25	Brucellosis	●	●	●
25	Nairobi sheep disease	○	○	●

Table 9.1. Diseases affecting cattle, sheep, and goats in the NCA as identified during participatory rapid appraisals conducted in Olbalbal, Endulen, and Nainokanoka. Solid circles signify the presense of the disease, open circles its absence.

	OLBALBAL	ENDULEN	NAINOKANOKA
1	East Coast fever	East Coast fever	East coast fever
2	Malignant catarrhal fever	Ormilo	Ormilo
3	Calf pneumonia	CBPP	Anaplasmosis
4	Anaplasmosis	Blackquarter	
5	Anthrax	Lumpy skin disease	Malignant catarrhal fever

Table 9.2. Priority ranking of livestock diseases by Maasai respondents during participatory rapid appraisals conducted in three sites in the NCA.

space is greatly reduced through concentration of animals in areas with low risk of transmission of disease causing agents such as the MCF virus during the wet season.

5. To balance pastoralism and conservation of natural resources in the NCA there is a need to develop a sustainable livestock management program for the control of tick-borne and infectious diseases. A prerequisite of the development of such a program is the presence of a capacity to diagnose disease both in wildlife and livestock. There is some capacity to recognize clinical disease and provide treatment, but there is a clear lack of diagnostic ability to deal with mortality epidemics in both livestock and wildlife.

Kajiado District, Kenya

Based on a brief survey of Kajiado District, a disease risk assessment using a participatory rapid appraisal (PRA) approach was begun. Dr. Kamaru, District Veterinary Officer in Kajiado cited enhanced livestock dis-

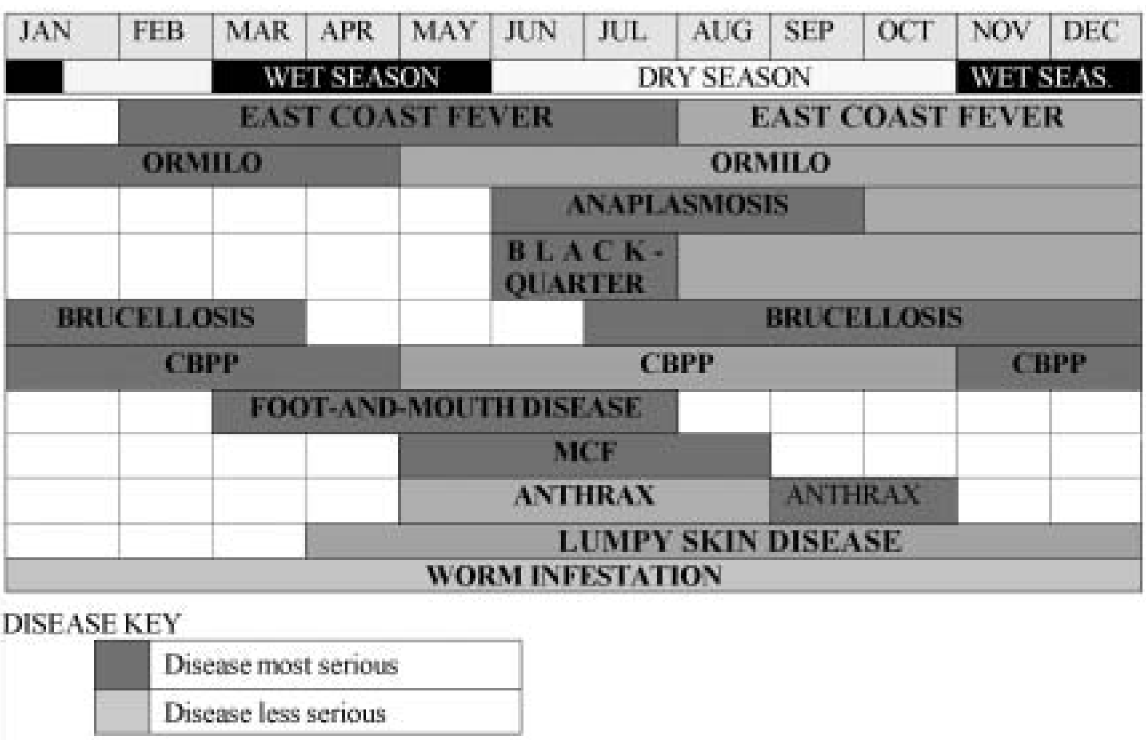

Table 9.3. Seasonal calender of livestock diseases in the NCA. The disease calender was derived from information obtained during PRAs in Nainokanoka, Olbalbal, and Endulen in 1998. CBPP is contagious bovine pleuropnemonia, and MCF is malignant catarrhal fever.

ease control problems because of the drought, including foot and mouth disease, contagious bovine pleuropneumonia, and ECF due to lack of adequate tick control. Transboundry issues (Kenya-Tanzania) relating to animal movement and disease introduction were also mentioned. The directors and several households in three group ranches that surround Amboseli National Park, including Eselenkei, Mbirikani, and Lolarash Group Ranches were interviewed

DISEASES	GEOGRAPHIC DISTRIBUTION	INTERVENTION
1 Tick-borne diseases 1. East Coast fever 2. Ormilo (turning sickness) 3. Anaplasmosis 4. Babesiosis 5. Heartwater 6. Nairobi sheep disease	1. Highlands 2. Crater 3. Slopes 4. Woodlands High humidity and vegetation cover. May be widespread risk because animal movement.	1. Early treatment with butalex 2. Infection and treatment with local parasite strains 3. Improved tick control with acaricides
2 Transboundary diseases 1. Foot-and-mouth disease 2. CBPP 3. CCPP 4. Lumpy skin disease	Not geographically defined. Risk increased by uncontrolled animal movement.	1. Vaccination 2. Vaccination and surveillance 3. Vaccination and/or antibiotics 4. Vaccination
3 Point source diseases 1. Anthrax 2. Blackquarter	Risk confined to limited areas for example in the Olbalbal swamp and depression.	1. Vaccination 2. Vaccination
4 Wildlife diseases 1. Malignant catarrhal fever 2. Trypanosomosis 3. Foot-and-mouth disease 4. Brucellosis 5. Tick-borne diseases 6. Intestinal parasites	1. MCF risk confined to short grass plains from Jan-April. 2. Tryps confined to low woodlands and riverine areas.	1. Keep cattle away from wildebeest 2. Chemoprophylaxis 3. Vaccination of cattle 4. Vaccination 5. Reduce ticks with acaricides 6. Strategic worming of cattle
5 Gastrointestinal parasites	Bomas	1. Strategic use of anthelminitics
6 Bacterial pneumonia	Bomas and highlands	1. Antibiotic treatments

Table 9.4. Geographic distribution, the risk of transmission, and the intervention strategy for control of common livestock diseases in the NCA. CBPP is contagious bovine pleuropnemonia, and CCPP is contagious caprine pleuropnemonia.

using a set of questions relating to livestock mortality and causes of ill-health by age class in cattle, sheep and goats. Information also was obtained about traditional knowledge of sources of diseases from observation of wildlife interactions, particularly MCF transmission to cattle from calving wildebeest. Several diseases consistently were cited as among the 5 most important problems including East Coast fever and other tick-borne diseases, malignant catarrhal fever, contagious bovine pleuropneumonia, foot and mouth disease, and anthrax. Mortality among calves was surprisingly high, often over 50%. The Veterinary Officer in Loitokitok, Dr. L. Mwamodo, was very helpful in translating Maasai names for these diseases into English.

DISEASE SUBMODULES

Introduction

Ecologists, epidemiologists and economists often find themselves faced with the need to model animal disease interactions in both time and space. However, the majority of animal disease interaction models that have been developed to-date characterize disease interactions only in time. Integrating these temporal disease spread models with spatial maps poses problems. The first recognized problem is that to integrate time and space requires a compromise in granularity of either time or space or both. Most often this compromise affects spatial resolution. Maps and areas of interaction of large animals that cover large amounts of space require enormous amounts of computer power to manipulate, and to integrate temporal disease models that show the spread of disease over time requires sacrificing either resolution in space or an increase of time intervals between each spatial snapshot. There are numerous references about temporal disease models and a few on spatial-temporal disease models. Very few of these spatial-temporal disease models actually use geo -referenced maps that depict animal density and animal movements over time. The reason seems to be that few researchers have developed methods for applying a temporal model to multiple spatial maps. The development of wildlife ecology modeling has become more important as decision makers realize the need to adjust to changes in climate, drought, fire and other natural effects on populations of both wild and domestic species.

Our goal in developing spatial disease models included development of models for malignant catarrhal Fever, rinderpest and East Cost fever in the NCA of Tanzania. We have finalized the model for MCF and have a draft model for rinderpest.

Malignant catarrhal fever

MCF is a highly fatal disease of cattle caused by *Alcelaphine herpesvirus* 1 (AHV-1) (Plowright, 1990). Affected cattle develop a multi systemic disease within a mean incubation of 4 weeks after exposure to virus. In Africa, wildebeest serve as unaffected carriers of the causative virus, AHV-1. After becoming infected from the dam, wildebeest calves shed the virus in nasal and ocular secretions and this serves as a source of infection for cattle exposed through grazing infected pasture.

For this project we used a mixture of long-term ecological data and computer (mathematical models) to examine epidemiology of MCF in the NCA. We have described the incorporation of a risk based biased mixing disease model (Hyman et al. 1989) into the spatial ecology model, SAVANNA. For this study, wildebeest and Maasai pastoralist cattle population and migration patterns have been compiled for SAVANNA, (McCabe et al. 1989; McCabe 1999.)

Recently reported data describe the annual removal of livestock from short grass plains, during the East Africa wet season, to intermediate and highland areas to avoid exposure to MCF virus secreted from 2–4 month old wildebeest calves. This confirms the use of proximity as an avoidance method in reducing spread of MCF from wildebeest to Maasai cattle (Figure

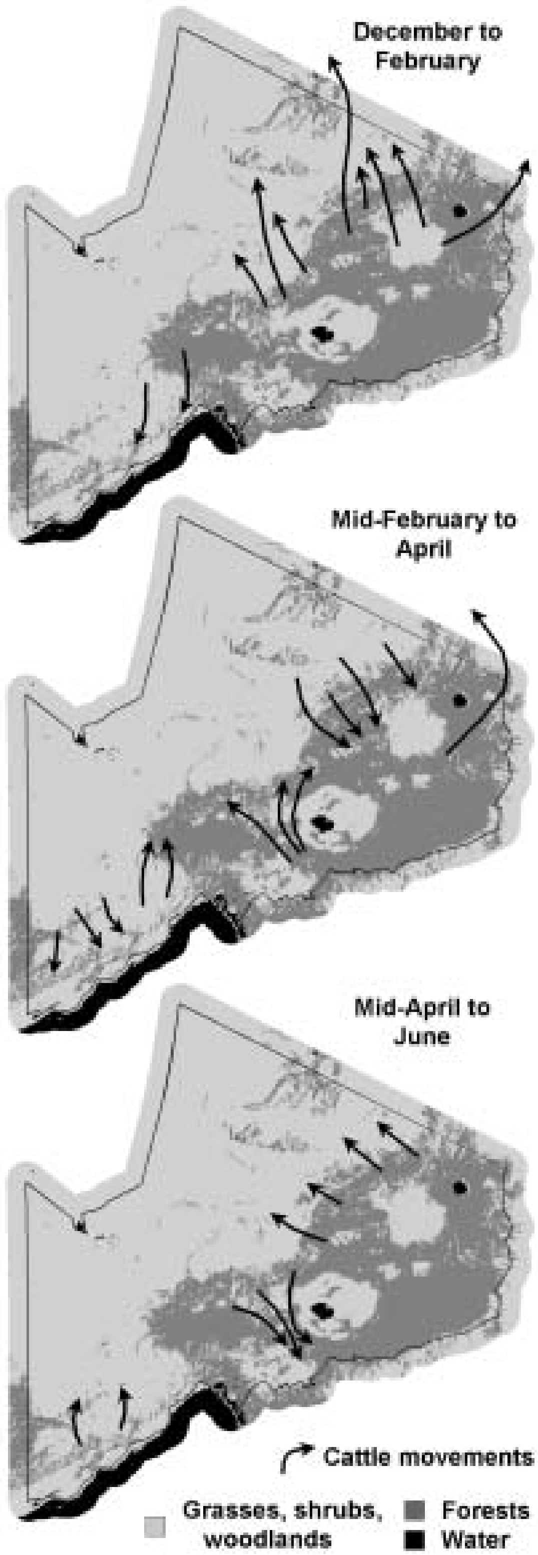

Figure 9.2. Maasai cattle movements, responding to the risk of MCF. In the dry season (not shown), the cattle occupy the midlands and highlands. Adapted from McCabe (1995).

9.2). Rweyemamu et. al. (1974), reported that AHV-1 is spread mostly through nasal secretions onto grass and grazing areas of the NCA and Serengeti, and Rossiter et al. (1983), found that the MCF virus survives in the environment for as little as 3 hours under the ultraviolet rays of the sun. These facts make the MCF model a point of contact model wherein cattle exposure to the virus depends on occupation of the same spatial area by wildebeest within a short period of time. All epidemiology and disease models track the spread and effects of disease within populations over time. It is only with recent advances in time step delineation of spatial data through computer simulation that models can be used to show spatial epidemiology curves and infection maps that represent both where and when disease in a target population is likely to occur.

In the development of spatial-temporal disease spread models the first step is to identify population densities on a map for each time interval or time step. The decision for the length of each time step is dependent upon the epidemiology of the disease. For MCF the largest time step possible is one week. This is based on the wildebeest calving cycle and the infectious period of MCF, which is relatively short. In some cases, such as rinderpest the incubation period must also be taken into account. Shortening the time step leads to magnitudes increase in computing time and mapping time to accomplish a diminishing return in accuracy. Spatial resolution becomes a consideration dependent on the size of the area. The area modeled, NCA and land within 5 km of NCA, is close to 10,000 km^2. Simple math will show that, for example: 52 weekly time step maps of 10,000 1-km x 1-km pixels for a period of 15 years equals 7,800,000 pixel elements that need to be processed for each species. Each pixel has to have estimates of seasonal population densities for at least two species. In this case a total of 15,600,000 pixels would be processed for wildebeest and domestic cattle with the probability that cattle might be exposed to MCF given parameters of prevalence, proximity, exposure and infectiousness of the disease agent. To ease the computational requirement we re-gridded the maps to 5 km x 5 km, with the study area 35 x 35 cells. This reduced the per species pixel count to a total of 955,500 for a 15 year simulation. (In practice, SAVANNA uses 12 months of 4 weeks each, for a total of 48 months in a year.)

The temporal model needed to be written in such a way that it can read the species population density map files. We found that writing these models in FORTRAN, Pascal, BASIC or Visual Basic was the best approach. The intersection of time step species maps, given probability input parameters, creates a series of weekly infection maps used in the display. (Figure 9.3) This is perhaps one of the limitations of creating spatial-temporal models. Many GIS and remote sensing software packages will export map images into flat file or binary format, but these software packages are not conducive to accessing map files directly without the use of import/export functions. At this time it is up to the researcher to read and write map files from a program written to model the intersection of two or more species maps and then write out an infection map readable by the GIS software of choice. When this process is automated it is possible to build a user interface screen to allow input and experimentation with sensitivity parameters such as proximity of one species to the next, exposure to disease time estimates, infectiousness estimates and prevalence estimates.

It is hoped that our work on spatial-temporal disease models can be used to further the science of building good simulations of disease interactions between wildlife and domestic cattle. One of our primary concerns has been the ability to evaluate the effectiveness of this type of modeling. To address this problem we considered modifying the model to accept input values for known quantities of exports of live animals from one area to another.

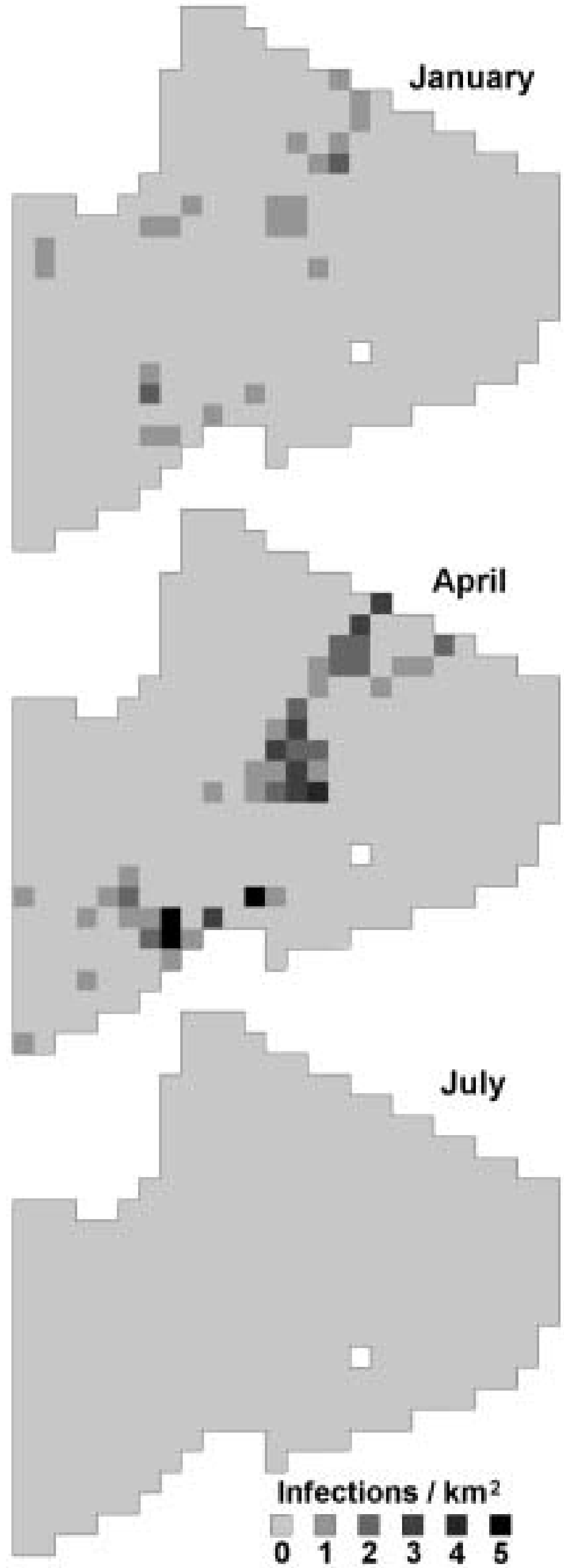

Figure 9.3. The number of MCF infections per pixel summed over four weekly time steps (one month).

Rinderpest

We sought to model the progression of rinderpest outbreaks in NCA herbivores. We required the model to: model patterns realistically, incorporate animal movements into disease risk and spread, ensure that the application was flexible enough to be applicable to other East African landscapes, and be compatible with logic used in the SAVANNA modeling system, since it is to be merged with SAVANNA.

To make the modeling effort more efficient, the modeling was made modular. We have finished an important module in that process, completing a model that predicts the spread of rinderpest throughout the host cattle population well. Because we sought to include the regional spread of rinderpest as cattle are moved about NCA, we required some 'tessellation,' some set of non-overlapping polygons covering NCA, to track cattle movements. We selected a set of 16 blocks used by K. Campbell and others to conduct aerial surveys in the early 1990s (Figure 9.4). These blocks were defined, in-part, based upon the densities of households and upon the geomorphology of NCA.

T. McCabe defined initial movement frequencies between the 16 blocks for 5 time periods during the year (i.e., dry season to short rains, short rains to early wet season, early wet season to wet season, wet season to transitional period, transitional period to dry season) using descriptions of movement patterns. R. Boone interpreted these descriptions; the matrices are draft, and will require review by T. McCabe to assure their accuracy. The matrices themselves are straightforward; there are 16 lines representing focal blocks, and 16 columns representing where cattle in the focal block moved in that season. Consider the following simplified matrix, representing three blocks:

1:	0	40	60
2:	10	80	10
3:	0	0	100

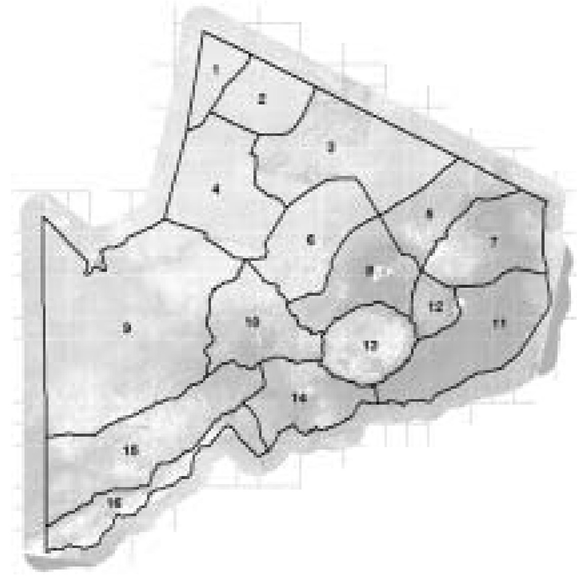

Figure 9.4. Aerial survey blocks used in describing the seasonal movements of cattle.

Here, the entire population in block 1 moved, with 40% going to block 2, and 60% going to block 3. In contrast, 100% of the animals in block 3 remained in that block. These matrices are used in the first week of the month or months in which they are set to be used, with entries in a parameter file used by the disease model dictating when matrices should be referenced.

In a simulation, SAVANNA provides to us a simulated population size for cattle for each 25 km^2 block within the landscape, which is composed of 407 blocks. R. Howe created a subroutine that estimates the proportion of a given population infected by disease, based upon a small suite of parameters. A parameter file is used that contains 16 copies of a set of parameters reflecting the proportion of a population susceptible, infected, exposed, and removed, as well as three parameters representing the spread of rinderpest, and a beta value, representing contact rate. These initial values may be customized for each block within NCA.

When first executed and during the first time step, a copy of the parameter file is created, which is then dynamic. During succeeding time steps, the values within the dynamic parameter file are modified reflecting the progression of the disease through the population. For example, as animals are infected and die or recover, the proportion of animals susceptible declines. At each time step, and for each block, SEIR (Susceptible, Exposed, Infected, and Removed) equations are applied. Differential non-linear coupled equations are used to yield a state transition model describing the proportion of the population susceptible, exposed, infected, and removed during each time step.

The model incorporates animal movements with the inclusion of beta values. Initial beta values for each of the blocks are given, but these are often modified based upon animal movements and population sizes. In general, for the block being modeled, the program calculates how many infected cattle had moved into the block from other blocks, based upon the movement matrices and animal population sizes. The number of infected animals moving into the block is divided by the population of the block during the previous time step (the population for the current time step is not yet available), yielding a ratio of infected animals to the total population. A multiplier is used to adjust the relative importance of incoming infected animals and the result is used to modify beta.

The program loops over the weeks of the year, currently running for 15 years, or 180 months. Infections can be set to start in any specific block, in a given month. Until an infection begins, rinderpest modeling is not conducted; the proportion of infected animals is set to zero for all blocks. When an infection begins, rinderpest modeling is conducted, the model returns the proportion of animals infected for each block, and tallies the total number of cattle in each block for the current time step. That total is multiplied by the proportion infected, to yield the number of infected animals. At the end of each cycle, the model loops through each of the blocks, asking if any of the blocks had more than 0.005 (0.5%) of the population infected. If none of the blocks are so infected, the outbreak is considered over.

From experiments, it appears that a given infection will move through a subpopulation within about seven weeks, with the current parameters. The time required for an outbreak to fade entirely from the system depends upon rates of movements and the block that is first infected. For example, as parameterized now, an outbreak fades from the entire population in about 14 weeks, when block 6 is first infect (Figure 9.5). Based upon the simulation and detailed analyses of outputs, the modifications to beta associated with animal movements are being modeled correctly.

CONCLUSIONS AND RECOMMENDATIONS

1. A risk-based disease model for MCF virus transmission from wildebeest calves to cattle in the NCA was developed and evaluated.

2. Surveys in the NCA indicated that:
- Livestock disease was perceived by the pastoralist as the most important constraint to livestock production.
- Lack of disease control was a constraint to livestock production.
- Tick borne diseases were identified as the main cause of mortality.
- High calf mortality (> 50%) and a major decline in cattle herd numbers were observed.

3. The impact of disease on land use in the NCA included unavailability of prime cattle grazing land during the wildebeest calving season and consequent increased cattle grazing pressure and cattle density along with enhanced risk of tick-borne diseases in the NCA highlands.

4. MCF has an indirect impact on ecosystem integrity by confining cattle to intermediate/highland areas leading to resource overuse and depletion.

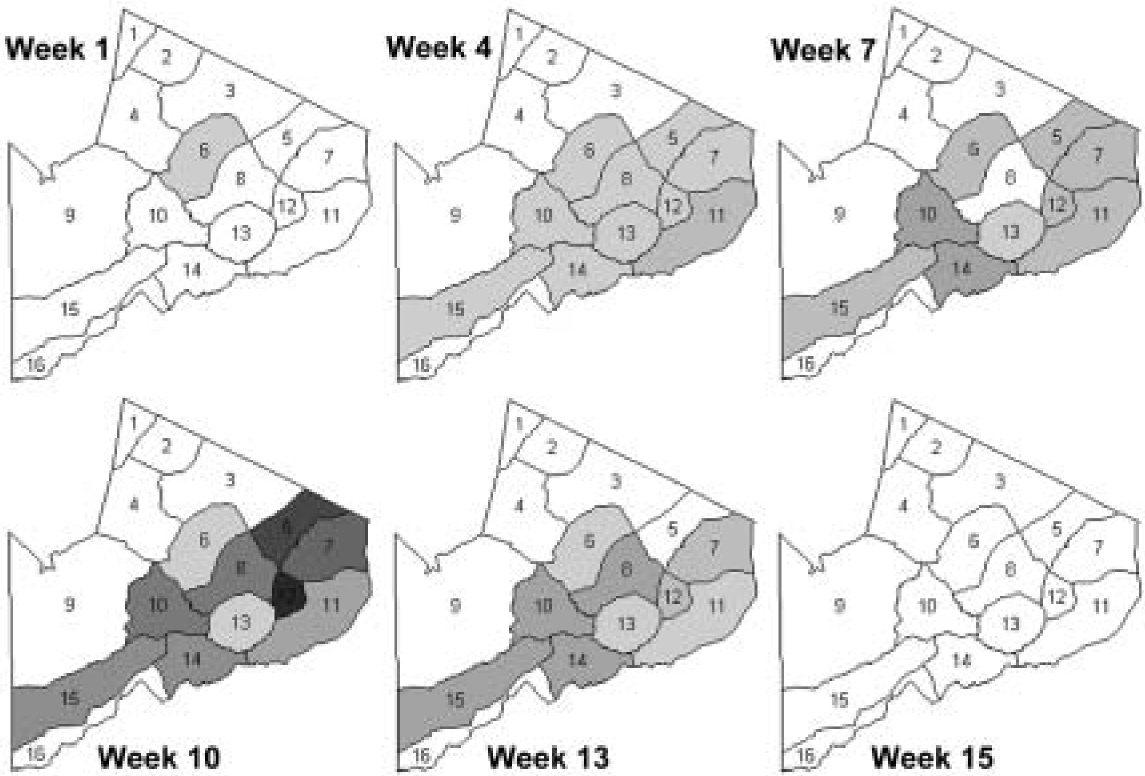

Figure 9.5. The spread of rinderpest amongst cattle populations is modeled, with darker shadings showing more infected animals. In week 1, an outbreak begins in block 6, perhaps from infected animals that were transported. Cattle from many blocks feed in block 6, and so the disease spreads to other blocks. The outbreak reaches its peak in week 10, and fades by week 15, as parameterized.

5. Alternative strategies for control of MCF disease risk in the wildebeest calving grounds in the NCA include: 1) avoidance of contact between cattle and wildebeest calves within the first 3 months of age, 2) erection of wildebeest-proof fencing to prevent co-grazing by cattle and wildebeest calves, taking into account the cost-benefit ratio, or 3) development of a vaccine for MCF.

6. Rinderpest (R) and anthrax (A) have a direct impact on the population of wildlife species, including buffalo (R, A), eland (R) impala (A), and elephant (A).

7. It is important to complete the rinderpest and East Coast fever submodules in the SAVANNA model.

8. A future effort should be directed toward quantifying the impact of disease on land use, livestock productivity, and ecosystem integrity in the NCA.

Chapter 10

Making GL-CRSP IMAS Useful to Stakeholders and Policy Makers

Michael B. Coughenour and Randall B. Boone

INTRODUCTION

The goals of the GL-CRSP Integrated Management and Assessment project included both conducting assessments of food security, conservation, and ecosystem integrity in East African sites, *and* building the capacity of East African land managers and policy makers to conduct their own assessments. To meet those goals we had to have a clear understanding of the problems in the region and approaches to solutions.

We used the expertise of African project personnel and input gathered during workshops to define issues of concern to stakeholders. Further input was received, and East Africans informed of our progress, during workshops and meetings demonstrating our results. Lastly, we put equipment in place and trained personnel to conduct their own assessments. These topics (*Input from Stakeholders, Outreach, Training, Capacity Building,* and *Impacts on Policy*) are expanded upon in the next section. Of course, there is a great deal of overlap in the sections – during outreach presentations or training we received many comments reflecting stakeholder concerns, for example. As another example, our work to inform policy makers overlapped with general outreach efforts, with many leading policy makers attending our workshops and presentations.

METHODS

Inputs from Stakeholders

Stakeholders and their concerns were essentially represented in the assessment project from the start. Ecologists and anthropologists on the team had decades of experience working on East African issues (e.g., M. Coughenour, K. Galvin, J. Ellis, T. McCabe, R. Davis) and had discussed issues of concern with stakeholders extensively. Our team members living in East Africa (R. Reid, P. Rwambo, M. Rainy, R. Kidunda, P. Thornton, J. Njoka, J. Kinyamario, and others) had similar levels of experience, plus sometimes daily exposure to the problems facing stakeholders of the pastoral lands of East Africa. To gain further input and formalize understanding a workshop was held in February of 1997 at the International Livestock Research Institute, Nairobi, Kenya. The workshop, entitled "*Developing a Decision Support System for Integrated Assessment of Pastoral-wildlife Interactions in East Africa: Team Formation, Stakeholder Input, and Preliminary Design*," brought together 22 scientists, conservationists, and a representative of pastoralists (Table 10.1a) to discuss project direction. Participants shared their experiences with pastoral-wildlife systems, and specified the types of information that would be useful from their perspectives. A conceptual framework for the assessment system was developed, research sites were evaluated, and overarching goals, objectives, and assumptions were identified. Meetings held in-concert with the workshop gathered input from eight additional directors and scientists (Table 10.1b).

A second workshop was held at the International Livestock Research Institute (ILRI) in May 1997 entitled "*Developing a Decision Support System for Integrated Assessment of Pastoral-wildlife Interactions in East Africa: Setting Regional Priorities*." Representatives from governments, non-governmental organizations, donor agencies and universities from Kenya, Tanzania, Ethiopia, and Uganda joined the assessment team to set regional priorities for the project. First, there were several demonstrations of how tech-

Table 10.1. Participants (a) in an GL-CRSP IMAS workshop held in February of 1997 at the International Livestock Research Institute, Nairobi, Kenya, and those with whom we met to discuss the project (b). Input from the participants in the project helped to guide the assessments conducted under IMAS and the tools we created. A similar workshop (participants not shown) was held in May of 1997, gathering more feedback.

a. **Workshop participants**		
1.	Ed Barrow	African Wildlife Foundation, Kenya
2.	Dennis Child	Colorado State University, USA
3.	Michael Coughenour	Colorado State University, USA
4.	Jim DeMartini	Colorado State University, USA
5.	Raoul DuToit	African Wildlife Foundation, Zimbabwe
6.	James Ellis	Colorado State University, USA
7.	James Else	Uganda Ministry of Tourism, Wildlife, and Antiquities,
8.	Jan Grootenhuis	Private consultant, Nairobi, Kenya
9.	Rashid Kidunda	Sokoine University, Morogoro, Tanzania
10.	Jenesio Kinyamario	University of Nairobi, Kenya
11.	Russ Kruska	International Livestock Research Institute, Nairobi, Kenya
12.	Patricia Moehlman	Private consultant, Arusha, Tanzania
13.	Terry McCabe	University of Colorado, USA
14.	Phillip Murithi	African Wildlife Foundation, Nairobi, Kenya
15.	Francis ole Ikayo	Inuyat e-Maa, Arusha, Tanzania
16.	E. B. O'Malley	University of Colorado, USA
17.	Mike Rainy	Bush Homes, Molepo, Kenya
18.	Robin Reid	International Livestock Research Institute, Nairobi, Kenya
19.	Paul Rwambo	Kenya Agricultural Research Institute, Nairobi, Kenya
20.	S. P. Shampole	Kenya Agricultural Research Institute, Nairobi, Kenya
21.	Philip Thornton	International Livestock Research Institute, Nairobi, Kenya
22.	Edna Wangui	International Livestock Research Institute, Nairobi, Kenya

b. **Discussions**		
1.	Augusta Abate	Kenya Agricultural Research Institute, Nairobi, Kenya
2.	Jesse Cheriot	Kenya Agricultural Research Institute, Nairobi, Kenya
3.	Holly Dublin	World Wildlife Fund for Nature
4.	Hank Fitzbugh	International Livestock Research Institute, Nairobi, Kenya
5.	John Mfula	Kenya Agricultural Research Institute, Nairobi, Kenya
6.	Adrian Mukhebi	International Livestock Research Institute, Nairobi, Kenya
7.	Dennis McCarthy	US AID Regional Economic Development Office,
8.	Jesse Njoka	University of Nairobi, Kenya

nology (e.g., the SAVANNA modeling system, GIS analyses) has been used to address various science and management questions and how the results have (or could) influence policy. Second, people from several organizations in the region presented their policy and management perspectives within the context of the integrated assessment system. Within the context of regional perspectives, workshop attendees identified scientific priorities, policy priorities, and priorities for the needs and welfare of pastoral peoples. Working groups discussed human ecology and economics; disease interactions, range ecology, livestock production and pastoral needs, range ecology and wildlife, and regional analyses and policy. Study sites were selected, and site-specific problems, data needs, and team members were identified.

R. Woodmansee joined the project to apply his Structured Analysis Methodology (SAM) to the problem of livestock-wildlife interactions. The SAM is a structured approach to addressing stakeholder concerns in natural resource management. It is especially useful in sites where multiple stakeholders share common interests in resources. SAM was used in a large workshop entitled "*Integrated Modeling, Assessment, and Management of Regional Wildlife-livestock Ecosystems in East Africa*," held at the International Livestock Research Institute in early July, 1999 and supported by the Regional Economic Development Services Office (REDSO) for East and Southern Africa, US AID. In the workshop, Dr. Woodmansee guided the participants in exercises using SAM, which identified stakeholder concerns (see Rainy et al. 1999 for more detail, *Appendix C*). Many of those concerns were incorporated into the Integrated Management and Assessment System project.

Outreach

GL-CRSP IMAS, the SAVANNA modeling system, and our experiments were demonstrated to East African scientists and managers at the REDSO workshop just mentioned (Rainy et al. 1999). A more technical demonstration of the work was given to ILRI technicians. Soon after, four demonstrations of IMAS were made throughout northern and central Tanzania (i.e., Arusha, Ngorongoro, Dar es Salaam, and Morogoro [Figure 10.1]). Finally, GL-CRSP IMAS and SAVANNA experimental results were demonstrated to personnel of the Kenyan Wildlife Service. All told, the IMAS project was introduced to over 100 East African land managers, scientists, and stakeholders during that outreach effort. During demonstrations of our work, we received positive feedback and encouragement. Some of the most ardent support came from those responsible for managing areas for which IMAS has yet to be applied (e.g., Tarangire National Park, Tanzania) but who struggle with issues the system can address.

We are pleased that AWF has shown a high degree of interest, facilitated by their representation at the REDSO workshop and other discussions. We have encouraged this collaboration from the outset of the project. The Director of AWF (P. Bergin) is fully informed. While in Tanzania we had discussions with A. Kijazi at the African Wildlife Foundation and with C. Sorenson, who is directing a large livestock development project for Danish Aid for Development Assistance (DANIDA) in the Ngorongoro Conservation Area (NCA) entitled Ereto. T. McCabe had the chance to discuss the utility of the model to their projects in more depth than we were able to do in the mini-workshops and model demonstrations. In addition, T. McCabe discussed the assessment and the model with potential users in the area north of the NCA called Loliondo Game Controlled Area. There are a number of non-governmental organizations working on land use issues in northern Tanzania, and are interested if we were to continue and expand the project to the Loliondo area. J. DeMartini, J. Grootenhuis, and R. Boone met with members of Terra Nouva to discuss use of disease modeling in their work with rinderpest, and J. Worden and R. Boone met with Dr. J. Wandera of the Semi Arid Rural Developement Programme to discuss their use of GL-CRSP IMAS.

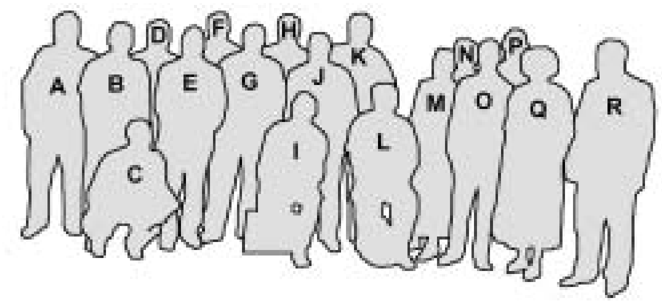

Figure 10.1. Participants in an IMAS demonstration held at Sokoine University of Agriculture, Morogoro, Tanzania in July of 1999. Those attending included: A. Terry McCabe; B. Hija Mwatawala; C. Angello Mwilawa; D. Daniel Komwihangilo; E. Faustin Lekule; F. J.K.K. Msechu; G. Judicate Mwanga; H. Jefta Mkonyi; I.Vitalis Temu; J. Julius Bwire; K. Randall Boone; L. Michael Coughenour; M. Germana Laswai; N. Patricia Moehlman; O. Constantine Shayo; P. Bjørn Figenschou; Q. Abiliza Kimambo; R. Rashidi Kidunda.

M. Waweru demonstrated the SAVANNA model's capabilities with M. Said at the Department of Resource Surveys and Remote Sensing (DRSRS) in May, 2000. The demonstration was very well received and DRSRS expressed strong interest to continue working as part of the CRSP team to develop, apply and demonstrate the IMAS. R. Reid and P. Thornton also demonstrated the IMAS to collaborators and donors from the World Bank, USAID-REDSO, USAID-Global Bureau, USDA and KWS. US team members presented IMAS results at several scientific meetings in the US and UK.

A feedback workshop was held by A. Mwilawa, M. Maskini, and V. Runyoro at the Ngorongoro Conservation Area in November of 2000. The workshop was well received – indeed, the pastoralists were pleased that we informed them of the outcome of the Mwilawa and Maskini field work, which involved assessments of range and livestock condition in various parts of the NCA. There was a good representation from pastoralists, and the Ngorongoro Conservation Area Authority (NCAA) was represented by Victor Runyoro and others. The primary issues that come-up from pastoralists and NCAA staff were as follows:

– The studies should be conducted for a longer period and should cover a larger area.

– There is a need for intensive range forage evaluation and possibly estimation of forage available for livestock and how livestock should be distributed over time. We informed the group as to how the IMAS Model could be useful if they updated it with projected livestock numbers and boma locations. This would consider which species of wildlife are grazing in similar areas, and then with proper adjustments to the grazing and boma locations in the model, they will be able to determine optimal stocking patterns.

– Participation of local pastoralists during field work was highly appreciated. Hence, there is a need for proper training where possible of pastoralists in areas of range condition and livestock condition.

– Where possible NCAA should assist to provide water sources for livestock so as to reduce movement and concentration of livestock during dry season around existing water sources.

– Pastoralists would like to visit some other places to see what other others are doing in relation to conservation.

– Pastoralists would like to know what can be done to improve the livestock grazing areas.

– Participants in the workshop showed a great appreciation for what IMAS has contributed and the efforts of the IMAS team in coming back to present results to the stakeholders.

The GL-CRSP IMAS Web site: *http://www.nrel.colostate.edu/projects/imas/* serves as an important and enduring outreach tool, with the main page accessed from more than 50 unique machine addresses from October 2000 (the earliest date stored within the access log) to December 2000. The IMAS site includes an introduction to the IMAS project, a brief description of the sub-projects under IMAS, contacts for project personnel, and a growing list of publications, including more than a dozen documents available on-line.

Finally, the GL-CRSP Integrated Management and Assessment System project and the SAVANNA modeling system were widely publicized in an ILRI sponsored report (Coughenour et al. 2000) and press release from the non-profit promotional organization Future Harvest. The press release drew broad journalistic and public interest, and was the basis for dozens of newspaper and Web stories throughout the world.

Training

A two-week GIS training course was developed and conducted at ILRI in April 1999. Nine participants attended: six from Kenya, one from Tanzania and two from Uganda. The course was conducted by six GIS technicians from ILRI and Kenyan Department of Resource Surveys and Remote Sensing, and was rated excellent by course participants.

GL-CRSP IMAS, the SAVANNA modeling system, SavView, and our experiments were demonstrated to participants of two workshops, and others, during a six-week outreach and training effort. A five-day workshop, coordinated by P. Moehlman, was held at the University College of Lands and Architectural Sciences within the University of Dar es Salaam, Tanzania (Figure 10.2). R. Boone trained 11 participants in IMAS goals, the SAVANNA modeling system, and how to conduct experiments (Table 10.2). Each participant was provided with a copy of a manual that was used in training (Boone 2000), plus a copy of a manual for use by those not needing to know the details of SAVANNA (Boone and Coughenour 2000), a CD storing IMAS software, and a CD storing a suite of experiments addressing management questions. Following the week-long workshop, a presentation on IMAS and ecosystem modeling was given at Mpwapwa, Tanzania, at the Livestock Production Research Institute. At Mpwapwa interest in IMAS was high, and Boone departed with Institute personnel running new experiments using IMAS software installed on their machines. Upon returning to Dar es Salaam, the IMAS software was installed on a computer of Dr. J.K.K. Msechu of the Ministry of Agriculture, and he was provided supporting materials. IMAS software was then installed on a computer GL-CRSP purchased, which was placed in the Community Conservation Center, African Wildlife Foundation, Arusha, Tanzania. That installation is available to anyone interested in using GL-CRSP IMAS to address potential management questions, and A. Kajazi and N. Abdallah of the African Wildlife Foundation attended the Dar es Salaam workshop, so

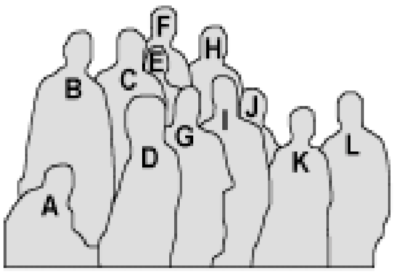

Figure 10.2. Participants in an IMAS workshop held in April of 2000 at UCLAS in Dar es Salaam, Tanzania included: A. Pauli Sadiki; B. Nicephor Lesio; C. Martin Loibooki; D. Naima Abdallah; E. Angello Mwilawa; F: Godwell Ole Meing'ataki; G. Emmanuel Gereta; H. Randy Boone; I. Victor Runyoro; J. Anna Maembe; K. Margaret Waweru; and L. Allan Kijazi.

people knowledgeable in IMAS are available for assistance. Boone then traveled to NCA, installed IMAS software on an NCAA computer, on another computer made available through the DANIDA Ereto program, and presented IMAS to a group of seven scientists and managers.

In April, 2000, the ILRI GIS team hosted and helped organize the SAVANNA model training held at ILRI in Nairobi. Three to four ILRI technical and scientific staff participated in the training. Before this training session, M. Waweru, the ILRI-CRSP GIS analyst replacing O. Okello, traveled with R. Boone to Tanzania to learn how to demonstrate the SAVANNA model. M. Waweru replaced Okello as a lead trainer and demonstrator of the IMAS in East Africa. The training workshop was coordinated by M. Waweru and O. Okello. The three-day workshop was attended by 15 scientists and managers (Table 10.3), with one traveling from Ethiopia to attend. Each was provided with the same GL-CRSP IMAS materials as workshop participants in Dar es Salaam. In the workshop, Boone reviewed details of SAVANNA necessary to know to understand the general system, introduced the interface tools SMS and SavView, then reviewed the results of the 16 experiments from NCA. Discussions with workshop participants helped improve the Kajiado application as well (see *Chapter 7*).

Individuals were trained in using IMAS tools during visits to CSU. A. Mwilawa received three weeks of training in IMAS during fall of 1999. That training, plus the week-long intensive workshop Mwilawa attended in Dar es Salaam, and the demonstrations he has attended, have made Mr. Mwilawa the Tanzanian most experienced in IMAS. Prof. F. Benyikwa received training in SAVANNA and other IMAS tools during the fall of 1999 as well.

Capacity Building

The GL-CRSP IMAS modeling system, including SAVANNA, is now installed in several computers at: 1) the University of Dar es Salaam, at computers at 2) the Mpwapwa Livestock Research Institute, 3) the Ministry of Agriculture, our central site at 4) the Arusha Community Conservation Centre of the, African Wildlife Foundation, two computers in 5) Ngorongoro Conservation Area, and on several machines at the 6) International Livestock Research Institute. Additional installations are on personnel notebook computers of people working in East Africa, such as that of J. Grootenhuis, M. Rainy, and J. Worden.

Table 10.2. Participants in an GL-CRSP IMAS workshop held April 3 - 7, 2000 at the University College of Lands and Architectural Studies, University of Dar es Salaam, Tanzania. The participants were trained in ecological modeling methods, and the use of IMAS modeling tools.

1.	Naima Abdallah	African Wildlife Foundation, Arusha, Tanzania
2.	Emmanuel Gereta	Tanzania National Parks, Arusha, Tanzania
3.	Allan Kijazi	African Wildlife Foundation, Arusha, Tanzania
4.	Nicephor Lesio	Njiro Wildlife Research Centre, Tanzania Wildlife Research Institute, Arusha, Tanzania
5.	Martin Loibooki	Tanzania National Parks, Arusha, Tanzania
6.	Anna Maembe	Tanzania National Environmental Management Council, Dar es Salaam, Tanzania
7.	Godwell Ole Meing'ataki	Tarangire National Park, Tanzania
8.	Angello Mwilawa	Livestock Production Research Institute, Mpwapwa, Tanzania
9.	Victor Runyoro	Ngorongoro Conservation Area Authority, Ngorongoro, Tanzania
10.	Pauli Sadiki	GeoInformation Centre, University College of Lands and Architectural Studies, Dar es Salaam, Tanzania
11.	Margaret Waweru	International Livestock Research Institute, Nairobi, and the Kenya Department of Resource Surveys and Remote Sensing, Nairobi, Kenya

IMAS computer interface software was created to allow local scientists, managers, and stakeholders to conduct their own analyses (see *Chapter 6*). At any of these installations, people may run their own experiments to assess potential effects of increased livestock populations, changes in rainfall, or changes in herbivore grazing patterns, as examples.

The current IMAS installations allow users to conduct innumerable experiments, but we were not able to anticipate every change in animal grazing limits that may need to be investigated, for example. Therefore at our central site, the Arusha Community Conservation Centre of the African Wildlife Foundation, we put in-place a geographic information system (Idrisi32 of Clark Labs, Worcester, Massachusetts, USA) and spatial data layers that users would need to change maps used in NCA-SAVANNA. The GIS allows users familiar with IMAS (e.g., A. Kijazi and N. Abdallah of AWF) to modify maps that control animal grazing to address new experiments proposed.

Impacts upon Policy

There is a distinction between policy makers and policy analysts/researchers. The latter are appropriately involved in IMAS development but the former are involved at the stage where there are results from the IMAS and there are opportunities to ask questions of the model. In the early stages of the development of the IMAS, our efforts were focused on the latter. Policy analysts/ researchers are being involved in the stages of

Table 10.3. Participants in an GL-CRSP IMAS workshop held April 26 - 28, 2000 at the International Livestock Research Institute (ILRI), Nairobi, Kenya. The participants were trained in ecological modeling methods, and the use of IMAS modeling tools. M. Waweru participated in both workshops, in anticipation of her in-depth involvement in IMAS, but is not listed below to avoid duplication.

1.	Fred Atieno	ILRI
2.	Shauna BurnSilver	CSU and ILRI
3.	Giulia Conchedda	Ethiopia ILRI, Addis Ababa, Ethiopia
4.	Lucy Gitau	Kenya Department of Resource Surveys and Remote Sensing, Nairobi, Kenya
5.	Russ Kruska	ILRI
6.	Andrew Muchiru	ILRI
7.	Wycliffe Mutero	Kenya Wildlife Service, Nairobi, Kenya
8.	Meshack Nyabenge	ILRI
9.	Wilber Ottichilo	International Institute for Aerospace Survey and Earth Sciences, Enschede, The Netherlands
10.	Judy Rainy	Bush Homes, Nairobi, Kenya
11.	Mike Rainy	Bush Homes, Nairobi, Kenya
12.	Robin Reid	ILRI
13.	Mohammed Said	Kenya Department of Resource Surveys and Remote Sensing, Nairobi, Kenya
14.	Cathy Wilson	ILRI
15.	Jeff Worden	CSU and ILRI

model building and testing. Policy makers have been kept informed of our progress through meetings, workshops, and presentations.

Our efforts to inform policy makers of the GL-CRSP IMAS project grew from 1997 to 2000, as expected. Early in our efforts we conducted an assessment of the laws, policies and customary relations that determine the use of land and wildlife resources in the NCA. Interviews were conducted in Arusha and Dar es Salaam, pertinent documents were collected and reviewed and opinions were solicited from other team members with lengthy experience at NCA. A major conclusion derived from this study is that there has been substantive change in the policy context for the NCA and these changes may in the long run, alter land use policy in the NCA.

In 1999 and 2000, Mr. ole Kamuaro, assistant to the Director, National Environment Secretariat in Kenya and a pastoralist, was instrumental in communicating the uses of IMAS to policy makers within the Kenyan government, and informing us of their needs. His activities led to considerably heightened awareness within the Ministry of the GL-CRSP IMAS project. In Tanzania our contact with policy makers has been quite direct, with Dr. J.K.K. Msechu, an official from the Ministry of Agriculture attending a miniworkshop in 1999, and having GL-CRSP IMAS software installed on a ministry computer. Other leaders, such as E. Gereta, Chief Ecologist with the Tanzania National Parks, A. Kijazi, Project Officer with the African Wildlife Foundation, and A. Maembe, National Project Leader with the National Environmental Management Council, attended a week-long workshop on the use of IMAS tools.

Reports were prepared summarizing Kenyan policy changes and historical land use (Davis 2000 in *Appendix C*), and trends in governance (Njoka 2000 in *Appendix C*). These reports are important because of the unique perspectives of their authors, and because of the complexities in the system. In the last 40 years land use has intensified in Kenya, control has been decentralized and the society made democratic. Local, regional, and international interests (through donor agencies) have merged to yield complex settings.

Of course, many of the reports and publications produced under GL-CRSP IMAS describe policy issues, implications of policies, and suggested solutions to ongoing problems. Examples from *Appendix C* include:

– Atieno (2000), where the implications of changing land cover and land use in Kajiado District, Kenya are explored;

– Boone et al. (In revision), which describes possible ecosystem responses to a series of 16 management questions based upon policy within NCA;

– Galvin et al. (2000), where one of many results is that Maasai living with NCA will need increasing levels of supplemental food as human populations increase;

– Lynn (2000), which includes extensive reviews of the effects of conservation policy on Maasai living within Ngorongoro Conservation Area and Loliondo Game Controlled Area;

– Rwambo et al. (1999), where the patterns of livestock-wildlife disease interactions in NCA are placed in-context with the policies affecting the distributions of livestock.

SUMMARY

Our outreach and training efforts have been a success, with countless people informed of the utility of the GL-CRSP Integrated Management and Assessment System project through the media, more than one hundred East Africans informed first-hand of our efforts, and two dozen East Africans with in-depth training in the use of IMAS tools. Research results have been reported in more than 50 publications, reports and selected presentations (see *Appendix C*) including 18 available world-wide through the Web (*http://nrel.colostate.edu/projects/imas/*).

The impact of the GL-CRSP Integrated Management and Assessment System project has had on policy development is difficult to quantify. Changes in leadership at the Kenya Wildlife Service and instability of the Board of Directors to the Ngorongoro Conservation Area Authority during our project made informing those leaders a periodic effort. The clearest evidence is the use, or interest in the use, of IMAS tools in planning. E. Chausi, the Conservator with the Ngorongoro Conservation Area Authority, and others are very interested in using IMAS to determine appropriate balances between wildlife and an increasing livestock population. We made our results available to DANIDA, a primary development agency working in Ngorongoro Conservation Area, who were quite interested in adopting the model and using it to assess the impacts of development (C. Sorenson, pers. comm.). We also have worked with the Ngorongoro Conservation Area Authority personnel to adopt the information and the technology we have developed (V. Runyoro, pers. comm.). We have also made the Tanzania National Parks Authority (TANAPA), and Tanzania Wildife Research Institute (TAWIRI) aware of our products, and both have expressed interest. The Tanzania Ministry of Agriculture is also quite interested in the IMAS, is involved through Mpwapwa Research Station, and through training we have provided. All three of these organizations are influential in effecting policy in Tanzania.

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Appendix B

Integrated Management and Assessment System
Team Members and Participating Institutions

TEAM MEMBERS

KENYA

Name	Title	Affiliation
Atieno, Fred	M.S. student	Department of Range Management, University of Nairobi International Livestock Research Institute
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Kruska, Russ	Geographic Information Systems Specialist	International Livestock Research Institute
Mariner, Jeff	Doctor of Veterinarian Medicine	Private Consultant
Mbogoh, Stephen	Professor	Department of Agricultural Economics, University of Nairobi
Mworia, John	M.S. Student	Department of Botany, University of Nairobi
Munei, Kimpe	Ph.D. Student	Department of Agricultural Economics, University of Nairobi
Njoka, Jesse	Research Scientist	Department of Range Management, University of Nairobi
Nyokabi Waweru, Margaret	Technical Specialist	International Livestock Research Institute Department of Resource Surveys and Remote Sensing
ole Kamuaro, P.	Assistant to the Director	Natural Environmental Secretariat
Onyango, Okello	Technical Specialist	International Livestock Research Institute (now at Texas Tech University, Lubbock)
Rainy, Michael	Ecotourism and Education Instructor and Consultant	Explore Mara Kenya, Ltd. Ololepo Hills Grazing Association Bush Homes of East Africa
Reid, Robin	Senior Ecologist	International Livestock Research Institute
Rwambo, Paul	Doctor of Veterinarian Medicine, Resident Scientist	Kenya Agricultural Research Institute
Said, Mohammed	Research Scientist	Department of Resource Surveys and Remote Sensing
Thornton, Phillip	Agricultural Economist	International Livestock Research Institute
Western, David	Chairman	African Conservation Centre

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Mwilawa, Angello	Livestock Research Scientist	Livestock Production Research Institute
Ndyamkama, Yusufa	M.S. Student	University College of Lands and Architectural Studies, University of Dar es Salaam
Nikundiwe, Alfeo	Professor	University College of Lands and Architectural Studies, University of Dar es Salaam
ole Ikayo, Francis	Director	Inuyat e-Maa (Maasai pastoralists organization)
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Appendix C

Publications, Reports, and Selected Presentations from the Integrated Management and Assessment Project

An Annotated List

Joyce Acen

1. Atieno, F. 2000. Effects of changing land use on land cover, vegetation species abundance and structure in pastoral areas: A case study of the greater Amboseli ecosystem, Kajiado District. Report (MSc Thesis, University of Nairobi).

A ten-year (1988-1998) land cover change analysis of the Greater Amboseli ecosystem was conducted using GIS and remotely sensed data as well as ground based studies. The study found a decline in vegetation cover and significant changes in species composition, diversity and structure. Bushed grassland and cultivated land increased, while bushlands, grasslands and wooded grassland reduced over the decade. Results also showed expansion and increase in intensity of rainfed agriculture in some areas, and a general increase in patchiness of the landscape.

2. Atieno, F., R. Reid, T. Njoka, and E. Harris. 2000. Land use trends and their effects on range vegetation: the case of Amboseli Ecosystem. (Poster).

The study mapped land use and range vegetation and analyzed changes in land use and vegetation cover between 1988 and 1998 using Landsat imagery and GIS. The results showed an increase in cultivated land, increased fragmentation of the landscape, and vegetation cover change from a herbaceous dominated to woody dominated.

3. Atieno, F. 2000. Landscape change patterns in rangelands, land use and environmental diversity. Greater Amboseli Ecosystem 1998-99.

A summary report of the MSc research described in the previous entries.

4. Boone, R.B. 2000. Integrated management and assessment system: training manual. Instruction manual created with the support of the Global Livestock Collaborative Research Support Program, US Agency for International Development.

A training manual used in workshops to give participants an understanding of the goals of the Integrated Management and Assessment System project, the SAVANNA modeling system, and the SavView user-friendly computer interface. A series of 16 experiments addressing potential management questions in the Ngorongoro Conservation Area are reviewed, with direction on how to conduct similar experiments, or to modify the assessments as needed.

5. Boone, R.B. and M.B. Coughenour. 2000. Integrated management and assessment system: using Savanna and SavView in ecosystem modeling. Instruction manual created with the support of the Global Livestock Collaborative Research Support Program, US Agency for International Development.

A manual for use by those conducting assessments using modeling tools of the

Integrated Management and Assessment System project. The volume contains a subset of Boone (2000), excluding the portions that explain the SAVANNA modeling system in detail. The volume is intended for use by those that want to use the tools, but do not need to know the full detail of the model.

6. Boone, R.B., K.A. Galvin, N.M. Smith and S.J. Lynn. 2000. Generalizing El Nino effects upon Maasai livestock using hierarchical clusters of vegetation patterns. Photogrammetric Engineering and Remote Sensing 66: 737-744.

This paper presented a method of extrapolating anthropological data over broader areas using remotely sensed spatial data to ensure more rigorous applicability to resource conditions and patterns. Hierarchical cluster analyses of vegetation biomass trends represented by AVHRR/NDVI were used to generalize household interviews conducted among the Maasai on the economic consequences of the 1997/98 drought and El Niño rains on Maasai herders in northern Tanzania. The study showed that socioeconomic data patterns were related to vegetation patterns.

7. Boone, R.B., M.B. Coughenour, K.A. Galvin, and J. E. Ellis. In revision. Addressing management questions for Ngorongoro Conservation Area using the Savanna Modeling System. African Journal of Ecology.

This paper reports the use of the SAVANNA model to predict responses to alternative management actions in the Ngorongoro Conservation Area. The model was used to simulate the impacts of several scenarios such as drought, increased livestock, improved veterinary services, increased access to grazing lands, improved water availability, increased cultivation and human population growth.

8. BurnSilver, S. 2000. PhD research progress report.

The research focuses on the impact of larger-scale environmental and political economic factors on pastoral welfare, livestock production and human-wildlife interactions in the greater Amboseli ecosystem. A survey detailing spatial distribution of settlements, economic activity, and land use in all bomas within the study area. In addition household interviews are being conducted on a sample of Maasai households and documenting economic and production strategies and daily grazing movements.

9. Coughenour, M.B. and R.B. Boone. 2000. Integrated Assessments and spatial-dynamic ecosystem modeling to assess development-biodiversity interactions in east Africa. Paper presented at the Symposium: Human Development and Biodiversity Conservation in the Developing World: Finding a Balance in Concept and Practice. Ecological Society of America Annual Meetings, Snowbird, Utah.

The integrated modeling and assessment system (IMAS), which includes an ecosystem model, an animal disease model, and a human ecology model was developed and applied to the Ngorongoro Conservation Area, Tanzania. The model was used to simulate the effects of scenarios of drought, increased livestock numbers, improved veterinary care, increased access to grazing lands, changes in water supplies and growth in human populations and agriculture.

10. Davis, R.K. 1998. Policies on land use on NCA and constraints on policy change: progress report.

A brief review of existing policies on land use in the Ngorongoro Conservation Area and constraints on policy change based on reports and interviews. The report recommended soliciting of local stakeholder views on policy.

11. Davis, R.K. 1999. Kajiado Notes - A review of historical land use policy changes in Kajiado District, Kenya.

A brief historical review of land use policy changes based on studies of the World Bank group ranch development program in Kajiado Distirct, Kenya. The studies covered issues of livestock management, economic strata among the Maasai ranchers, land use, game cropping, and sport hunting.

12. Davis, R.K. 2000. The Kajiado group ranches: A perspective.

The paper presents a review of the developments in the group ranching program in Kajiado district, Kenya, over a 30-year period since its inception in 1962 through various legislation, failures, and changes in land tenure towards sub-division and individual ownership. It discusses issues of policy, land use and tenure, ecology and wildlife conservation, and socio-economics.

13. Ellis, J. START/NAFCOM/CARPE Workshop on Land Use and Land Cover Change (LUCC) in West and Central Africa, in Accra, Ghana Nov.3-5, 1997 and presented the keynote lecture entitled "Exploring the science-policy interface: Assessing and affecting land use and land cover change".

14. Ellis, J. Invited Address: Pastoral Ecosystems: Human -Ecosystem Linkages. At the NREL 30th Anniversary Symposium. October 1998.

15. Ellis, J., R. Reid, P. Thornton, and R. Kruska. 1999. Population growth and land use change among pastoral people: local processes and continental patterns. Paper presented at International Rangeland Congress, Townsville, Australia.

16. Galvin, KA. 1998. Compatibility of pastoralism and conservation? How to assess management strategies in the Ngorongoro Conservation Area, Tanzania. Paper presented at the International Congress of Anthropological and Ethnological Sciences, Williamsburg, VA. July 1998

17. Galvin, K.A., M.B. Coughenour and J.E. Ellis. 1998. Ecology and economy of pastoral nutrition. A test case using integrated assessment in the Ngorongoro Conservation Area, Tanzania. Poster presented at Heifer Project International. 1998 Symposium on Human Nutrition and Livestock, October.

18. Galvin, K.A. 1998. Issues of sustainability of pastoralism in East Africa. Talk presented at the International Connections Seminar Series, Colorado State University, October.

19. Galvin, K.A. 1999. Integrated multidisciplinary human ecological research in anthropology. Invited paper presented at the public policy session on Anthropology and Multi-disciplinary Research at the annual meeting of the American Anthropological Association, November.

20. Galvin, K.A., R.B. Boone, N.M. Smith and S.J. Lynn. 1999. Impacts of climate variability on East African pastoralists: Linking social science and remote sensing. Paper presented at a special session on social science contributions to climate change, at the annual meeting of the Society for Applied Anthropology, Tucson, April.

21. Galvin, K.A., A. Magennis, J.E. Ellis, S. Lynn and N.Smith 1999. Effects of conservation policy on human well-being: A comparative study of pastoral Maasai nutrition and economy in northern Tanzania. Poster presented at the annual meeting of the Human Biology Association meetings, Columbus, Ohio, April.

22. Galvin, K.A. 2000. Community based conservation: does it work? Invited paper presented at the Symposium, Human Development and Biodiversity Conservation in the Developing World: Finding a Balance in Concept and Practice at the Ecological Society of America annual meeting, Snowbird, Utah.

23. Galvin, K.A. 2000. Human/cultural dimensions of development and conservation issues. Invited paper presented at the Workshop, Sustainable Biodiversity in the International Arena, at the Ecological Society of America annual meeting, Snowbird, Utah.

24. Galvin, K.A., R. B. Boone, N. M. Smith and S. .J. Lynn. Impacts of climate variability on East African pastoralists: linking social science and remote sensing. (forthcoming in Climate Research).

The paper reviewed the effects of the 1997 drought and El Niño rains on Maasai herders in northern Tanzania and used satellite data to generalize the results on the regional scale. Hierarchical cluster analyses of regional vegetation biomass trends and results of household surveys conducted among the Maasai were used to map the distribution of the economic consequences of climatic events at a regional scale.

25. Galvin, K.A., J.E. Ellis, R.B. Boone, A.L. Magennis, N.M. Smith, S.J. Lynn and P. Thornton. Compatibility of pastoralism and conservation? A test case using integrated assessment in the Ngorongoro Conservation Area, Tanzania. *In:* Displacement, Forced Settlement and Conservation. D. Chatty, ed., Berghahn, Oxford (forthcoming).

This paper presents the results of a comparative study of human welfare and land use between the Ngorongoro Conservation Area and Loliondo Game Control Area that differ in conservation policies. The Integrated Modeling and Assessment System (IMAS) was applied to assess alternative policy and management strategies on human welfare and conservation value. The study discusses several options for optimizing human welfare, development and conservation concludes that the costs of wildlife conservation are partially borne by residents of conservation areas.

26. Galvin, K., P. Thornton, and S. Mbogoh. 2000. Integrated modeling and assessment for balancing food security, conservation and ecosystem integrity in East Africa: Final Report to the GL-CRSP socio-economic modeling component, 1997-2000.

Report on the development of the socio-economic sub-model PHEWS (Pastoral Household and economic Welfare Simulator Model) and its integration into the savanna model.

27. Howe, R. 1998. Spatially integrated disease risk assessment model (SIDRAM) (Phase I): a white paper for the GL-CRSP Project.

The white paper outlined data required to characterize the spread of malignant catarrhal fever (MCF) in a wildlife reservoir to domestic livestock, and rinderpest in both wildlife and domestic livestock reservoirs, and disease interchanges using the spatially integrated disease risk assessment model (SIDRAM). The data include population density and movement maps, AVHRR scenes, and contact rate

probabilities for both the wet and dry seasons.

28. Howe, R., R. Boone, J. DeMartini, T. McCabe, and M. Coughenour. In revision. A spatially integrated disease risk assessment model for wildlife/livestock interactions in the Ngorongoro Conservation Area of Tanzania.

This paper reports the use of long-term ecological data and mathematical models to examine epidemiology of malignant catarrhal fever (MCF), in the Ngorongoro Conservation Area. A risk based biased mixing disease model was incorporated into a spatial ecological model (SAVANNA) to predict the occurrence of MCF in the target population. The MCF model fitted a simple growth curve with a Gaussian distribution of inverse half life decay, simulating rapid spread of the disease as the probability of exposure increases dependent on virus survivability in the environment. Risk mitigation in the MCF model was sensitive to spatial proximity of pastoral cattle with migrating wildebeest.

29. Magennis, A.L. and K.A. Galvin. 2000 Growth patterns among Maasai pastoralists in northern Tanzania. Poster presented at the Human Biology Association meetings, April.

30. Magennis, A. L. and K.A. Galvin 1999 Maternal-child nutrition among Maasai Pastoralists, Loliondo District, Tanzania. Paper presented at the annual meeting of the American Anthropological Association, November.

31. Maskini, M.S. 1999. Spatial and temporal grazing patterns of livestock and herbivores in Ngorongoro Conservation Area. MSc Thesis, Sokoine University, Tanzania.

A progress report on an MSc thesis based on research conducted at three sites in the Ngorongoro Conservation Area to investigate variables affecting the distribution of pastures.

32. Maskini, M.S. and R. Kidunda. 2000. Spatial and temporal grazing patterns of livestock and wild herbivores and their impact on range condition at Ngorongoro Conservation Area.

This study sampled three sites in the Ngorongoro Conservation Area to investigate and quantify the variables affecting the distribution pastures. Range condition for each site was related to the spatial and temporal utilization patterns of wild herbivores and livestock. There was a high correlation between range condition and herbivore grazing patterns. Seasonal variations in rainfall explained the migratory movements of wild herbivores.

33. Mbogoh, S. G., K. Munei, and P. Thornton. 1999. Study on wildlife, livestock and human interaction in Kajiado District in Kenya: results of the economic study.

An economic study was conducted in the wildlife dispersal areas the Amboseli National Park thought to have high intensity of interaction between wildlife and pastoral livestock. It investigated livestock keeping, non-livestock economic activities, and ecotourism in two group ranches, Kimana and Mbirikani. The study found that both pastoralism and agro-pastoralism gave relatively high returns to capital. It did not find evidence of strong competition between crop production and livestock, but some degree of supplementarity instead.

34. McCabe, J.T. 1999. Anthropology, conservation and protected areas: An overview. Paper presented at the annual meeting of the

Society for Applied Anthropology, Tucson, April.

35. McCabe, J.T. 1999. Conservation with a human face? Lessons from forty years of conservation and development in the Ngorongoro Conservation Area, Tanzania. Paper presented at the Conference on Displacement, Forced Settlement and Conservation, St. Anne's College, University of Oxford, September.

36. Mwilawa, A. J., V. A. Runyoro, and P. Moehlman. 1999. Forage range survey and monitoring livestock nutrition in Ngorongoro Conservation Area.

A field study was conducted to identify preferred forage range species under pastoral assessment, determine chemical forage nutritive value among the preferred species, and to monitor livestock condition from June through August on two routes in the Ngorongoro Conservation Area Authority. Over 20 preferred forage species were identified, and livestock were shown to be in better condition in June than the following months.

37. Mwilawa, A. J., V. A. Runyoro, and P. Moehlman. 1999. Forage range survey and monitoring livestock nutrition in Ngorongoro Conservation Area.

A presentation at DASP-SUA (07/16/1999) highlighted the results of a study conducted to identify forage species preferred by livestock, determine their nutritive value, and to establish monitoring of livestock nutrition in the Ngorongoro Conservation Area Authority.

38. Mworia, J., and J. Kinyamario 1999. The impact of land use changes on the vegetation, soil and water balance in Kajiado, Kenya. Progress Report (PhD Research, Nairobi University, Kenya).

This report presented the preliminary analysis of results of a study to assess the differences in vegetation structure, composition, production, soil and hydrology of sites under different management approaches and grazing pressure. The results showed that soil moisture, fertility and rainfall are the main determinants of vegetation cover. Ordination of sites with respect to cover produced distinct groupings of sites under similar management.

39. Mworia, J. K., J. I. Kinyamario, J. W. Kiringe, and M. B. Coughenour. 2000. Tree layer dynamics under different land uses and soils in a semi-arid area of Kenya.

A study was conducted to characterize the main factors determining the distribution of key wood species and to quantify the effects of different land uses and management types, namely, small-scale farms, group ranches, small-scale ranches, and conservation areas on the tree layer in semi-arid area of south-eastern Kenya. The study found that small-scale farms were the most intensively utilized, and with the highest livestock density. Soil moisture and phosphorus accounted for the highest variation in tree distribution and abundance. Multivariate analyses identified 5 plant associations differing in diversity and soil factors. The study concluded that land use, human population density and environmental gradients were all important determinants of wood species distribution, composition and structure, and that land use impacts were superimposed on vegetation gradients, which in turn were largely explained by environmental variation.

40. Njoka, J. 2000. Sustainable Livelihoods of Maasai Kaputiei of Kajiado District of Kenya.

This paper is based on a study conducted in 1999 to assess natural resources in Kaputiei and the sustainability of Maasai livelihoods based on it. The assessment used trends in natural resource, livestock production, human population growth, cultural and socio-economic aspects, and national and international economic projections in the context of food security to evaluate the livelihoods of Maasai Kiputiei.

41. Pelissier, P.G. 1999 Preliminary assessment on the progress and feasibility of developing disease sub-models for MCF, Rinderpest, and ECF in the Ngorongoro Conservation Area of Tanzania.

This is a progress report on the development of the disease sub-model for the integrated modeling and assessment system (IMAS) for malignant catarrhal fever (MCF), rinderpest, and East Coast Fever (ECF).

42. Rainy, J., M. Rainy, and E. Harris (eds.). 1999. Integrated modeling, assessment, and management of regional wildlife-livestock ecosystems in east Africa: Report of a REDSO/USAID funded workshop held at the International Livestock Research Institute, Nairobi, Kenya – July 6-8, 1999.

43. Rainy, M.E., and J.S. Worden. 1998. Ecotourism and wildlife conservation: some new insights from practical experience in the Melepo Hills, Kajiado District, Kenya.

44. Reid, R.S., Kruska, R.L, Wilson, C.J. and Thornton, P.K. (1998) Conservation crises of the 21st century: Tension zones among wildlife, people and livestock across Africa in 2040. Paper presented at the International Congress of Ecology, Florence, Italy, 19-26 July, 1998.

45. Reid, R.S., Kruska, R.L, Wilson, C.J. and Thornton, P.K. (1998) Conservation crises of the 21st century: Tension zones among wildlife, people and livestock across Africa in 2040. Paper presented at the Annual meeting of the Ecological Society of America, Baltimore, Maryland, 2-6 August, 1998.

46. Reid, R. S., M. E. Rainy, C. J. Wilson, E. Harris, R. L. Kruska, M. N. Waweru, and J. Worden. 2000. (Draft). People and livestock attract wildlife in an African savanna or wildlife form biodiversity rings around pastoral settlements in Africa.

This paper examines the response of spatial concentrations of ungulates to human and livestock use in pastoral lands outside parks. A new fine-resolution sampling method was developed to map detailed spatial interactions across the landscape, and applied to group ranches at the northern tip of the Serengeti-Mara ecosystem. Spatial analyses using GIS and statistical methods showed that livestock congregated near bomas while wildlife clustered in a ring of density, biomass, and biodiversity at intermediate distances from bomas, and their distribution changed seasonally. Three hypotheses based on nutrient requirements, predators and Maasai settlement location choices are suggested to account for these observations.

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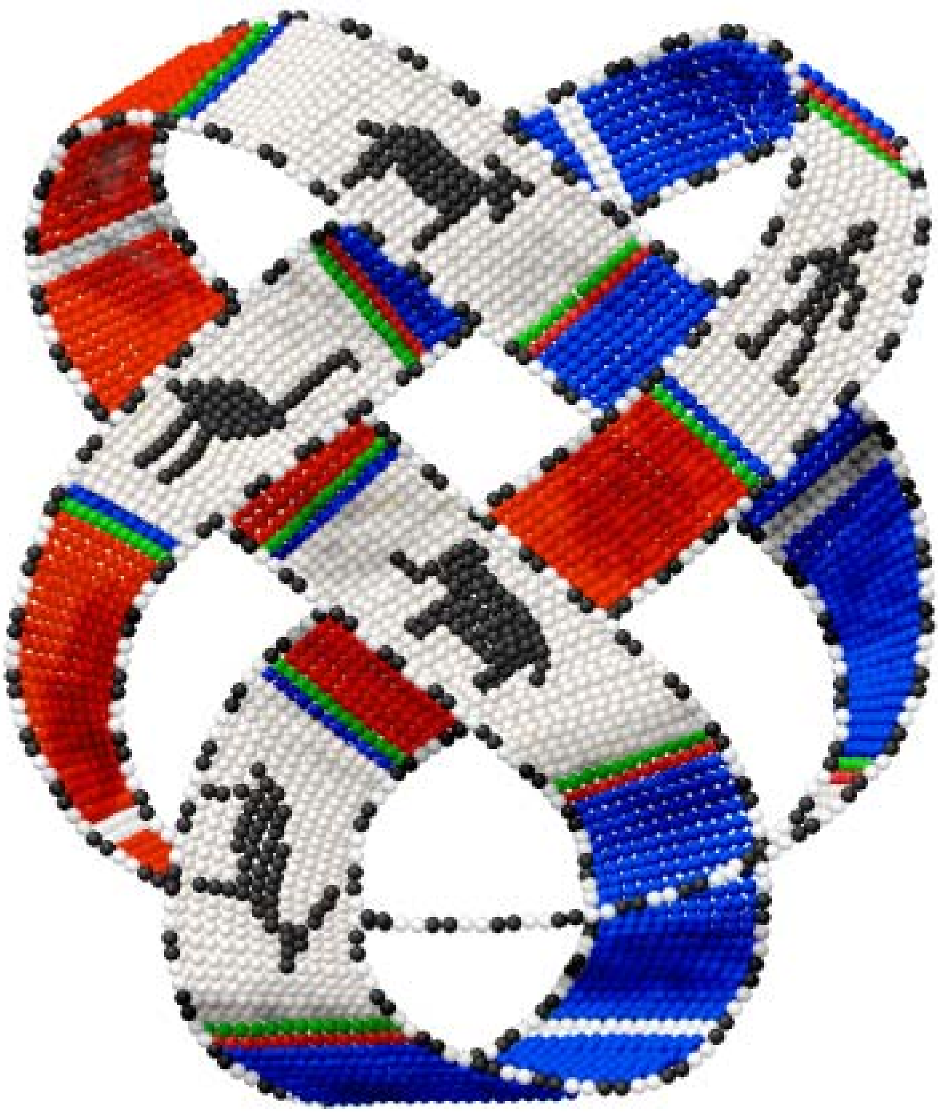
In a field study of the spatial distribution of Maasai settlements and their effects on vegetation and wildlife, study sites encompassing precipitation gradients and various levels of sedenterization were selected. Maasai settlements were identified and surveyed. A high-resolution total census of livestock and wildlife was completed. More censuses are planned.



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