# Optimizing Aspects of Land Use Intensification in Southern Kajiado District, Kenya

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## EXECUTIVE SUMMARY

Land use is intensifying in southern Kajiado District, Kenya. In the 1960s and 1970s, land used communally by Maasai was divided into group ranches with title held collectively by ranch members. Some ranches have since been divided into parcels owned by individual members. Other sources of land use intensification include human population growth and immigration, more intensive livestock management, and a rapid diversification of livelihood strategies. Livestock keeping remains the dominant livelihood strategy, but many practice rain-fed agriculture, do intensive irrigated agriculture in the swamps, earn wages, or own businesses. Land use intensification may be an inevitable or even desirable process in Kajiado. However, there are many pathways to intensified use. Pathways will have deleterious effects for some and positive effects for others. Computer modeling provides one means of identifying potential impacts from decisions, and which stakeholders they will affect. We use an integrative ecosystem model called SAVANNA joined with a model called PHEWS that simulates household decision making. We undertook a research effort for the International Livestock Research Institute (ILRI) under a project supported by the Belgian Ministry of Foreign Affairs, Foreign Trade and International Co-operation. We met with many pastoralists in southern Kajiado District in early 2005 to discuss their concerns, then with project personnel at ILRI to define scenarios to address using our modeling tools. Our analyses focused upon four scenarios, summarized below.

### 1. Ecological and Social Effects of Improved Livestock Breeds

In early 2005, BurnSilver conducted focus groups with pastoralists and found that the potential for using improved breeds had become a dominant question. Kajiado pastoralists are experimenting with adding improved Boran and Sahiwal cattle to their herds of small East Africa shorthorn Zebu (or Maasai Zebu). The improved breeds are larger, produce more meat and milk, and sell for higher prices. But they also are less drought resistant, are able to travel shorter distances, require more forage, can be more susceptible to disease, and are more expensive to purchase. We wished to determine what benefits there would be to households owning mixed herds of Zebu and improved cattle. We used a literature review to modify a suite of parameter values (e.g., body mass, milk production, travel costs) in SAVANNA and PHEWS that characterize Maasai Zebu and improved breeds. We then modeled populations on four group ranches, with cattle herds comprised of pure Zebu to pure improved cattle. In one method we modified the traits of the cattle herd in the modeled system to be intermediate between Zebu and improved traits. In a second method, we incorporated two cattle herds in the model, and set population ratios for the two herds so that they varied from 0% to 100% Zebu and 0% to 100% improved breeds. We could not include all traits of improved breeds in our modeling, nor all reasons why Kajiado pastoralists may keep improved breeds, but our results will be indicative of some important ecological and household effects.

In simulations, populations composed of improved breeds declined in many simulations, reflecting their limited dispersal distance from water and need for more forage. Their larger biomass offset these declines to a degree. Results were variable in each of the group ranches, but in general, livestock abundance appeared to peak when herds were composed of 40% to 60% improved breeds, except in Oselalei Group Ranch, which is the most productive of the group ranches in the study. Changing the breeds leads to considerable variability in livestock numbers of both types (zebu and improved) as well as variability in measures of household well-being. This may be because of missing factors in our pastoral decision making model. Cultural preferences, water use by improved breeds, detailed disease losses, and efficiencies of production are not captured well in our modeling system. A more complex understanding of household objectives and attitudes toward breed selection would be needed to capture more subtle decision making. Regardless, there appears to be considerable trade-offs in maintaining herds of Maasai Zebu or improved breeds. These conclusions resonated storngly with pastoralists during dissemination meetings and led to active discussion among researchers and community members regarding the substantial trade-offs associated with mixing cattle breeds. If this form of intensification is to development in Kajiado, more work is warranted to understand the costs and benefits.

### 2. Adding Water Sources in Imbirikani Group Ranch

In Imbirikani Group Ranch, a series of natural water sources are augmented by wells, boreholes, and small reservoirs. The Nolturesh Pipeline extends north from the Tanzania border on the slopes of Mount Kilimanjaro. Herders graze their animals around the water sources on this pipeline and make their permanent residences in the area. The higher elevation areas of the Chyulu Hills to the east are retained as a grazing reserve. In the dry season, herders move successively further from the pipeline and towards the hills in stages. Ultimately, in the late dry season, large stock will be grazed high in the Chyulu Hills, with animals returned to the pipeline for water every three to six days, depending on conditions, what is known as staged grazing. Currently, however, the Imbirikani Group Ranch committee is constructing a spur on the existing pipeline, extending east-northeast from Nolturesh Pipeline to the Chyulu Hills. The pipeline will end at a large water tank to be used by livestock and group ranch members. We modeled some repercussions of adding the water source at the terminus of the Chyulu pipeline and adding water sources at 5 km intervals along the pipeline. We modeled effects of having the current staged grazing, unlimited access to the new water sources, access in all but the wet season, and access only when the previous months had been unusually dry (i.e., < 75 mm the preceding three months).

Adding a water source at the end of the Chyulu pipeline had a small effect on ungulates. Adding sources every 5 km had a larger effect, causing a decline in the biomass of livestock and wildlife supported. Livestock grazing in areas that were intended to be reserves or used in staged grazing decreased the numbers of animals that could be supported. When the new terminal water source was allowed to be used only during the driest periods, livestock populations were higher than in current conditions. If livestock and wildlife have access to the new water sources, the pattern is in some ways opposite to that when livestock only have access. Adding a water source allowed wildlife that were restricted to use lands near water to use the area near the new pipeline. Use of the grazing reserve ultimately led to a decline in livestock as well as wildlife. Again, allowing animals to use the water sources only when it is dry yielded relatively high ungulate biomass. When the PHEWS model was enabled, less supplemental relief was required by households when the new water sources were used in the dry periods only. To clarify responses, we ran 20 simulations using randomized weather, and with livestock sales disabled. When ungulates had access to the new water sources only during the driest months of the simulated period, the numbers of livestock increased markedly, and wildlife increased as well. Our results suggest that there is some risk that the new water sources will allow grazers to overuse what to this point has been a grazing reserve. Regular grazing by either livestock, or livestock and wildlife, within the grazing reserve can leave the reserve unsuitable when it is needed in the late dry season. Our modeling shows that allowing herders to use the new water sources only when it had been dry the previous three months yielded the highest livestock and wildlife populations, and pastoral well-being. If allowed to use the new sources only when the previous three months had less than 75 mm of rainfall, an additional 7000 TLUs were supported in simulations. The additional water source can increase the well-being of residents of Imbirikani, but policies by the ranch committee or other stakeholders will be required to prevent over-use of what now serves as a grazing reserve.

## 3. Pathways to Subdivision in Imbirikani and Eselenkei Group Ranches

Starting in the late 1960s, large sections of land Maasai used in Kajiado were divided into group ranches. Early in the creation of group ranches, parcels claimed by individual people were created. Later, some group ranches were divided into parcels owned by individual ranch members. The tendency in subdivided group ranches is for use to become more exclusive. Currently, most lands in Eselenkei and Imbirikani Group Ranches are communally owned. Rain-fed and irrigated agricultural lands have been, or are in the process of being, officially subdivided. Eselenkei, Imbirikani, and Olgulului/Lolorashi Group Ranche committees have decided in principle to subdivide communal grazing lands, however the process has not yet begun. The typical pathway is to divide the ranch into equal-sized parcels, one for each group ranch member. Given the size of the group ranch and number of official ranch members (Ntiati 2002), Imbirikani Group Ranch members would receive parcels of 60 ac (24 ha). Members of Eselenkei Group Ranch may expect to receive parcels about 100 ac (40 ha). Research has suggested that such subdivision can cause dramatic declines in livestock, if lands are used exclusively by parcel owners. We explored alternative pathways to subdividing Eselenkei and Imbirikani Group Ranches, so that members benefited from owning a portion of the group ranch, but areas were maintained for communal use. We used modeling to quantify some effects of the: 1) current staged grazing pattern, 2) subdivision of the entire ranches into small parcels, 3) subdivision of currently settled areas into 5 ac (2 ha) parcels owned by herders and used in the wet season, 4) the same parcels but allowing livestock to move up to 5 km from the settled areas in the wet season and use communal areas in the dry season, and 5) in Imbirikani, if parcels for agriculture were provided to each group ranch member.

In Eselenkei Group Ranch, there were 1934 one-hundred acre parcels, approximately one per member of the ranch. In Imbirikani Group Ranch, there were 5504 sixty acre parcels. Livestock populations in both ranches were similar under current staged grazing and when they were evenly distributed, although the staged grazing yielded populations in general with less variability. When livestock were confined to 5 ac parcels within settled areas during the wet season, livestock declined dramatically. Allowing livestock to move up to 5 km beyond the limits of the subdivided area in the wet seasons allowed livestock to remain on-par with current levels. Wildlife populations varied inversely with livestock populations. With PHEWS enabled, residents bought and sold livestock. Overall, however, trends in livestock populations were similar to those when PHEWS was disabled. Allowing livestock to use areas within 5 km of subdivided sites in the wet seasons allowed the livestock to persist, but livestock numbers were two-thirds their initial value. Wildlife populations increased when livestock were confined to subdivided areas, or areas with 5 km. When Imbirikani was divided to provide agricultural areas to ranch members, 917 members received irrigated 2 ac plots, and 4587 received 5 ac plots in Chyulu Hills totaling 22,935 ac (9282 ha). In a simulation with PHEWS disabled, livestock populations were similar to those in current conditions, but wildlife biomass was lower. Our modeling shows that livestock cannot be supported on 5 ac parcels around developed areas for the three months of the wet season. This work suggests that the pathway to subdivision that has been proposed, with people owning 5 ac parcels near developed areas but able to graze within about 5 km of the subdivided area, is reasonable. Group ranch members would agree to graze communal lands during the drier eight months of the year, and graze areas near their own parcels during the wet months (March, April, May, and November).

## 4. Diversification in Southern Kajiado District, Kenya

Areas of Kajiado District, Kenya have residents who are impoverished relative to the rest of Kenya. Rapid human population growth and immigration have amplified food insecurity. Land tenure changes have reduced livestock mobility in subdivided areas and households have been sedentarized around permanent settlements and infrastructure. In detailed surveys by BurnSilver, households from six study areas were classified into one of eight livelihood categories. All households raised livestock. Some households included members that owned some type of business or earned wages. Households also participated in agriculture, with some doing rain-fed agriculture, some agriculture around Loitokitok Town, and others do irrigated agriculture. Whether modifying pastoral livelihood strategies would improve household well-being was of interest to us and to community members. In other scenarios we modeled quantitative responses to detailed queries supported by data from the field or literature. Here, a more illustrative approach was used, where we estimated potential increases in cultivated areas in southern Kajiado, and assigned pastoralists to switch from raising livestock and perhaps owning a business to also doing rain-fed or irrigated agriculture. Our estimates are coarse, but the simulations illustrate the potential for additional cultivation to improve the well-being of Kajiado residents. Areas appropriate for irrigation are essentially fully allocated in southern Kajiado District, Kenya. We estimated that there are no more than 5% additional lands that can be irrigated with the water currently available (yielding 1890 ha). Similarly, much of the area of Loitokitok appropriate for cultivation is already being used. We estimate that roughly another 20% in agriculture in the Loitokitok region is the maximum that can be expected, yielding 635 ha. Land is available for rain-fed agriculture throughout the district, but not all areas are suitable for cultivation, many households are already cultivating plots, and shortages of labor will prevent some households from cultivating large swaths of land. Here, we assume that rain-fed agriculture may increase by 30% to 1170 ha.

Results from simulations suggest that very modest improvements in the livelihoods of Maasai are possible through increased cultivation. These analyses suggest that options available to residents to improve their well-being cannot rely only on increased cultivation. In addition, livestock populations have been relatively stable for several decades. The capacity of the region to support livestock and wildlife is in a balance, and sizeable increases in livestock populations are unlikely without intensive management. Diversification of livelihoods has been on-going in Kajiado and elsewhere for many years, but intensification that relies on explotation of natural resources appears limited. Residents of southern Kajiado must find other means to improve their well-being, such as through businesses like sales, wage earning, or through providing services. Community benefits from conservation and tourism may provide a boost to the economy of southern Kajiado. Agricultural and livestock production may be increased through intensified management, but dramatic increases are unlikely in the near future. Residents of Kajiado will need to rely upon diversification and other means to improve the well-being of the community as a whole. Governmental policies that seek to improve the livelihoods of the growing human population in Kajiado should focus on means other than those that rely on the exploitation of natural resources.

## INTRODUCTION

Land use is intensifying in southern Kajiado District, Kenya (Figure 1). Decades ago, Maasai pastoralists grazed their livestock across large sections of land, using seasonal movements to maximize forage access for their cattle, goats, and sheep. Wildlife migrated from the swamps of Amboseli Basin used in dry seasons into the surrounding landscape during wet seasons (Ole Katampoi et al. 1990). Use of the swamps by livestock was truncated when a portion of the area was made a national reserve, and in 1974, a national park, but Maasai lands remained relatively intact. In the 1960s and 1970s, the Kenyan government sought to increase economic growth in semi-arid lands through improved livestock production, and to make it more likely that the lands would remain in the hands of pastoralists. Lands used commonly by Maasai were divided into group ranches with title held collectively by ranch members (reviewed more thoroughly in Scenario 3 below). As group ranches were being formed, some parcels were subdivided and claimed by indvidiual ranch members. That process has accelerated, with entire group ranches now subdivided into small parcels, with ranches in the more mesic areas to the north the earliest to subdivide. In our study area (Figure 1), Osilalei Group Ranch is subdivided, and Eselenkei, Imbirikani, and Olgululului/Lolorashi Group Ranches have plans to subdivide. Ranch committees will still agree to allow others to use their lands during drought, but following subdivision the trend is toward an increase in exclusive use through fencing (Kristjansen et al. 2002).

Other sources of land use intensification include human population growth and immigration by both Maasai and non-Maasai (reviewed in Thornton et al. 2006), increasing frequencies of drought (CA 2006), increases in some wildlife populations, such as elephants (Moss 2001) that can compete with livestock and cause wildlife-human conflicts, more intensive livestock management (e.g., use of improved breeds and more veterinary care), and a diversification of livelihood strategies (BurnSilver, In prep.). Livestock production remains the dominant livelihood strategy for residents of Kajiado, but few remain purely pastoralists. Many practice small-scale rain-fed agriculture in the grasslands and brushlands of the district. Others do intensive irrigated agriculture in the swamps that are east of Amboseli National Park. Some residents earn wages or own businesses, such as small-scale trading, craft production, and making and selling charcoal.

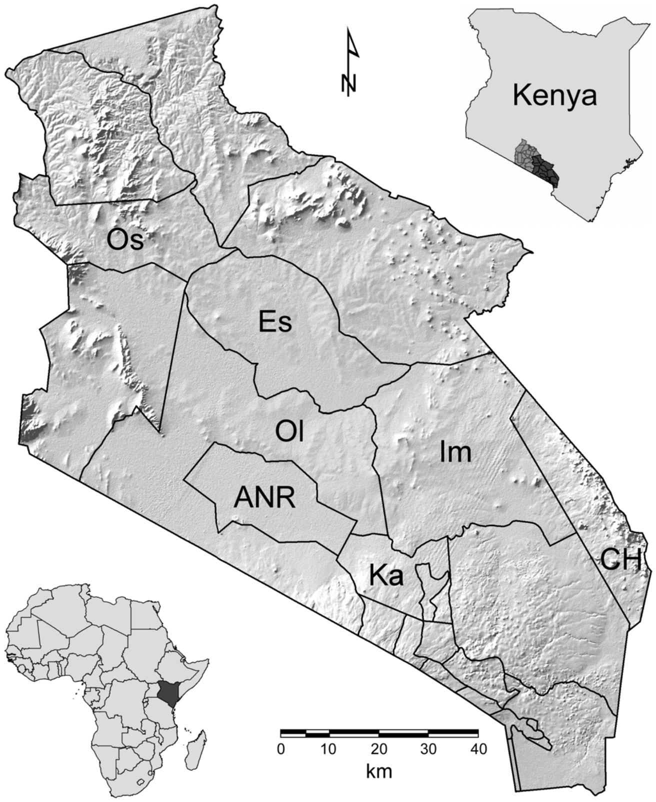

**Figure 1**. The area of study, southern Kajiado District, Kenya. Labeled group ranches include Eselenkei (Es), Imbirikani (Im), Kimana (Ka), Olgulului/Lolorashi (Ol), and Osilalei (Os). Amboseli National Reserve is labeled (ANR), as are the Chyulu Hills (CH). The area of Chyulu Hills neighboring Imbirikani is used by those ranch members, and included in modeling that group ranch.

Land use intensification may be an inevitable, and in some cases desirable, process on the Kajiado landscape. However, there are many pathways to intensified use. Pathways will have deleterious effects on some ecosystem traits or some households, and positive effects on others. Computer modeling provides one means of forming opinions about how pathways may affect aspects of the ecosystem and households. Computer programs exist that can simulate the important ecosystem interactions in a region such as southern Kajiado, and represent decision making by pastoralists and agro-pastoralists. The tools cannot predict outcomes far in the future, but they can highlight potential effects of land use change, and suggest the magnitude and direction of those effects.

We use an integrative ecosystem model called SAVANNA in our work, tightly joined with a model called PHEWS that simulates pastoral households and decision making. M. Coughenour began developing SAVANNA in the Turkana region of Kenya more than 20 years ago (Coughenour 1985), and it has been modified and improved continually and applied around the world (e.g., Coughenour 1992; Ludwig et al. 2001; Boone et al. 2002; Thornton et al. 2003; Christensen et al. 2004; Boone et al. 2005). SAvanna is a spatially explicit ecosystem model that divides landscapes into a grid of square cells. Spatial data are used to characterize the cells as to elevation, slope, aspect, and soil and land cover type. Weather data from a series of stations are used by the model to create estimates of rainfall and temperature. Plants are represented by functional groups, such as palatable grass, annual grasses, unpalatable shrubs, and acacias, and distributed on the landscape based on mapped land cover. During simulations, plants compete for water, nutrients, light, and space. Herbivores are represented as functional groups as well, but are often species, such as wildebeest (*Connochaetes taurinus*), African buffalo (*Syncerus caffer*), elephants (*Loxodonta africana*), cattle, and sheep. Animals are distributed on the landscape based on forage quality and quantity, distance to water, elevation, slope, woody cover, and temperature. Animals are also distributed using force maps, which capture non-ecological relationships such as land tenure. Animals feed on specified plant functional groups and gain energy, and use energy for basal metabolism, gestation, lactation, and travel. Surplus energy goes to weight gain, reflected in reported condition indices. Birth and mortality rates are tied to animal condition indices, so that birth rates decrease and mortality increases as condition indices decline, one of many potential feedbacks within the model. Savanna is generally used on landscapes from 500 to 20,000 km$^2$, and in simulations that span from 10 to 100 or more years.

PHEWS, the Pastoral Household Economic Welfare Simulator, was developed by P. Thornton with K. Galvin, R. Boone, and others. PHEWS is a rule-based model that represents decision making by pastoralists. People consume milk and home-grown grain and vegetables, sugar in tea, and some meat. Their energy intake is compared to their needs, and if inadequate and they have funds, they will purchase grain for consumption. If funds are in surplus, they may purchase livestock. If the pastoralists cannot afford to purchase food, it is assumed to be contributed by friends or agencies. Savanna passes livestock numbers and climatic information to PHEWS, which may be used in decision making about livestock and crop management, purchases and sales. In turn, PHEWS passes changes in livestock numbers back to Savanna, to keep accurate accounting of herds.

In analyses supported by the Global Livestock Collaborative Research Support Program of USAID and the US National Science Foundation, we created an application of Savanna and PHEWS to southern Kajiado District, Kenya. In the district, lands are being divided into 60-100 ac (24-40 ha) parcels used by individuals. Animals confined to parcels have few options to reach ephemeral forage patches. Integrated assessments suggested that, even with access to water retained, subdivision to individual parcels can lead to large declines in livestock. In Eselenkei Group Ranch, subdivision to 1 km$^2$ parcels led to a 25% decline in livestock that could be supported, relative to the intact group ranch (Boone et al. 2005). In more productive Osilalei Group Ranch, livestock populations did not decline under subdivision. We hypothesized a uni-modal relationship, where areas of very low or very high productivity and landscape heterogeneity are not strongly affected by fragmentation, but areas of intermediate productivity are sensitive to heterogeneity. Results from PHEWS confirmed that declines in livestock populations have profound negative effects on the well-being of Maasai (Thornton et al. 2006a).

In the work reported here, we undertook a research effort (e.g., two-month full-time equivalent for Boone) for the International Livestock Research Institute (ILRI), Nairobi, Kenya for a project supported by the Belgian Ministry of Foreign Affairs, Foreign Trade and International Co-operation, under their program for Belgian Support of International Agricultural Research for Development. The larger project is known as *Reto-o-Reto*, meaning locally “I help you, you help me.” Our efforts began with meetings in early 2005, when BurnSilver carried out 17 focus groups (n=75 people) that included young and old pastoralists. Two focus groups consisted mainly of women. These meetings identified the issues that were most salient to community members and were then followed by meetings with ILRI personnel, where we turned these questions into modeling scenarios. Boone conducted ecosystem and household modeling, with assistance from Thornton and BurnSilver. BurnSilver provided data, coordinated research assistants in the field, and led the outreach effort to inform Maasai of our results. Thornton, a Co-Principle Investigator on the *Reto-o-Reto*, provided modeling expertise and guidance.

Our analyses focused upon four primary questions, addressed as scenarios below. In each, we essentially attempt to represent the most important interactions in the ecosystem as it exists currently, in baseline or control simulations. We then alter select attributes of the simulations, and only those attributes, to address land use or policy questions that are pending. For example, if managers wish to judge the effects of a program to improve veterinary practices, we may model livestock populations with current treatments in place, then with reduced mortality and compare differences in vegetation, livestock, wildlife, and household food security.

## ECOLOGICAL AND SOCIAL EFFECTS OF IMPROVED LIVESTOCK BREEDS

In 2000, BurnSilver conducted household surveys and stakeholder meetings within Kajiado District, Kenya, where she asked participants about their main concerns. Effects of including improved breeds in livestock production were mentioned, but not at the forefront of concerns among the pastoralists, land managers, and policy makers present. In January 2005 focus groups, the issues involved with integrating enhanced breeds of cattle into their herds was extermely salient to pastoralists across the study area. Many families were already, to quote a community member, "experimenting" with or considering increasing their dependence on larger breeds of livestock. We believe this change in emphasis is in part from surveying a more focused group (i.e., pastoralists versus stakeholders), and in part because early efforts under the *Reto-o-Reto* project enabled people in the southern part of the study area to import breeding bulls.

Livestock in industrialized nations have been adapted through intensive breeding and feeding programs to generally have, for example, high milk yields, short juvenile periods, rapid weight gain, and long lactation periods. In contrast, breeds indigenous to Kenya such as the small East Africa shorthorn Zebu have been adapted through natural and pastoral selection for resistance to heat, disease, and to survive with limited food (Cunningham and Syrstad 1987; Peterson 1995). Purebred European livestock of the *Bos taurus* lineage are unlikely to be economically viable in tropical grazing systems. Importing breeds from the northern hemisphere has often led to high disease levels, high mortality, low fertility, and low production (Cunningham and Syrstad 1987). For example, purebred dairy herds can only be economically viable if health services are available and feed is good (Syrstad 1991). There is a history of introducing European breeds into East Africa, but few have persisted (Blench 1999).

However, tropical *Bos indicus* livestock breeds have been highly developed – the small East Africa shorthorn Zebu (hereafter Maasai Zebu) is one of about 75 shorthorn Zebu breeds globally. Kenyan livestock breeders used animals from the Borana herders in southern Ethiopia to produce the Boran breed, which is larger bodied than the Maasai Zebu, but retains a resistance to water scarcity and diseases, acceptance of low-quality feed, and a docile nature. Maasai are incorporating more Boran into their herds, valuing the breed's greater milk production, meat production, and higher price at sales. Another breed being considered by Kajiado residents are Sahiwal, which originated in India and Pakistan, and were improved into Kenya in the early 1930s (Kahi et al. 1995). Like the Boran, Sahiwal cattle are medium-sized, larger than Maasai Zebu cattle. Sahiwal are heat and disease resistant, and excellent milk producers. Their large body size and high milk production make Sahiwal cattle a good mixed-use breed. Collectively we will call these animals breeds "improved," to distinguish them from Maasai Zebu. The term agrees with the impression of local pastoralists as bigger animals, but should not suggest the animals are improved in every regard. There are substantial tradeoffs in keeping such large-bodied cattle in semi-arid systems. Boran and Sahiwal cattle are not able to travel long distances, as can Maasai Zebu cattle, they require more forage, are more expensive to purchase, are less drought resistant, and are more difficult to assist to water during droughts (King et al. 1984). First reproduction in Maasai Zebu cows is late (4.4 years in Kajiado) and the calving interval is long (13.9 months) (Mwacharo and Rege 2002). Their milk production is relatively low (1.6 l/d). That said, Maasai Zebu cattle can produce milk at times when improved cattle would be dry, or even dead (Mwacharo and Rege 2002).

Our study area represents a communally grazed system, where animals may have to walk long distances to access water, with mixed production goals, including milk production for the family and milk production for sale (Bebe et al. 2003). Meat production is a secondary consideration. Cattle are grazed on natural pasture, and uncontrolled mating of animals is not uncommon as herds mix.

Factors affecting the establishment of improved breeds are: 1) ecology and feed availability, 2) disease, 3) animal traction, 4) marketing systems, and 5) cultural preferences (Blench 1999: 39). Animals may be more or less selective in their diets. For example, some breeds are adapted to use more woody vegetation than others, and some are adapted to herbaceous plants of a given region. Breeds with more specialized diets tend to have more restricted ranges. Disease effects are poorly known, except for trypanosomoses (Blench 1999). Trypanosomiasis does not limit cattle in southern Kajiado District, Kenya. Using cattle for plowing and cart-pulling are not culturally acceptable to Maasai (Mwacharo and Rege 2002), and so do not play a role in breed selection. In surveys in Kajiado District, 63% of respondents said they preferred Maasai Zebu cattle because of their ability to survive drought, and another 18% cited their resistance to disease (Mwacharo and Rege 2002). From this, and the nature of the tools we use in analyses, our work focuses on ecological relationships with traditional versus improved breeds. We do not address factors such as cultural preferences in breed selection, and the value of conserving indigenous genetic diversity (Karugia et al. 2001). We consider those factors important, but they are not included in the PHEWS household model. The repercussions of these and other exclusions from PHEWS are discussed below. In these analyses, we take the systems approach lauded by Karugia et al. (2001). We do not consider all the biodiversity issues and external costs they recommend, but we include ecosystem services in an integrated systems way, which is novel.

We sought to characterize some effects on ungulate populations, other ecosystem effects, and pastoral food security and income when improved breeds were included in herds. Our application is parameterized to reflect the mix of livestock breeds in southern Kajiado in the early 2000s, with the cattle functional group dominated by Maasai Zebu cattle but with some Boran and Sahiwal. There are ecological, financial, and cultural reasons why the collective residents of southern Kajiado District will not own wholly Maasai Zebu or wholly improved breeds, but we set aside those concerns in our analyses, and explored the entire range of simulation responses. We asked what an optimum mix of Maasai Zebu and improved livestock would be and how it might vary spatially, and formulated and proposed Scenario 1 (see Box 1).

## Adjustments to Scenario Proposed

We had proposed conducting analyses using improved goat and sheep breeds. There is some information about small stock breed performance (e.g., Mason and Buvanendran 1982), but unlike for cattle, most that we found was not quantitative. Also, whereas controlled breeding is often practiced for cattle in Kajiado (Mwacharo and Rege 2002), breeding for small stock is almost always haphazard (Blench 1999). Retaining genes from improved breeds in small stock herds over multiple generations would require a significant change in herd management. Therefore, because of a lack of quantitative results in the literature and a lack of breeding management of small stock in Maasai culture, we dispensed with analyses using improved goat and sheep breeds.

We had proposed doing analyses in Kimana Group Ranch, given the areas of interest in the *Reto-o-Reto* project. A Savanna model of Kimana Group Ranch at 1 km$^2$ resolution was prepared, but ultimately we determined that we had insufficient information on Kimana households to parameterize the PHEWS model. Modeling in Kimana Group Ranch was therefore not conducted.

## Methods

A literature review was conducted to identify differences in Maasai Zebu, Boran, and Sahiwal livestock breeds. Our literature review suggested that parameters in Savanna that should be altered for improved breeds include body mass, milk production, calving interval as reflected in annual calving rate, mortality associated with disease, travel costs, the distance from water the animals will travel, and sales, purchase, and veterinary prices (Table 1). Some other traits, such as water usage, are higher for improved breeds, but are not included in this Savanna application, or were considered minor affects with resolutions below the level we can model (e.g., age at first calving, where Savanna has essentially an annual resolution but different breeds vary by weeks or months). The information that was available was primarily from research stations, and dwelled upon milk production and weight gain. Results from East African studies were fairly common. Control values for tropical breeds in publications reporting results from crossing purebred animals with European breeds were helpful. Few studies we located reported results from animals grazing in unfenced parcels. Information on travel costs and differences in distance-to-water for improved stock was difficult to locate, for example. For some parameters, we used estimations of effects, which are labeled (Table 1).

This scenario does not rely upon explicit spatial features of the landscape, like a new water source or pattern of subdivision. Each group ranch was simulated 33 times in these analyses. To speed analyses, 1 km$^2$ resolution spatial data were used in modeling, whereas in other scenarios 500 x 500 m resolution was used.

The existing Savanna application (see Boone et al. 2005 for details) includes a single cattle population. As we proposed (Box 1), we altered the traits of that population in a series of simulations reflecting a gradient from almost all Maasai Zebu cattle to all Boran and Sahiwal cattle. In these analyses, we assumed that an animal with 50%, say, indigenous stock and 50% improved stock would be intermediate in the parameters altered in Savanna. This approach is used to generate a full spectrum of responses – we do not hold that the traits represented are linearly associated with genetic composition, only that the method used illustrated a reasonable suite of responses.

We followed those analyses with some where we included two cattle populations in the Savanna application, so that four livestock and 10 total ungulate groups were modeled. In those analyses, parameters shown in Table 1 were

**BOX 1. ORIGINAL SCENARIO 1: Changes in Livestock Breeds**

**Goals**: To 1) quantify the benefits and costs of maintaining pure and mixed-breed herds, and to 2) identify a mix of breeds that maximize animal productivity and expected returns.

**Pathway**: Work on each of the five group ranches (Imb., Os., Ol., Es., and Kimana). SAVANNA includes a zebu cattle breed, typical sheep and goats, plus six wildlife species or groups. In analyses, make those breeds intermediate in their attributes to represent hybrid animals. Also add to SAVANNA another species representing Boran or Sahiwal cattle, another representing doper, black-head Persian, or red Maasai sheep, and another representing an improved goat breed, such as Galla. Changes will be made to the SAVANNA dietary files, biomasses, milk production and livestock sale prices (PHEWS), distance-to-water relationships, energetic travel costs, and disease and mortality relationships (if available). We must find the costs and prices of different animal breeds.

**Scenarios**: For each group ranch, first calculate the trade-offs in types of livestock based on TLUs and initialize livestock populations to those values. Then run simulations with multiple rainfall patterns:

For each livestock group, cattle, goats, and sheep, simulate the following:

1. Individuals 100% native breed, 0% improved breed
2. Individuals 90% native breed, 10% improved breed

…

10. Individuals 10% native breed, 90% improved breed
11. Individuals 0% native breed, 100% improved breed

and:

1. Herd 100% native breed, 0% improved breed
2. Herd 90% native breed, 10% improved breed

…

10. Herd 10% native breed, 90% improved breed
11. Herd 0% native breed, 100% improved breed

**Possible types of results**: General bell-shaped curves for productivity, where pure zebu yield relatively low livestock sales and income, a mixed herd more, and a pure boran herd less because of decreased stocking and higher mortality. Compare expected income at different herd compositions.

**Notes**: These analyses include a significant number of simulations, to account for variations in rainfall patterns. If the results for herd-centric and hybrid-centric analyses for cattle are similar, only hybrid-centric analyses for goats and sheep will be conducted. A limited number of analyses may be conducted with all livestock improved, etc.

set uniquely for each cattle functional group, and were not altered. Instead, the ratio of number of Maasai Zebu cattle to improved animals was initialized using a biomass relationship, using a cow as a reference biomass, 225 kg for Maasai Zebu, and 305 kg for Boran and Sahiwal cattle. For example, Eselenkei Group Ranch has 16,985 Maasai Zebu cattle in the base simulation. When 50% Maasai Zebu and 50% improved breeds were simulated, the Maasai Zebu functional group was initialized to 8493 animals, and the improved group to 6265. Similarly, when a single mixed herd was simulated, in the example given, 16,985 cattle would be initialized when the herd is 100% Maasai Zebu, 14,758 when the animals are 50% Maasai Zebu and 50% improved breeds, and 12,530 when 100% improved breeds. In these analyses, and in all the scenarios, results are summarized using Tropical Livestock Units (TLUs) and Large Herbivore Units (LHUs). The two are similar measures. Livestock populations were converted to TLUs that represent 250 kg body mass, using masses cited in Boone and BurnSilver (2002). Wildlife were standardized to LHUs, using an equivalent 250 kg body mass, with masses listed in Boone and BurnSilver (2002). In this scenario, summary calculations using TLUs incorporated greater body masses for improved

**Table 1**. Parameters manipulated in analyses of improved cattle breeds.

| Parameter | Maasai Zebu Cattle[a] | Boran and Sahiwal Cattle | Sources |
|---|---|---|---|
| **Body mass[b]** (kg, age/sex classes) | 45, 110, 120, 225, 315 | 61, 120, 140, 305, 427 | 2, 4, 5, 11, 12, 16, 18, 22, 23 |
| **Milk production[c]** (kg/cow/d, by month) | 0.8, 0.8, 1.5, 1.5, 1.5, 0.8, 0.8, 0.8, 0.8, 0.8, 1.4, 1.4 | 1.5, 1.5, 2.8, 2.8, 2.8, 1.5, 1.5, 1.5, 1.5, 1.5, 2.6, 2.6 | 2, 7, 10, 12, 20, 21 |
| **Proportion calving[d]** (annually, related to calving interval) | 0.67 | 0.70 | 1, 2, 6, 14, 16, 17, 20, 23 |
| **Mortality[e]** (Relative adjustment, related to condition index, both 0-1) | 0.85 : 0.00 0.72 : 0.12<br>0.50 : 0.80 0.00 : 0.95 | 0.90 : 0.00 0.72 : 0.15<br>0.50 : 0.85 0.30 : 0.99 | 1, 4, 7, Estimate |
| **Distance to water[f]** (habitat suitability) | 10 km, 70% suitable<br>25 km, 0% suitable<br>Variable across months | 10 km, 50% suitable<br>18 km, 0% suitable<br>Variable across months | 10, 11, 12, 13, 19, Estimate |
| **Travel costs[g]** (joules/kg/m) | 1.57, 2.20 | 2.13, 3.0 | 12, Estimated from relative body mass |
| **Lactation cost[h]** (proportion of basal metabolism) | 0.5 | 0.75 | 2, 7, 10, 20, 21, Estimate |
| **Sale prices[i]** (Kenyan shillings, age/sex classes) | 1500, 3000, 3000, 10,000, 11,000 | 2250, 4500, 4500, 15,000, 16,500 | 4, 8, 15, Estimate relative to Zebu |
| **Purchase prices[j]** (Kenyan shillings, age/sex classes) | 2000, 4000, 4000, 12,000, 14,000 | 3000, 6000, 6000, 18,000, 21,000 | 4, 8, 15, Estimate relative to Zebu |
| **Veterinary costs[k]** (Kenyan shillings, by wealth category) | 670, 975, 2460 | 1005, 1463, 3690 | 1, Estimate |

[a] - Parameterizing Savanna within a reasonable period requires that functional groups of plants and animals be used. Here, for example, we recognize that many breeds of indigenous cattle are included in the group known as zebu, and that crosses with other indigenous breeds are common (Blench 1999). In the model, they are represented as a single species, indigenous Maasai Zebu cattle. The values shown are those used throughout all scenarios. They represent primarily Maasai Zebu cattle [e.g., during the surveys of Bekure et al. (1991), 95% of cattle were small East Africa Zebu], but with some improved stock as well, essentially the conditions of herds in ca. 2000.

[b] - Body masses for five age/sex classes, first-year animals of both sexes, female and male juveniles, and female and male adults.

[c] - Maximum milk production, by month (i.e., 12 values). Milk production is reduced if condition indices are low.

[d] - The proportion of females calving each year, related to the calving interval.

[e] - Mortality is modified based on animal condition indices. The pairs of values shown are a linear regression, so for example in Maasai Zebu cattle, a condition index of 0.72 yields an upward adjustment of 0.80 to the baseline mortality rate.

[f] - Distance to water relates to the habitat suitability of modeled cells. Sites 0 m from water were 100% suitable, with the suitability declining as shown. Staged grazing is simulated, so that distance to water plays a stronger role in wet months (March, April, May, June, July, November, December), weaker in the short dry season as animals are watered every other day (January, February), and weakest in the dry season using three-day watering cycles (August, September, October).

breeds, using proportional weighting where appropriate. For analyses using PHEWS, TLUs were adjusted after modeling had been completed, so that the ratio of Maasai Zebu cattle to improved breeds was used as a multiplier on TLUs to yield adjusted TLUs per Adult Equivalent.

**Results and Interpretation**

In simulations, populations composed of improved breeds declined in many simulations, reflecting their limited dispersal distance from water and need for more forage (e.g., Figure 2). Their larger biomass offsets these declines to a degree, yielding similar TLUs across simulations. Changes in livestock abundances are shown for Imbirikani Group Ranch (Figure 3a), Eselenkei Group Ranch (Figure 4a), Olgulului/Lolorashi Group Ranch (Figure 5a), and Oselalei Group Ranch (Figure 6a). Results were variable in each of the group ranches, but in general, livestock abundance appeared to peak where herds were composed of 40% to 60% improved breeds, except in Oselalei Group Ranch, which is the most productive of the group ranches in the study. Specifically, in Imbirikani Group Ranch, livestock biomass in the three modeling approaches peaks with the herd composed of 50% Maasai Zebu and 50% improved animals (Figure 3a). Wildlife populations were generally similar across analyses in Imbirikani, but were higher when two cattle populations were included in the model (Figure 3b). This is likely an artifact of the necessity to rebalance the ecosystem model when the additional functional group was added – a different balance was settled upon. Household food security is best in the Imbirikani simulations when the herd is 50% Maasai Zebu and 50% improved animals.

In Eselenkei Group Ranch, 40 to 60% improved breeds yield TLUs 4000 to 5000 greater than most other simulations, when modeled as a mixed herd (Figure 4a). Results when PHEWS was enabled and when two cattle groups were used were variable. With 50% of the animals Maasai Zebu and 50% improved stock, livestock numbers were low when PHEWS was enabled, but higher when represented by two cattle populations (Figure 4a). Household well-being was lowest at 50% improved stock (Figure 4c).

In Olgulului/Lolorashi Group Ranch, in general, livestock biomass peaks in the three modeling approaches used at 40% improved stock (Figure 5a), at a lower percentage than other ranches. When represented as two herds, higher proportions of improved animals yield greater livestock biomass. Wildlife biomass is typical for the ranch when herds were 40% improved stock, but much lower when all livestock are the improved breeds (Figure 5b). In general, household well-being is best when herds are 40% improved, or 10% or less improved (Figure 5c). The responses for Olgulului/Lolorashi Group Ranch on one hand and Imbirikani and Eselenkei Group Ranch on the other show marked differences in the balance point at which livestock populations are highest. This reflects that Olgulului is much dier than the other group ranches. Pastoralists echoed these relationships, and the changeover from traditional to improved breeds is more complete in the more productive areas, areas where improved breeds are apt to find adequate forage and water.

Lastly, in Osilalei Group Ranch, livestock TLUs were relatively stable regardless of the mix of breeds present (Figure 6a). Wildlife densities were similar across runs as well, except that when livestock were 70% improved, wildlife populations were about 25% higher than in other simulations with improved breeds present (Figure 6b). The relief used is variable, inversely related to TLUs per adult equivalent (Figure 6c) and TLUs overall (Figure 6a), but not exhibiting a trend. The differences between

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[g] - Travel costs are in joules/kg/m, with two values, for horizontal and vertical travel.

[h] - Lactation cost as a proportion of basal metabolism energy costs.

[i] - Sale prices are in Kenyan shillings, for five age/sex classes, first-year animals of both sexes, female and male juveniles, and female and male adults.

[j] - Purchase prices are in Kenyan shillings, for five age/sex classes, first-year animals of both sexes, female and male juveniles, and female and male adults.

[k] - Costs are shown for poor, medium, and rich households. Values vary across the eight livelihood methods. The values shown are most common, but rich households with only livestock are estimated to spend 1460 KSH under current conditions, and rich household with livestock and doing Loitokitok agriculture spend 1260 KSH monthly.

Sources: 1 - Karugia et al. (2001); 2 - Demeke et al. (2004a); 3 - Demeke et al. (2004b); 4 - Bekure et al. (1991); 5- Demeke et al. (2003); 6 - Dubey and Singh (2005); 7 - Trail and Gregory (1981); 8 - Rutten (1992); 9 - KARI (2001), as cited in 8; 10 - Coppock (1993); 11 - King et al. (1984); 12 - King (1983); 13 - Sandford (1983); 14 - Mukasa-Mugerwa (1989); 15 - Bekure and Tilahun (1983); 16 - Trail et al. (1984); 17 - Omore (2003); 18 - Mwandotto et al. (1988); 19 - Nicholson (1987); 20 - Gaur (1996); 21 - Singh and Nacarcenkar (1997); 22 - Maichomo et al. (2005); 23 - Joshi et al. (2005). These sources provided values or suggested directions and magnitudes of differences between breeds.

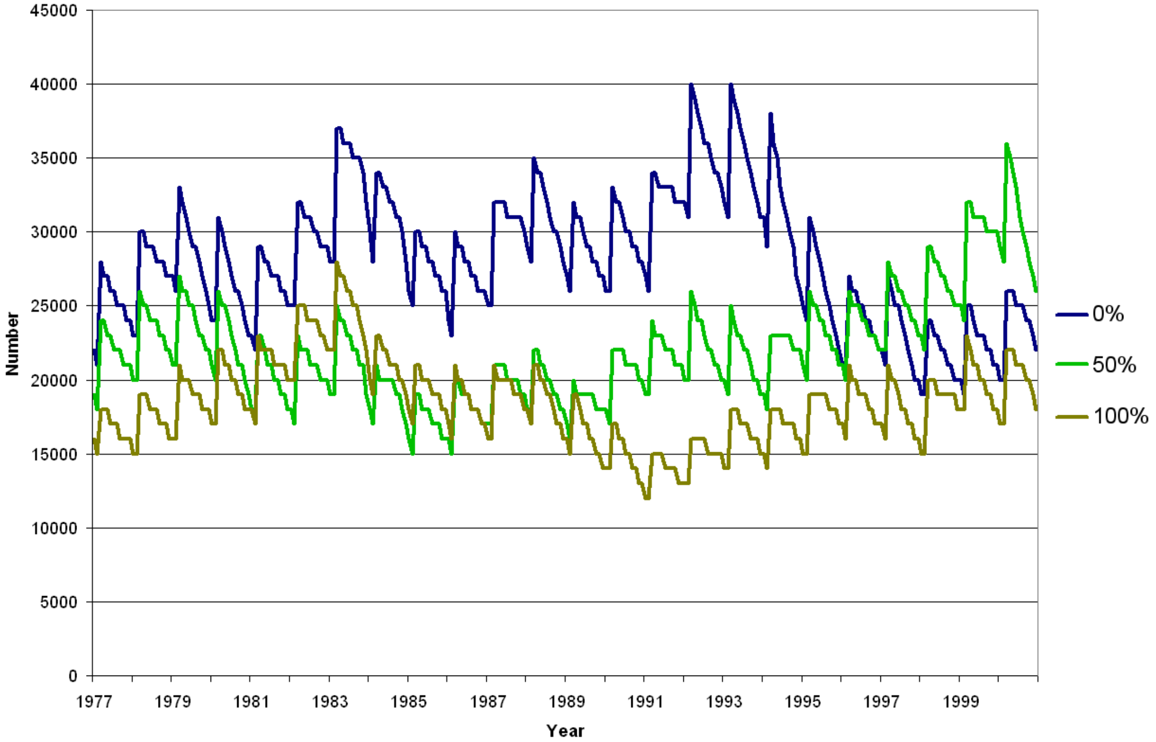

**Figure 2**. Cattle populations in Imbirikani Group Ranch, with populations composed of 0% improved breeds, 50% improved breeds, and 100% improved breeds. In these analyses, livestock sales were disabled.

group ranch responses may be due to increased productivity in Osilalei Group Ranch, with the ranch able to support increased numbers of larger animals without straining the forage supply.

These results should be interpreted recognizing the complexity of decisions pastoralists make when selecting livestock breeds. The randomness of some of the modeling results may be an outcome of missing factors in our pastoral decision making model. As discussed above, there are cultural reasons why pastoralists will move toward larger breeds. Such relationships are not represented in PHEWS or these results. Water usage is not included in the modeling, although distance-to-water relationships are. So the fact that improved breeds require more water per individual animal is not represented. Differences in disease rates between Maasai Zebu and improved breeds are captured in a coarse way (Table 1), but more detailed disease modeling may alter results. More subtle questions of economic efficiencies of production are not considered by modeled pastoralists, such as the rate of meat production per unit time. What are captured are the ecological and economic relationships implicit in the data shown in Table 1. Simulations that are without livestock sales (i.e., without PHEWS enabled) capture the ecological relationships included in SAVANNA. Simulations that include livestock sales (i.e., with PHEWS) include the ecological and economic relationships cited. A more complex adaptation of the PHEWS model, and field data appropriate for its parameterization, would be needed to capture the more subtle decision making of Kajiado pastoralists. For Imbirikani and Olgulului Group Ranches, livestock biomass is relatively high when the population is 100% Maasai Zebu cattle. That is likely a result of the SAVANNA application being designed for a herd with that composition. For example, in parameterizing the model, we ensured those populations were relatively stable. Subsequent simulations could vary as the parameters deemed.

## Conclusions

Analyses using mixed breeds yield variable results (Figures 3-6). That said, a subtle pattern appears to emerge across the group ranches studied – mixed herds with between 40% and 60% improved stock yield relatively high livestock biomass, do not markedly change wildlife populations or the percentage of relief used by households. Within that range, from 40% to 60% improved stock, drier areas appear better suited to 40% improved stock, and wetter areas to 60% improved stock. Overall, there are trade-offs involved in switching from Maasai Zebu cattle to herds that include introduced breeds. If switching to introduced breeds becomes widespread in Kajiado, more research is warranted to establish the costs and benefits.

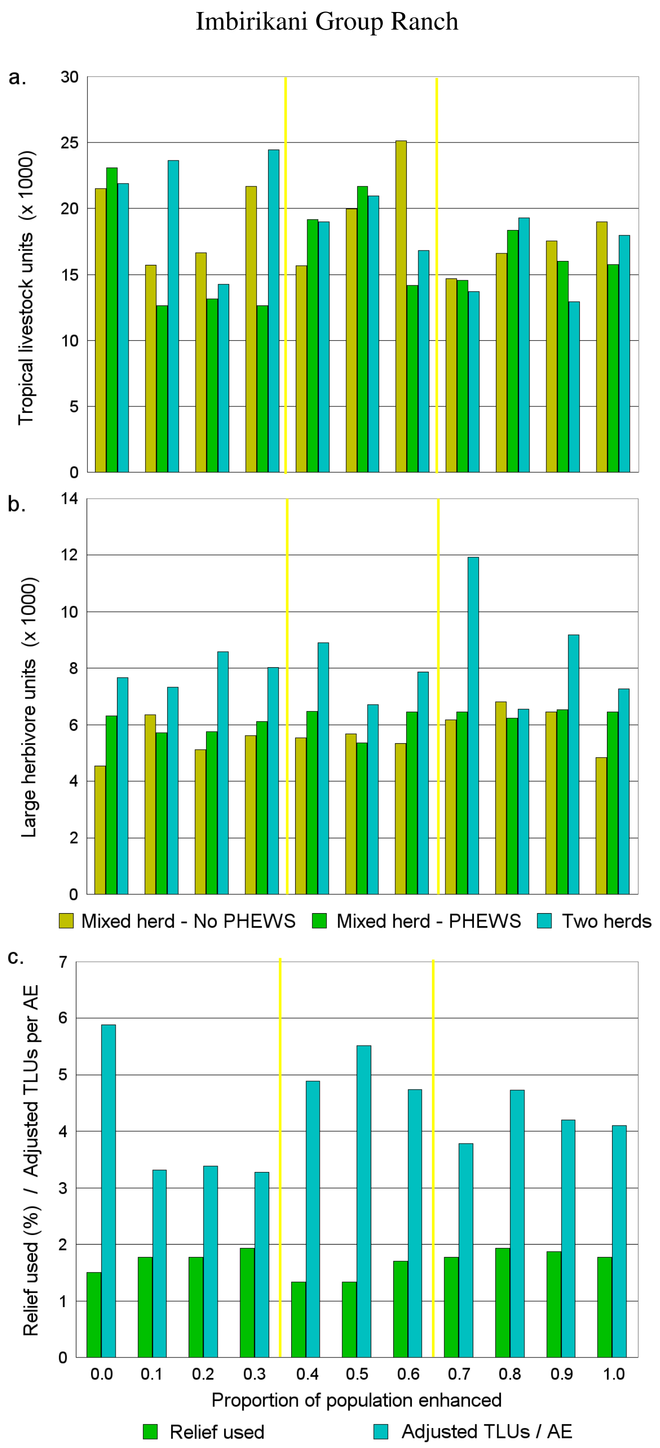

**Figure 3**. Effects of changing proportions of Maasai Zebu to improved breeds on ecosystem and household attributes in Imbirikani Group Ranch. Livestock TLUs (a), wildlife LHUs (b), and select household attributes (c) are shown. Mixed herd modeling used a single herd for cattle, with attributes altered to be reflect proportions. Two herd modeling used separate herds for the Maasai Zebu and improved breeds. Overlaid lines delimit herd mixes of 40% to 60% improved breeds.

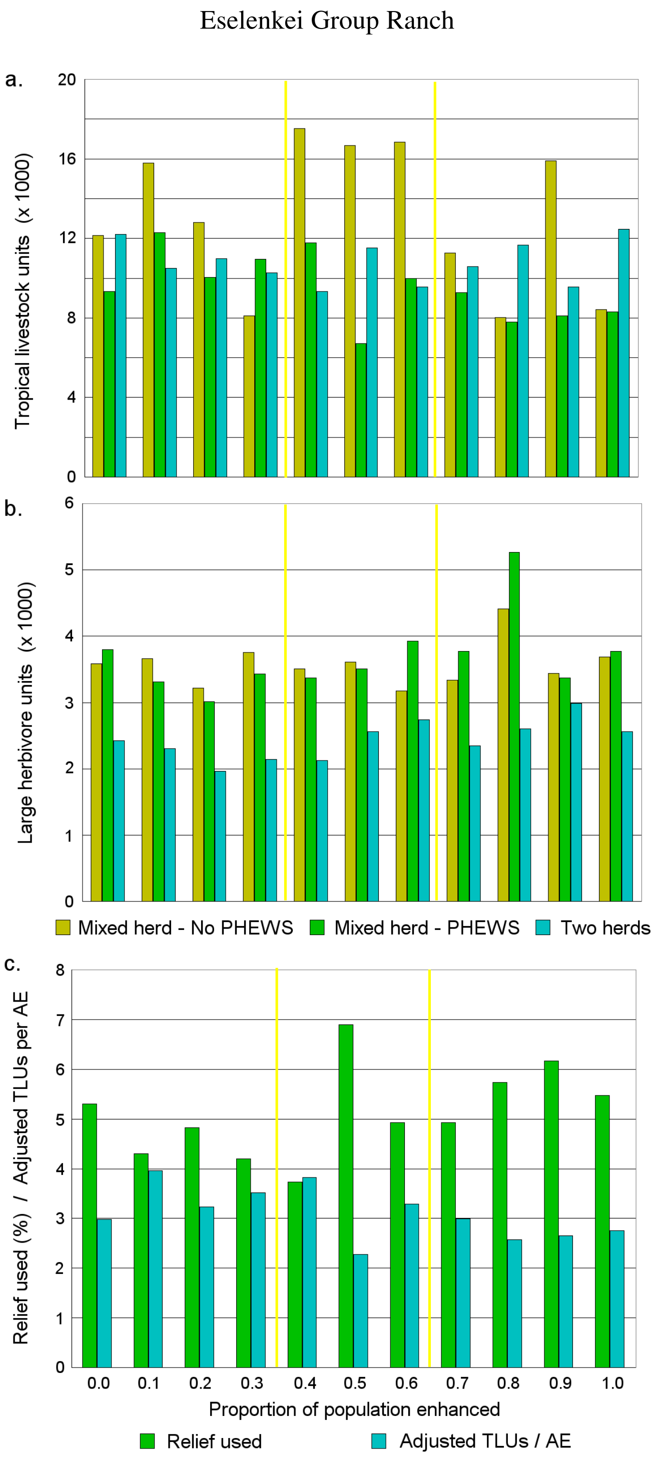

**Figure 4**. Effects of changing proportions of Maasai Zebu to improved breeds on ecosystem and household attributes in Eselenkei Group Ranch. Livestock TLUs (a), wildlife LHUs (b), and select household attributes (c) are shown. Mixed herd modeling used a single herd for cattle, with attributes altered to be reflect proportions. Two herd modeling used separate herds for the Maasai Zebu and improved breeds. Overlaid lines delimit herd mixes of 40% to 60% improved breeds.

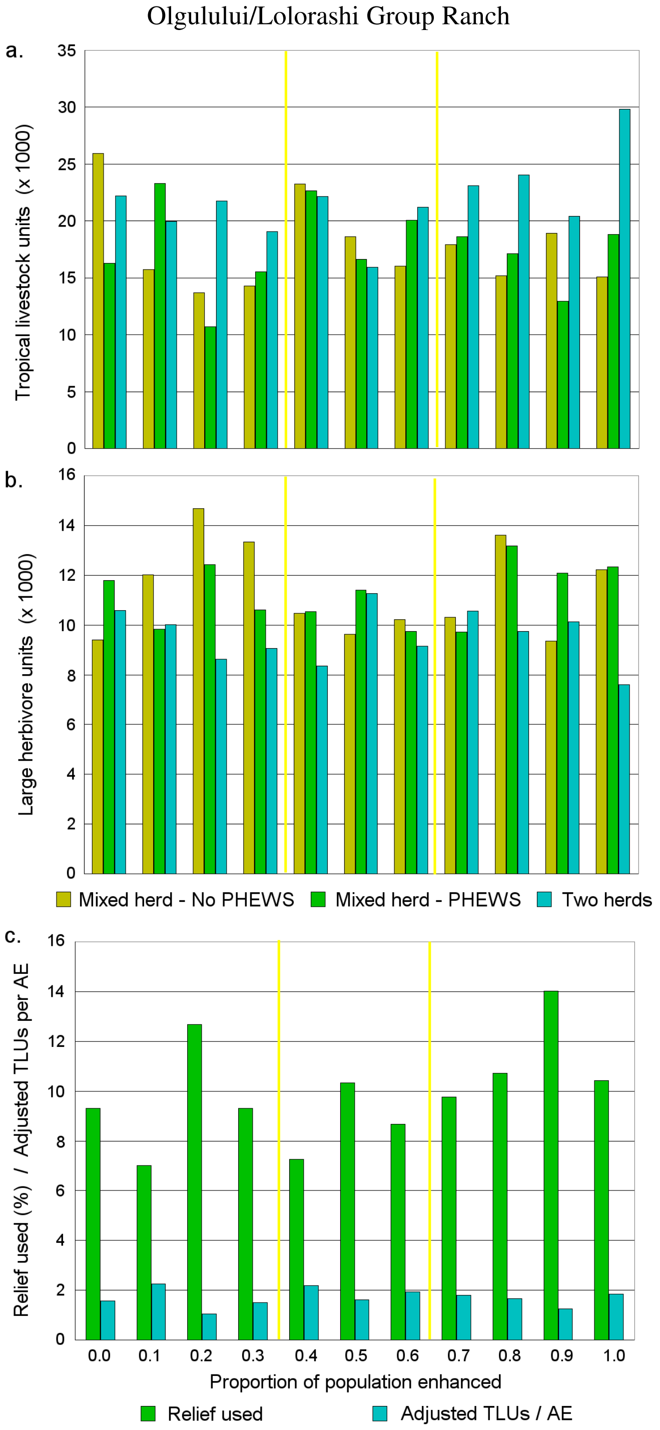

**Figure 5**. Effects of changing proportions of Maasai Zebu to improved breeds on ecosystem and household attributes in Olgulului/Lolorashi Group Ranch. Livestock TLUs (a), wildlife LHUs (b), and select household attributes (c) are shown. Mixed herd modeling used a single herd for cattle, with attributes altered to be reflect proportions. Two herd modeling used separate herds for the Maasai Zebu and improved breeds. Overlaid lines delimit herd mixes of 40% to 60% improved breeds.

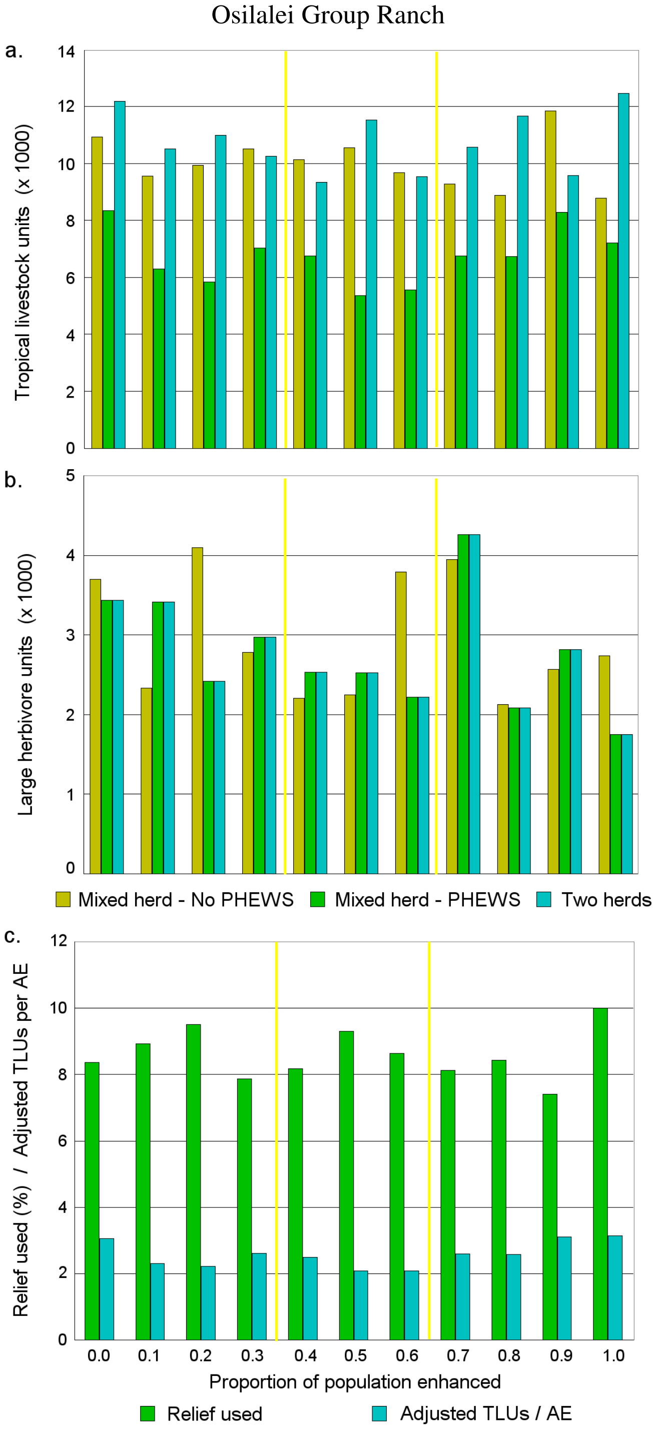

**Figure 6**. Effects of changing proportions of Maasai Zebu to improved breeds on ecosystem and household attributes in Osilalei Group Ranch. Livestock TLUs (a), wildlife LHUs (b), and select household attributes (c) are shown. Mixed herd modeling used a single herd for cattle, with attributes altered to be reflect proportions. Two herd modeling used separate herds for the Maasai Zebu and improved breeds. Overlaid lines delimit herd mixes of 40% to 60% improved breeds.

## ADDING WATER SOURCES IN IMBIRIKANI GROUP RANCH

For much of the year, water is a rarity in semi-arid and arid systems, and its availability affects the decisions that people and animals make. For many wild and domestic ungulates, their need to drink regularly and the energetic costs of travel limit their grazing areas to points around water sources (Western 1975; Redfern et al. 2003). Animals differ in their need for water, for example, Thompson's gazelles (*Gazella thomsonii*) require water almost every day, whereas Grant's gazelles (*Gazella granti*) get much of their water from the grasses they eat. Ideally, Maasai Zebu cattle drink daily, but they can drink on alternate days, and at the height of the dry season, can be led to water every three days, allowing a wider area to be grazed (King 1983). At the height of droughts or just before the rains return, Maasai Zebu can go as long as every six days before watering, surviving off morning dew that collects on grasses (BurnSilver, pers. obs.).

In Imbirikani Group Ranch, Kajiado, Kenya, a series of natural water sources used by livestock and wildlife are augmented by wells, boreholes, and small reservoirs. An important additional series of sources are from a pipeline that extends from the Tanzania border on the slopes of Mount Kilimanjaro, and draws from the Nolturesh River (Figure 7). The large-diameter Nolturesh Pipeline (61 cm) was constructed to provide water for the residents of the town of Kajiado (Ntiati 2002). However, much of the water is now used for irrigating farms near Nairobi where flowers are grown for export. Water sources within Imbirikani Group Ranch are clustered around Nolturesh Pipeline (Smucker et al. 2004). Herders graze their animals around the pipeline and their permanent residences for much of the wet season. The higher elevation areas of the Chyulu Hills to the east are retained as a grazing reserve by group ranch members, although there are cases where richer pastoralists who own vehicles have set-up permanent settlements within the reserve areas and transport water. The traditional system, however, has required that herds remain for most of the wet season at their permanent settlements on the pipeline. As forage is depleted, they begin to move outward from the pipeline (east and west) in stages. As distances increase, herders begin to camp in temporary households, and water and graze their animals on alternate days, eventually extending the time between watering based on forage availability and grazing distance. Ultimately, in the late dry season, large stock may be grazed in the Chyulu Hills or far west of the pipeline. When the rains return, herders take advantage of the seasonal dams in these reserve grazing areas, but when these sources dry, they collapse back into the permanent zones of settlement along the pipeline, and the seasonal cycle begins again. Rainfall variability will dictate how far herders graze their animals into the grazing stages each dry season, with substantial differences in grazing duration in reserves between good and bad years (reviewed in BurnSilver, In prep.).

**Figure 7**. A pipeline spur extends northwest in Imbirikani Group Ranch to Chyulu Hills, from the Nolturesh Pipeline, which flows north. The pipelines are shown in heavy lines. A water source at the end of the spur was modeled (large symbol), and sources every 5 km along the spur were modeled (smaller symbols). Topography is shown in shades of grey, and insets show the location of the study area in Imbirikani Group Ranch, and the ranch in Kenya.

One means of alleviating constraints of water shortages is to add water sources to areas far from existing ones. Areas distant from water can have standing forage biomass that goes unused by livestock, with only wildlife species less reliant on water sources using the areas (Western 1975; Redfern et al. 2003). In 2004, the Imbirikani Group Ranch Committee received permission to construct a spur on the existing pipeline, extending east-northeast from Nolturesh Pipeline in the center of the group ranch, to the Chyulu Hills (Figure 7). Construction began in early 2005, with the pipeline being built in two sections, the first about 11.5 km in length, the second 11 km (specifically, from UTM zone 37 coordinates: x : 336402, y :

**Box 2. ORIGINAL SCENARIO 2: Additional water sources in Imbirikani Group Ranch**

**Goals**: Quantify regional and local changes in livestock production in Imbirikani and the entire study area when a new pipeline is put in place.

**Pathway**: Modify the distance-to-water maps used by SAVANNA to distribute herbivores. Include a single source at the terminus of the pipeline, and sources perhaps every five kilometers along the pipeline. SAVANNA can be modified to have water available to livestock and wildlife, wildlife, or livestock. Here we will allow livestock and wildlife to access the water. We may include differential costs for households, dependent upon their place on the landscape.

**Scenarios**: First, outside of modeling, create a subdivision map by artificially placing parcels. Calculate their mean distance to water without and with the pipeline in place. Complete the following analyses:

1. For the entire area, run the model without and with the single water source in place, and compare the results critically.
2. For the entire area, run the model without and with the multiple water sources.
3. Alter the seasonal timing of access (retain dry season access, and prevent wet season access?), and run a simulation.
4. Alter access to prevent use except when the previous three months have been dry, and run a simulation.

**Possible types of results**: The benefits of adding a water source (or several sources) will be quantified, along with the risks associated with promoting grazing in a reserve year-round.

**Notes**: The pipeline is being installed in phases, and these phases may be modeled. Boone will likely model the water source(s) available to only livestock (and humans), and to all herbivores separately.

-280310 at Nolturesh Pipeline; x : 347649, y : -277700 at the end of the first section; x : 358447; y : -275580 at the terminus). The pipeline will end at a large water tank, designed to be used by livestock and group ranch members. The first phase of the new pipeline is under construction. The core question asked by community members was "How can we use this pipeline most effectively?"

The Nolturesh Pipeline has been pierced at intervals along its length, both legally and illegally, to provide water for residents, and damage or leaks can occur. We model some repercussions of adding the water tank at the terminus of the Chyulu pipeline spur. We also model the repercussions of adding water sources at 5 km intervals along the pipeline. We originally formulated and proposed the scenario described in Box 2. Modeling methods were modified as needed, as described below.

## Adjustments to the Scenario Proposed

The scenario was modeled essentially as proposed. We did add an additional set of analyses that used randomized weather to quantify variance in modeled results, allowing standard error bars to be generated.

## Model Adaptation

The Savanna application to the larger study area was modified to better capture seasonal movements by Maasai herders. In the larger application, the suitability of areas to livestock with respect to distance-to-water was constant across months of the year. Livestock were only allowed to use the Chyulu Hills the last three months of the long dry season (August, September, October). This combination reasonably represented livestock distributions across the larger study area (Boone et al. 2005), but a more precise representation was sought. Specifically, we sought to capture the patterns of herders as they switch from watering animals every day to every second and every third day. First, herders were allowed to use Chyulu Hills in November, to better represent use (BurnSilver, In prep.). Second, the strength of the distance-to-water relationship was weakened in August, September, and October, as well as in January and February, when herds may move further from permanent water sources.

Two sets of maps are used in the base Savanna model that show the distance for any modeled cell to the nearest water source; three for livestock in the wet season, transitional season, and dry season, and three for wildlife in the wet season, transitional season, and dry season. This approach allows water from boreholes, for example, to influence the distribution of livestock without affecting wildlife. Twelve additional maps were created, at 500 x 500 m resolution; three for livestock that included the original and new water point, three for wildlife that include the new water point, three for livestock that included water points every 5 km along the new pipeline, and maps for wildlife that include water points every 5 km.

The southern Kajiado application of Savanna did not include a method to use one set of distance-to-water maps during a wet period, and another set of maps during a dry period (i.e., analysis 4 in the original scenario, Box 2). Instead, the programming of the application was altered so that the distribution of livestock was sensitive to the average rainfall across the group ranch in the previous three months. In that analysis, the established water sources were used if the system precipitation in the previous three months exceeded 75 mm. If the previous three months were drier, the map used included the new water source or sources. This emulated pastoralists and their livestock having access to the water point in only the driest months, and by inference grazing to the surrounding lands without the need for long-distance trips to water.

Our results must be interpreted in light of our two modeling approaches, one with the PHEWS model disabled, so that livestock sales and purchases do not occur, and one where PHEWS is enabled. When PHEWS is disabled, the ungulate populations presumably approach some capacity of the system (past analyses suggest southern Kajiado District is an equilibrial system; Toxopeus 2000; Boone et al. 2005). That said, idiosyncratic changes associated with one of nine populations becoming dominant over others adds noise to the results. In PHEWS, as in reality (BurnSilver, In prep.), residents that are food insecure sell cattle to purchase maize and other foods, and purchase goats or sheep at that time. These livestock sales often decrease the number of animals supported in the group ranch. For example, with existing water sources and PHEWS enabled, there were on average about 1,600 fewer livestock TLUs on the landscape than when PHEWS is disabled. The difference in animals reflect food insecurity by residents, and their need to use emergency livestock sales.

## Results and Interpretation

Figures 8-10 provide some indication for the changes in distributions of total green biomass, cattle, and wildebeest

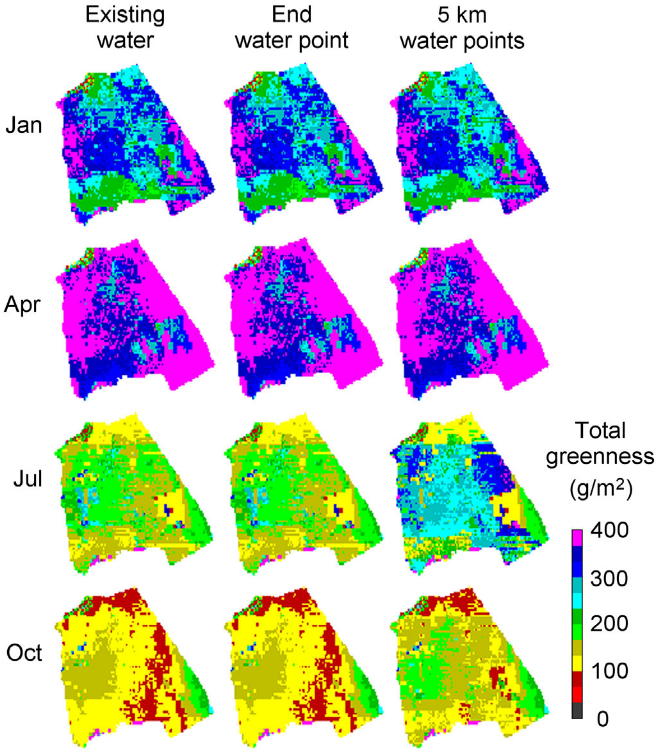

**Figure 8**. The distribution of total green biomass in selected months of modeled year 1978, with existing water sources in place, the new water source at the terminus of the pipeline, and sources every 5 km along the new pipeline.

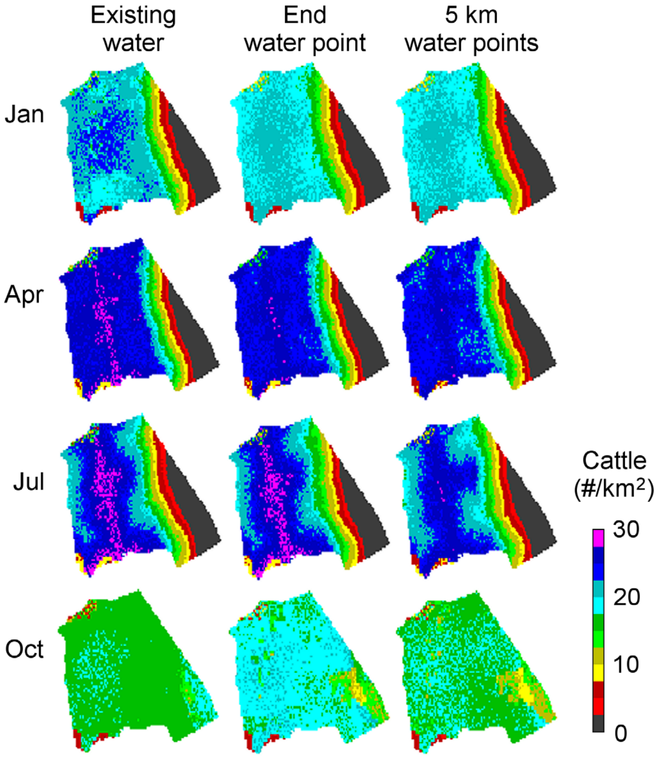

**Figure 9**. The distribution of cattle in selected months of modeled year 1978, with existing water sources in place, the new water source at the terminus of the pipeline, and sources every 5 km along the new pipeline. Livestock only had access to the new water sources.

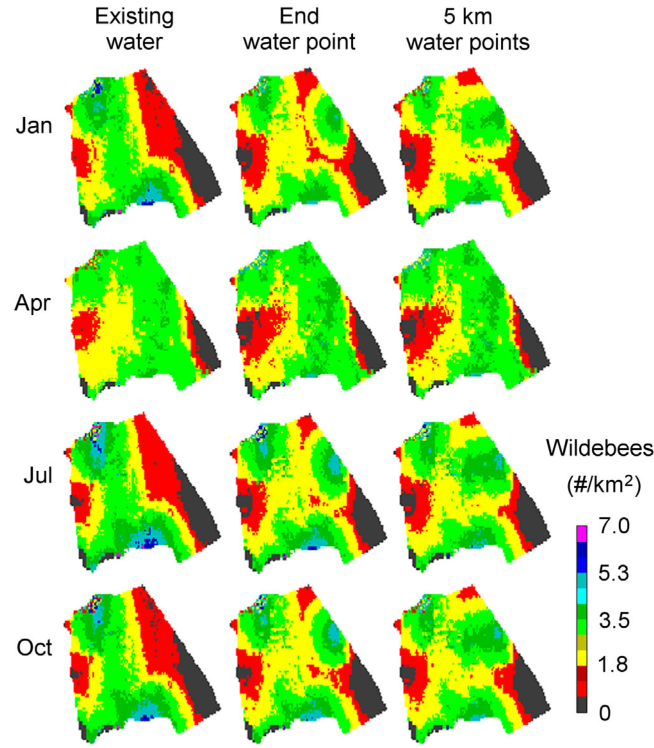

**Figure 10**. The distribution of wildebeest in selected months of modeled year 1978, with existing water sources in place, the new water source at the terminus of the pipeline, and sources every 5 km along the new pipeline. Livestock and wildlife were assumed to have access to the new water sources.

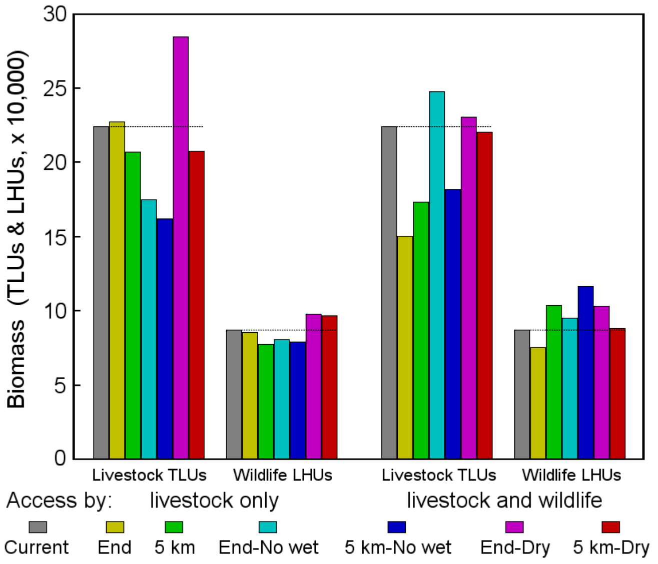

**Figure 11**. Livestock and wildlife biomass in simulations with different water sources available, and with livestock sales (PHEWS) disabled. Simulations included livestock only having access to new water sources, and livestock and wildlife having access. Average biomasses across the period of simulation are shown.

under conditions of existing water, with the new water point at the terminus of the pipeline in place, and with water points at 5 km intervals along the new pipeline. In these images, new water sources were available to livestock and wildlife (e.g., via leakage). Figure 11 shows the changes in ungulates reported. Four sets of bars are shown, in two groups of two. The first two sets of bars are livestock and wildlife where only livestock have access to the new water sources. The second two sets are livestock and wildlife where both domestic and wild ungulates have access to the new water sources. The seven treatments are shown below the figure: 1) 'Current' conditions, representing existing water sources, 2) 'End,' where the new water source at the terminus of the new pipeline is included, 3) '5 km,' where water source every 5 km along the new pipeline are used, 4) 'End-No wet,' where the terminal source is not available during the wet season, 5) '5 km-No wet,' where the sources every 5 km along the pipeline are not available during the wet season, 6) 'End-Dry,' where the terminal water source is only used when rainfall in the ecosystem in the previous three months is less than 75 mm, and 7) '5 km-Dry,' where the sources every 5 km along the pipeline are only available if rainfall in the previous three months is less than 75 mm. Note that in all simulations, staged grazing and the retention of the Chyulu Hills as a grazing reserve (i.e., grazed four months out of the year) continued to be in effect. Treating the area as a reserve and preventing access to the water source in the wet season were duplicative restrictions for some modeled cells, for example, so that the effect of the new water source is more subtle than may have been expected.

Adding a water source at the end of the Chyulu pipeline had a small effect on ungulates. Adding sources every 5 km had a larger effect, causing a decline in the overall biomass of livestock and wildlife supported (Figure 11). More continuous livestock grazing in areas that were treated as reserves (for the terminal water source) and in areas used in staged grazing (for the 5 km sources) decreased the numbers of animals that could be supported overall. Biomass declined further when livestock were prevented from using the water sources in the wet season. Distances in the distance-to-water maps for the wet season do not exceed 3 km, so the source of this decline is not clear. When the new terminal water source was allowed to be used only during the driest periods (i.e., rainfall was low enough for the water source to be used 81 times during the 288 months simulated), livestock populations were much higher than in current conditions

(Figure 11). The high value reflects cattle increasing rapidly prior to a decline in fitness (not shown), which would have led to a decline in the population had the simulation continued. However, wildlife biomass was higher in the simulation as well, suggesting that more ungulates could be supported in Imbirikani Group Ranch when the Chyulu Hills continued to be treated as a grazing reserve during typical periods, but the new nearby water source was available in times of drought. When water was available every 5 km along the pipeline and used only in dry periods, ungulate populations were relatively high, although livestock were slightly below what is modeled using current water sources, probably because of their use of forage that would otherwise have been stored as grazing reserves.

If livestock and wildlife have access to the new water sources (Figure 11), the pattern is in some ways opposite to that when livestock only have access. For example, with the new terminal water source available, wildlife biomass is slightly lower and livestock biomass is fully one-third lower. Livestock are prevented from using the Chyulu Hills for eight months of the year, but wildlife are not restricted in that way. Adding a water source allowed wildlife restricted to using lands near water, such as wildebeest, to use the area more often. However, use of the grazing reserve ultimately led to a decline in livestock as well as wildlife. Adding additional water sources increased ungulate biomass somewhat. The simulation that included the end water source and prevented ungulates from using that source in the wet season showed very high biomass (Figure 11). The relative abundances of the populations modeled stayed reasonable. Lastly, allowing animals to use the water sources only when it is dry yielded relatively high ungulate biomass.

Results were qualitatively similar when livestock sales were enabled (Figure 12), although differences between simulations are smaller, and when ungulates use the new terminal water source only during dry periods, the large increase in populations is not seen. Table 2 shows selected metrics reflecting the well-being of all households in Imbirikani Group Ranch when livestock only have access to the new water sources. Selected metrics are also shown for when both livestock and wildlife have access to the new sources (Table 3), again averaged for all household types. Looking at responses separated by the wealth categories 'poor,' 'medium,' and 'rich' where livestock only used new water sources (Table 4) and livestock and wildlife used new water sources (Table 5), we see differences are more dramatic for poor households across the experiments. For example, responses in food produced at home ("Own food") varied by 3.2% in poor households when livestock used new water sources (Table 4), but only 0.2% for rich households. The range in the percent of needs met by gifts or relief was slightly higher for poor (0.4%) people than rich (0.1%) as well. The range of responses for TLUs / adult equivalent were smaller for poor households, but the corresponding val-

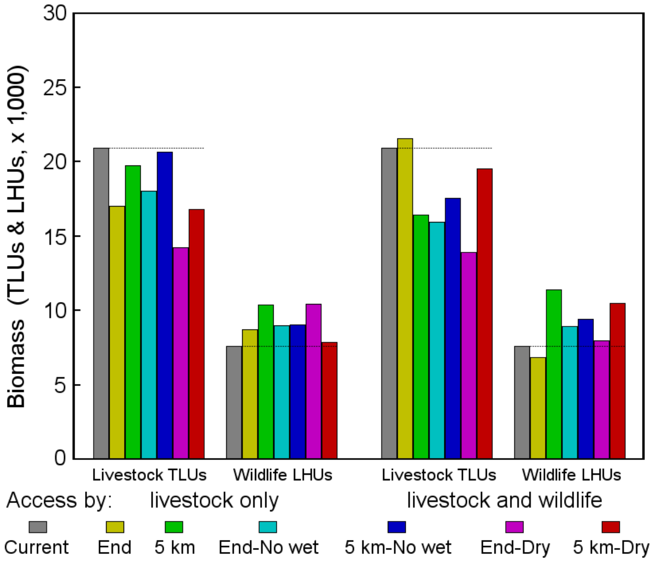

**Figure 12**. Livestock and wildlife biomass in simulations with different water sources available, and with livestock sales (PHEWS) enabled. Simulations included livestock only having access to new water sources, and livestock and wildlife having access. Average biomasses across the period of simulation are shown.

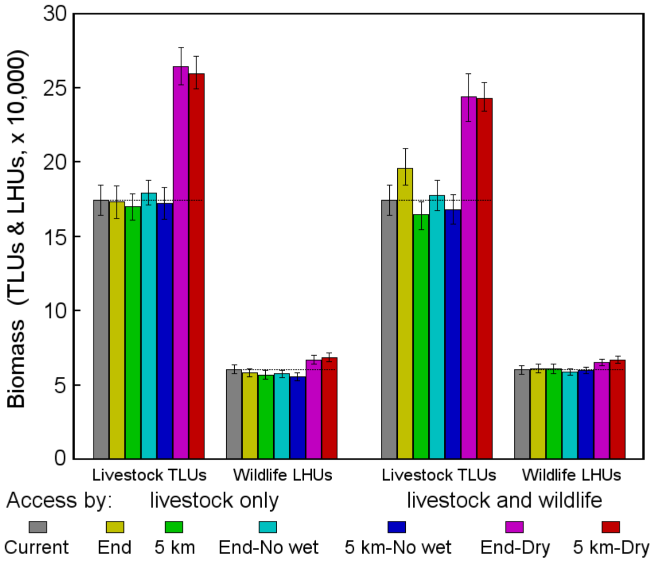

**Figure 13**. Livestock and wildlife biomass in repeated (n = 20) simulations with different water sources available, with livestock sales (PHEWS) disabled. Simulations included livestock only having access to new water sources, and livestock and wildlife having access. Average biomasses across the period of simulation are shown.

**Table 2**. Effects on households of adding water sources to Imbirikani Group Ranch, where *livestock only* had access to new water sources. 'Existing access' represents current conditions, 'No access in wet season' has livestock prevented from using the new sources in the wet season, and 'Access when dry' has livestock using the new sources only when average precipitation in the preceding three months is 75 mm or below.

| | **Existing water** | **New source at end** | **New sources each 5 km** |
|---|---|---|---|
| **Existing access** | | | |
| Selling income (KSH) | 490,335 | 499,131 | 503,161 |
| Average cashbox (KSH) | 159,208 | 162,596 | 161,633 |
| Own food (%) | 66.7 | 66.0 | 66.6 |
| Livestock (TLUs per AE) | 5.27 | 4.37 | 5.07 |
| Gifts/Relief (%) | 1.63 | 1.77 | 1.70 |
| **No access in wet season** | | | |
| Selling income (KSH) | 490,335 | 499,305 | 501,848 |
| Average cashbox (KSH) | 159,208 | 161,023 | 163,351 |
| Own food (%) | 66.7 | 66.4 | 66.8 |
| Livestock (TLUs per AE) | 5.27 | 4.64 | 5.26 |
| Gifts/Relief (%) | 1.63 | 1.77 | 1.60 |
| **Access when dry** | | | |
| Selling income (KSH) | 490,335 | 494,266 | 498,769 |
| Average cashbox (KSH) | 159,208 | 157,592 | 160,642 |
| Own food (%) | 66.7 | 65.2 | 66.4 |
| Livestock (TLUs per AE) | 5.27 | 3.77 | 4.29 |
| Gifts/Relief (%) | 1.63 | 1.63 | 1.73 |

ues were smaller. When standardized using a coefficient of variation, poor, medium, and rich households had similar variation in TLUs / Adult equivalent (e.g., 11.6%, 11.7%, and 12.5% in Table 4, respectively).

To reinforce these results and clarify some conflicting responses, we ran 20 simulations for each type of access at 1 km$^2$ resolution (to speed the 280 simulations), using randomized weather, an option within Savanna, and with livestock sales disabled. The results were striking. At the coarser resolution and with random weather, average populations were lower. Differences in ungulates were basically not significant when animals had access to the new water sources each year (Figure 13). In contrast, when ungulates had access to the new water sources only during the driest months of the simulated period (i.e., < 75 mm of rainfall in the previous three months), the numbers of livestock increased markedly, and wildlife increased as well (Figure 13). The region surrounding the new water sources continued to act as a grazing reserve for livestock in most months (i.e., 72% of the 288 months modeled had rainfall in the preceding three months exceeding 75 mm). However, in dry periods when forage (either green or standing dead) was in the shortest supply and energy reserves of the animals were low, the areas around the water sources provided forage without the need and energetic cost of traveling to distant water sources. Presumably wildlife benefited somewhat by the redistribution of livestock, reducing interspecific competition in places further from the new water sources.

## Conclusions

Our results suggest that there is some risk that the new water sources will allow grazers to over-use what to this point has been a grazing reserve. New water points that allow yearly grazing by either livestock, or livestock and wildlife within the grazing reserve can leave the reserve unsuitable when it is needed in the late dry season. The results with PHEWS disabled are most clear (i.e., Figures 11, 13); when PHEWS was enabled, livestock sales by food insecure residents seeking to purchase maize confounded the results (Figure 12). Although the results are mixed, the preponderance of evidence from our fine-scale modeling shows that allowing herders to use new water sources only when it had been dry the previous three

**Table 3**. Effects on households of adding water sources to Imbirikani Group Ranch, where *livestock and wildlife* had access to new water sources. 'Existing access' represents current conditions, 'No access in wet season' has ungulates prevented from using the new sources in the wet season, and 'Access when dry' has ungulates using the new sources only when average precipitation in the preceding three months is 75 mm or below.

| | **Existing water** | **New source at end** | **New sources each 5 km** |
|---|---|---|---|
| **Existing access** | | | |
| Selling income (KSH) | 490,335 | 502,318 | 494,603 |
| Average cashbox (KSH) | 159,208 | 163,787 | 160,561 |
| Own food (%) | 66.7 | 67.0 | 66.1 |
| Livestock (TLUs per AE) | 5.27 | 5.51 | 4.19 |
| Gifts/Relief (%) | 1.63 | 1.53 | 1.77 |
| **No access in wet season** | | | |
| Selling income (KSH) | 490,335 | 493,647 | 499,812 |
| Average cashbox (KSH) | 159,208 | 160,551 | 161,329 |
| Own food (%) | 66.7 | 66.0 | 66.3 |
| Livestock (TLUs per AE) | 5.27 | 4.08 | 4.53 |
| Gifts/Relief (%) | 1.63 | 1.83 | 1.73 |
| **Access when dry** | | | |
| Selling income (KSH) | 490,335 | 495,711 | 502,825 |
| Average cashbox (KSH) | 159,208 | 157,994 | 162,353 |
| Own food (%) | 66.7 | 65.3 | 66.8 |
| Livestock (TLUs per AE) | 5.27 | 3.63 | 5.01 |
| Gifts/Relief (%) | 1.63 | 1.60 | 1.60 |

months yielded the highest livestock and wildlife populations. Results at a coarser resolution, where standard errors were generated, were more clear. They strongly suggest that flexible access to the new water sources will allow the most livestock and wildlife to be supported on Imbirikani Group Ranch (Figure 13). If herders and their livestock were allowed to use the new sources only when the previous three months had less than 75 mm of rainfall (28% of months in the observed weather data), an additional 7000 TLUs were supported in simulations. In short, during wet periods animals were prevented from using the new water sources – sometimes years passed where animals did not have easy access to water in the Chyulu Hills, and grazing was limited. The quantity and quality of forage remained relatively high in those years. Then in dry periods, animals had access to those water sources and to the high quantity forage surrounding them. The conditions and populations of animals therefore did not decline as much as under existing conditions. In general, and focusing on results with livestock sales disabled, in fine-scale modeling adding water sources (e.g., Figures 11, 13) had little or negative effect on the numbers of livestock and wildlife that could be supported on Imbirikani Group Ranch. Where decreases in populations were large, it is likely the animals used forage that would have otherwise been stored in a grazing reserve; new water sources can allow animals to 'mine' in normal months forage that would otherwise have been available in grazing reserves for use in severe months. In contrast, when animals were only allowed to use the new water sources when the previous three months had been dry, ungulate populations were similar to current conditions (e.g., Figure 11) or increased greatly (Figure 13). If an adaptive management plan that allowed use of the water sources only during dry periods was culturally acceptable, modeling suggests more animals could be supported on Imbirikani Group Ranch than if the new water sources are available all the time. Otherwise, areas that now serve as grazing reserves will be overused.

**Table 4**. Effects on households of adding water sources to Imbirikani Group Ranch, where *livestock only* had access to new water sources. Results are presented by wealth category for each of the types of analyses done, including current conditions ("Current"), a new pipeline with a single terminal source ("End"), a new pipeline with water sources every 5 km ("5 km"), and the previous two settings with water sources unavailable during the wet season ("End – No wet", "5 km – No wet"), and available only when the pervious three months were dry ("End – Dry", "5 km – Dry").

| | Gifts (%) | Income (KSH) | Cash holdings (%) | Own food (%) | TLUs/AE |
|---|---|---|---|---|---|
| **Poor** | | | | | |
| Current | 2.0 | 579,753 | 222,786 | 65.88 | 1.96 |
| End | 2.3 | 599,169 | 228,406 | 64.50 | 1.64 |
| 5 km | 2.1 | 600,111 | 227,584 | 65.76 | 1.90 |
| End – No wet | 2.3 | 595,106 | 227,192 | 65.24 | 1.74 |
| 5 km – No wet | 2.0 | 593,139 | 228,886 | 66.22 | 1.97 |
| End – Dry | 1.9 | 595,997 | 224,556 | 63.01 | 1.43 |
| 5 km – Dry | 2.2 | 596,521 | 227,146 | 65.06 | 1.61 |
| **Medium** | | | | | |
| Current | 1.8 | 393,877 | 103,037 | 66.61 | 4.44 |
| End | 1.8 | 399,819 | 106,119 | 65.93 | 3.70 |
| 5 km | 1.8 | 403,326 | 105,474 | 66.44 | 4.29 |
| End – No wet | 1.8 | 401,177 | 104,975 | 66.27 | 3.93 |
| 5 km – No wet | 1.7 | 403,379 | 106,741 | 66.57 | 4.44 |
| End – Dry | 1.8 | 396,594 | 102,158 | 65.01 | 3.23 |
| 5 km – Dry | 1.9 | 400,350 | 104,705 | 66.38 | 3.64 |
| **Rich** | | | | | |
| Current | 1.1 | 497,374 | 151,802 | 67.58 | 9.41 |
| End | 1.2 | 498,403 | 153,261 | 67.63 | 7.76 |
| 5 km | 1.2 | 506,045 | 151,839 | 67.64 | 9.02 |
| End – No wet | 1.2 | 501,632 | 150,902 | 67.74 | 8.24 |
| 5 km – No wet | 1.1 | 509,033 | 154,426 | 67.66 | 9.38 |
| End – Dry | 1.2 | 490,208 | 146,061 | 67.56 | 6.64 |
| 5 km – Dry | 1.1 | 499,436 | 150,074 | 67.65 | 7.63 |

**Table 5**. Effects on households of adding water sources to Imbirikani Group Ranch, where *livestock and wildlife* had access to new water sources. Results are presented by wealth category for each of the types of analyses done, including current conditions ("Current"), a new pipeline with a single terminal source ("End"), a new pipeline with water sources every 5 km ("5 km"), and the previous two settings with water sources unavailable during the wet season ("End – No wet", "5 km – No wet"), and available only when the pervious three months were dry ("End – Dry", "5 km – Dry").

| | **Gifts (%)** | **Income (KSH)** | **Cash holdings (%)** | **Own food (%)** | **TLUs/AE** |
|---|---|---|---|---|---|
| **Poor** | | | | | |
| Current | 2.0 | 579,753 | 222,786 | 65.88 | 1.96 |
| End | 1.9 | 592,718 | 229,215 | 66.67 | 2.06 |
| 5 km | 2.4 | 588,023 | 226,934 | 64.53 | 1.57 |
| End – No wet | 2.5 | 588,376 | 226,993 | 64.36 | 1.53 |
| 5 km – No wet | 2.2 | 598,649 | 227,618 | 65.02 | 1.70 |
| End – Dry | 2.0 | 600,308 | 224,840 | 63.14 | 1.37 |
| 5 km – Dry | 2.0 | 597,498 | 228,304 | 66.14 | 1.88 |
| **Medium** | | | | | |
| Current | 1.8 | 393,877 | 103,037 | 66.61 | 4.44 |
| End | 1.6 | 403,394 | 107,153 | 66.77 | 4.65 |
| 5 km | 1.7 | 398,389 | 104,716 | 66.18 | 3.54 |
| End – No wet | 1.8 | 396,584 | 104,667 | 66.11 | 3.45 |
| 5 km – No wet | 1.8 | 401,173 | 105,256 | 66.35 | 3.85 |
| End – Dry | 1.6 | 396,628 | 102,619 | 65.12 | 3.10 |
| 5 km – Dry | 1.7 | 403,949 | 106,051 | 66.66 | 4.24 |
| **Rich** | | | | | |
| Current | 1.1 | 497,374 | 151,802 | 67.58 | 9.41 |
| End | 1.1 | 510,844 | 154,992 | 67.67 | 9.82 |
| 5 km | 1.2 | 497,396 | 150,035 | 67.63 | 7.45 |
| End – No wet | 1.2 | 495,981 | 149,994 | 67.64 | 7.27 |
| 5 km – No wet | 1.2 | 499,613 | 151,113 | 67.64 | 8.05 |
| End – Dry | 1.2 | 490,198 | 146,524 | 67.57 | 6.43 |
| 5 km – Dry | 1.1 | 507,029 | 152,704 | 67.66 | 8.90 |

## PATHWAYS TO SUBDIVISION IN IMBIRIKANI AND ESELENKEI GROUP RANCHES

Kajiado District was the first to be subdivided into group ranches in the late 1960s, under an effort supported by international development organizations and the Kenyan government (Kimani and Pickard 1998). Maasai that previously selected grazing areas from large sections of land (8 in Kajiado, averaging 2731 km$^2$; Ole Katampoi et al. 1990) became members of group ranches (ca. 52 in Kajiado averaging 340 km$^2$). Adjudication into group ranches was done to provide incentives to herders to: manage their lands for the collective good, increase livestock production, more easily provide services to members, and give ownership to groups of Maasai to prevent lands from be sold to outsiders. Most of the goals spurring group ranch formation have gone unmet (Bekure et al. 1991). Group title has allowed Maasai to retain ownership of their lands, but on-balance, group ranch formation has been deleterious (e.g., Galaty 1994; Kimani and Pickard 1998; Kristjanson 2002).

Early in the process of subdivision to group ranches, parcels owned by individual people were created. In 1983, subdivision of individual parcels was supported in legislation by the Kenyan government (Grandin 1989). Later, entire group ranches were divided into parcels owned by individual ranch members. In the ranches studied by our team, for example, Osilalei Group Ranch was divided in 1990, with each member receiving a parcel of about 100 ac (40 ha). Livestock herding in semi-arid areas such as Kajiado requires animals to be moved to access ephemeral forage patches (Behnke and Scoones 1993). However, the tendency in subdivided group ranches is for use to become more exclusive. In ranches where subdivision of cultivated areas is ongoing (i.e., southern Imbirikani, portions of Olgulului/Lolorashi), areas that are not under cultivation are not fenced. In Osilalei Group Ranch, lands are used more exclusively, unless in drought (Rutten 1992; BurnSilver, unpub. data; Worden, unpub. data). In the Athi-Kaputiei Plains, which is south of Nairobi and was subdivided in 1989, fences are common (Kristjanson et al. 2002; Reid et al., In press).

Currently, lands in Eselenkei, Imbirikani, and Olgulului/Lolorashi Group Ranches are communally grazed. We focus on Eselenkei and Imbirikani Group Ranches in these analyses. Areas of permanent settlement are designated on each group ranch, but then staged grazings (see Scenario 2) takes place. In southern Imbirikani, households settled around the swamps are, for the most part, agropastoral and sedentary, with nearby areas providing grazing during the wet and dry seasons for livestock. Stages grazing is not relevant for a majority of thise households, although some households with larger herds are still mobile.

Subdivision is planned in Eselenkei and Imbirikani Group Ranches (subdivision of cultivated plots has already occurred in southern Imbirikani). At this time, members within Eselenkei Group Ranch may expect to receive parcels about 100 ac (40 ha) in area. Members of Imbirikani Group Ranch are scheduled to receive parcels of about 60 ac (24 ha). We used counties within the United States as boundaries that were mosaiced and rescaled to simulate parcels in Eselenkei that averaged 100 ac, and in Imbirikani that averaged 60 ac. The visual impact of dividing intact ranches into 60 or 100 ac parcels (Figure 14) was striking to community members, when shown during dissemination meetings.

Research and stakeholders' opinions have suggested that dividing group ranches into small parcels that are used exclusively would have deleterious effects for rangelands, livestock, and household food security (Boone 2005; Boone et al. 2005; Thornton et al. 2006a). Forage patches in semi-arid areas tend to heterogeneous in their quality or quantity, and livestock confined to small parcels have fewer patches to choose from. For example, in simulations in Eselenkei Group Ranch, Boone et al. (2005) estimated a 25% reduction in livestock populations would occur if the ranch was subdivided into 1 km$^2$ (247 ac) parcels – the loss would presumably be more extreme if divided into 100 ac parcels used exclusively.

Alternatives to dividing ranches into parcels of almost equal area have been suggested. In *Reto-o-Reto* project meetings in January 2005, members cited an option where lands near settlements were divided into small (5 ac, 2 ha) parcels, with each member to receive a parcel for a permanent household. The remainder of the group ranch was to remain in communal grazing. This pathway to subdivision would allow ranch members to own title to their lands, with its benefits, but retain the benefits of a large communal grazing area.

We proposed to explore potential effects of subdivision into equal-area parcels versus small parcels for permanent households plus large areas of communal land. Eselenkei and Imbirikani Group Ranches were used in experiments. In Imbirikani, a new pipeline is being constructed (see Scenario 2). We incorporated that pipeline into this scenario. Also, for Imbirikani, group ranch members wanted to explore a subdivision option whereby as

**Figure 14**. Eselenkei Group Ranch (a) (783 km$^2$) divided uniformly into 100 ac (40 ha) parcels, and Imbirikani Group Ranch (b), including portions of Chyulu Hills (1341 km$^2$), divided uniformly into 60 ac (24 ha) parcels. The parcels are for illustration only, derived from unrelated parcel boundaries.

many members as possible receive a small parcel (2 ac) in that portion of the ranch where irrigated agriculture is possible, and for those unable to be accommodated, they would receive a 5 ac parcel on the slopes of the Chyulu Hills, for rain fed agriculture. We integrated this scenario into our analyses, and our original proposed questions are described in Box 3.

Settlements in Eselenkei Group Ranch fall along general tracks (Worden, unpub. data), in uplands alongside Eselenkei River, and bordering the lowlands in the south. Five acre parcels were distributed along these settlement tracks, ca. one for each group ranch member (Figure 15a). In Imbirikani, parcels were distributed around the divided swamps to the south, and the Nolturesh Pipeline (Figure 15b). An additional map (Figure 15c) shows parcels around the existing pipeline, plus the new pipeline. Parcels were placed around the proposed new pipeline in the belief that access points and areas of leakage would encourage permanent settlement, as they have on other pipelines.

### Adjustments to Scenario Proposed

The subdivision map created for Imbirikani Group Ranch contained parcels 60 ac in size, as proposed for both Imbirikani and Eselenkei Group Ranches. However, currently members of Eselenkei Group Ranch are expected to receive ca. 100 ac parcels under subdivision. We therefore used 100 ac in that map. Otherwise, the scenario was analyzed as proposed.

### Model Adaptation

We were requested to increase the spatial resolution of modeling during our project meetings, so that the spatial units modeled in Savanna would represent less ground area. Existing applications of Savanna to Eselenkei and Imbirikani Group Ranches at 1 km resolution (i.e., cells the landscape was divided into represented areas 1 km x 1 km on the ground) were revised to be at 500 m resolution, meaning that cells that comprise the landscape matrix were each 500 x 500 m.

We needed a method to represent staged grazing and the pathways to subdivision in Imbirikani and Eselenkei. Here, as in past research (Boone 2005; Boone et al. 2005), effects of subdivision have been modeled by incorporating effects on livestock movements. One method of modeling movements of groups of animals of the same species (e.g., cattle) in the ecosystem model is to represent them as separate herds. Force maps may then be used to move the herds about the landscape. It was not practical for us to incorporate thousands of herds into Savanna, one for each household. Instead, we used careful calibration of water relationships and minimum and maximum densities to represent staged grazing and subdivision.

The relationship between distance-to-water and habitat suitability in Savanna was used to emulate a staged grazing pattern. Whereas in past applications the distance to water was equally important in all months (the use of different distance-to-water maps incorporates effects of seasonality), here the importance of distance to water varied across months, reflecting a one-, two-, or three-day grazing cycle (as in Scenario 2). Multipliers of the distance-to-water entry in the habitat suitability compo-

**Box 3. ORIGINAL SCENARIO 3: Subdivision in Eselenkei and Imbirikani Group Ranches**

**Goals**: To quantify the usefulness of maintaining some portion of group ranch lands as communal grazing. Include in them the repercussions of having a pipeline in Imbirikani in place.

**Pathway**: First, create the candidate subdivision maps (a creative exercise). Include in them: 1) a map where lands are divided into 60 ac plots, 2) a map where the area within 5 km of the existing pipeline or settled areas is divided into 5 ac plots, and the remainder is left intact, 3) a map where the area within 5 km of the existing and new pipeline are divided into 5 ac plots, and the remainder is left intact. Set the model to allow access to the individual parcels during the wet season, and disperse into the communal lands during the dry season. If feasible, modify the model to incorporate staged movements. We may include differential costs for households, dependent upon their place on the landscape.

**Scenarios**: Run analyses for -

1. The group ranch in its current state, perhaps including staged movements.
2. The entirely subdivided group ranch.
3. The map where areas near the pipeline or permanent settlements are subdivided, others intact.
4. The map where areas near the swamps are divided into 2 ac parcels, plus families that do not receive areas near the swamps will get 5 ac parcels on the western slopes of the Chyulu Hills.

**Possible types of results**: Livestock populations that can be supported on the different subdivision maps. Differences between the numbers of animals that can be supported on the system will be less dramatic if staged movements are incorporated (the two patterns are relatively similar), but more realistic.

**Notes**: Currently, animals cannot be confined to a parcel at one period, then allowed to compete with many other animals in another period. Rather than control actual animal distributions, force maps and changes to the habitat suitability indices may be used to simulate staging. The last scenario will be run for Imbirikani only. We will need a new household classification/typology, and more explicit rules about how some households use natural resources, and how they diversify.

nent of the model were reduced to 30% in January and February, 20% in August, and 10% in September and November. In Imbirikani, for example, that allowed livestock to move further away from water sources, and use grazing areas within the Chyulu Hills in the driest months. Regardless, force maps still prevented livestock from using the core grazing reserves in Chyulu Hills from January to July, and December.

Subdivision into uniformly sized parcels was emulated by reducing the maximum density of animals allowed in each square kilometer. For example, in the application representing current conditions, the density of cattle are allowed to reach 500 / km$^2$, effectively disabling that control on animal distributions. To emulate subdivision where parcels are distributed throughout the group ranches (Figure 14), the maximum density of cattle was reduced to 20 / km$^2$, goats to 5 / km$^2$, and sheep to 7 / km$^2$. These limits may be exceeded if the numbers of animals in the populations exceed what the landscape can support at the specified density, but the values allow initial populations to be distributed evenly [e.g., Imbirikani, at 1340 km$^2$, would support 26,800 cattle if evenly distributed across the land, whereas the initial population used in modeling (Boone et al. 2005) was 21,703]. Also, in Imbirikani Group Ranch, the force map used to prevent livestock from grazing in Chyulu Hills was disabled. These methods approximated an even distribution; there remained some variation in livestock densities across the landscape, but the same would be true if the group ranch were completely subdivided and used exclusely.

Boone found that when Eselenkei Group Ranch was initially modeled with the household model PHEWS enabled and the number of households calculated based on the number of households in the simulation for the entire

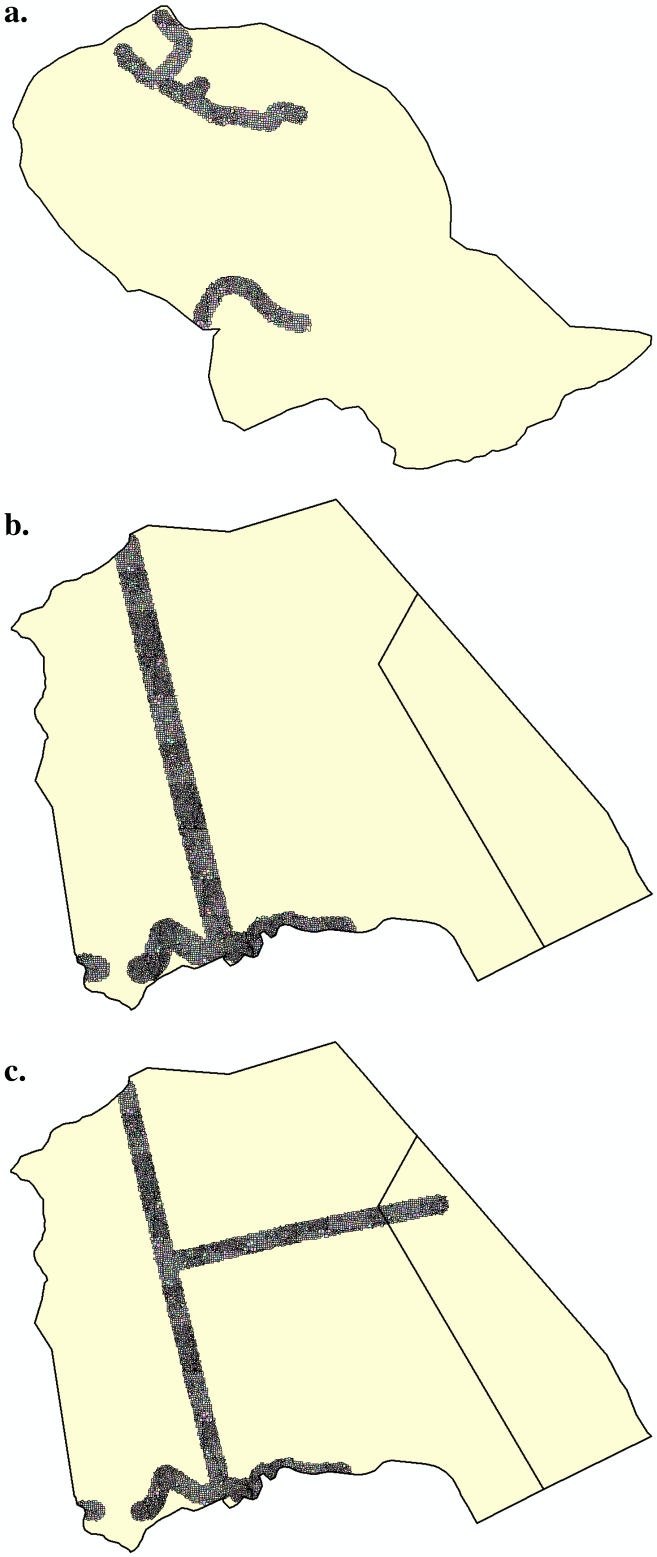

**Figure 15**. Eselenkei Group Ranch (a) and Imbirikani Group Ranch (b), with areas most densely populated subdivided into 5 ac parcels, with the remaining rangeland open grazing. Also shown is Imbirikani Group Ranch, with areas most densely populated subdivided into 5 ac parcels, with parcels also distributed near a pipeline being built (c) shown.

study area, the number of livestock sold by Maasai was too great. A beginning population of 20,000 decreased to 10,000 within five years, and ended at 700. We found there was a disjoint in modeling methods. The original southern Kajiado Savanna/PHEWS application had 3820 households. That value was extrapolated from household survey data and censuses (BurnSilver, In prep.; Thornton et al. 2006a), and represents the number of households within the entire 10,746 km$^2$ area modeled. The information on percentage of households within each of the six areas intensively studied could therefore not be used to estimate numbers of houses in Eselenkei and Imbirikani; Eselenkei included 15% of the households intensively studied, but the area of intensive study was ca. 4256 km$^2$, not 10,746 km$^2$. We chose to estimate the number of households by assuming that in aggregate, households in the group ranches have a similar number of livestock. From DRSRS data (see Boone et al. 2005 for details) we estimated that Eselenkei had about 7.2% of the total livestock population in southern Kajiado. From that, we estimated 275 households occurred within Eselenkei. Imbirikani had 9% of the cattle in the region and an estimated 352 households. The number of households modeled was therefore not precisely defined, but was the same across all simulations for each group ranch. We are thus highlighting changes in simulated results from scenarios that are parameterized exactly the same in all other respects.

Related to the livestock declines observed while modeling, when simulated Maasai households became food stressed, they sold cattle, and purchased maize and goats, as in reality (BurnSilver, In prep.). However, the number of animals sold exceeded what was reasonable, with cattle declining dramatically and goat populations rising markedly. Thornton suggested that the threshold used to trigger a sale be adjusted. The threshold need for money was changed from 6000 KSH in the original applications (Thornton et al. 2005) to 7000 KSH. That change prevented the dramatic changes in livestock populations, but increased the food insecurity simulated households must face prior to selling their cattle.

In total, 26 simulations were run under Scenario 3. In analyses, we typically use one or more simulations as base results to which other results are compared, and that is the case here. Also, we are interested in effects on pastoral livelihoods, contributed by the PHEWS model, and also on ungulate population trends. Changes in ungulate populations due to forage shortages confound with Maasai decision making in PHEWS – the livestock owners may buy or sell livestock depending upon their needs

(Thornton et al. 2006a). We therefore ran two models for each situation, one with PHEWS enabled, and one with PHEWS disabled. Simulations modeled include:

- The main control model representing reality to the degree possible;
- A control model representing subdivision into similar sized parcels, with animals evenly distributed;
- Areas in Eselenkei with 5 ac parcels used during the long wet season, March to May, with the rest of the area communally available June to February;
- Areas in Imbirikani with 5 ac parcels around the original pipeline used during the long wet season, March to May, with the rest of the area communally available June to February;
- Areas in Imbirikani with 5 ac parcels around all pipelines used during the long wet season, March to May, with the rest of the area communally available June to February;
- Areas in Eselenkei with 5 ac parcels and areas within 5 km of the settled areas used during the long wet seasons (Figure 16a), March to May plus the short wet season, November, with the rest of the area communally available in other months;
- Areas in Imbirikani with 5 ac parcels around the original pipeline and all areas within 5 km of the settled areas (Figure 16b) used during both wet seasons, with the rest used communally other months;
- Areas in Imbirikani with 5 ac parcels around all pipelines and all areas within 5 km of the settled areas (Figure 16c) used during both wet seasons, with the rest of the area communally available other months;
- Areas in Imbirikani with 2 ac parcels in irrigated lands assigned to as many group ranch members as possible, with the remaining members assigned 5 ac parcels in the Chyulu region.

In the simulations where herders moved freely across communal areas, in months where animals could use the communal areas, they did so following the timing used in staged grazing described in Scenario 2.

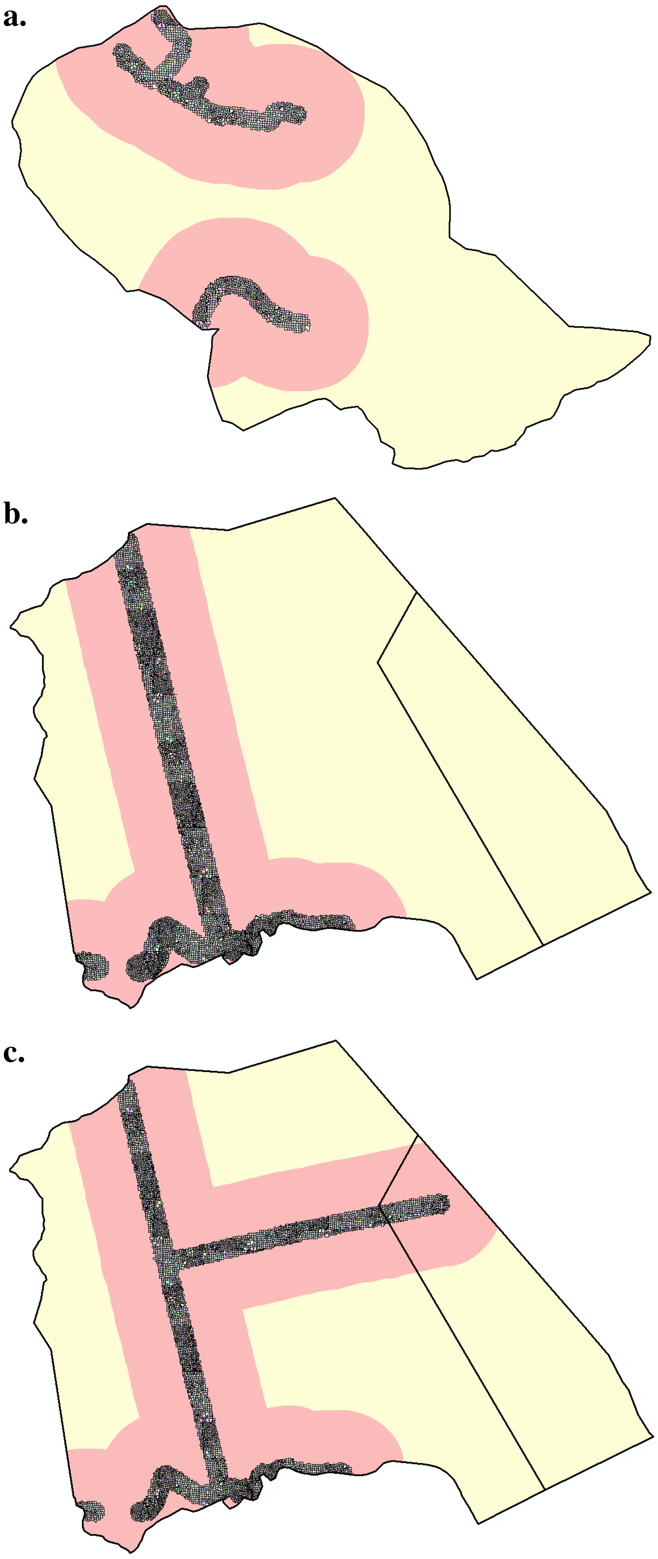

**Figure 16**. Eselenkei Group Ranch (a) and Imbirikani Group Ranch (b), with areas most densely populated subdivided into 5 ac parcels, and livestock able to graze within 5 km of the edge of the subdivided areas in the wet seasons.. Also shown is Imbirikani Group Ranch (c) with the newly constructed pipeline in place, and the area where livestock may graze in the wet seasons shaded.

## Results and Interpretation

In Eselenkei Group Ranch, there were 1934 one-hundred acre parcels, approximately one per member of the ranch at the time subdivision was planned. In Imbirikani Group Ranch, there were 5504 sixty acre parcels. With parcels at 5 ac, 1934 parcels in Eselenkei occurred within 613 m of the settlement tracks (Figure 15a). Within the settlement areas of Imbirikani Group Ranch, 5504 five acre parcels could be placed within 1080 m of the Nolturesh pipeline, river, and swamp areas. When the new pipeline was included, that area declined to 770 m.

Livestock populations in Eselenkei Group Ranch were similar under current staged grazing and when they were evenly distributed (Figures 17 and 21, "Current" versus "Even"), although the staged grazing yielded higher populations in general with less variability (which proved of interest to pastoralists, who wish to reduce variability in their herds). A drought in the late 1980s led to more dramatic declines in livestock, as relatively evenly distributed livestock were unable to make use of ephemeral forage. Figures 18-20 provide an indication of the spatial variability of total green biomass, cattle, and wildebeest under three patterns of landscape use: 1) staged grazing representing current conditions, 2) with the area fully subdivided, and 3) with livestock confined to areas near the existing pipeline, and areas within 5 km of that during the wet seasons.

When livestock in Eselenkei were confined to 5 ac (2 ha) parcels within settled areas during the long wet season of March, April, and May, numbers similar to the current population could not be supported (Figure 17, "5 ac wet" and Figure 21, "5 ac"). For example, initial cattle densities exceeded 580 / km$^2$ in March, April, and May, when animals were confined to subdivided areas. Allowing livestock to move up to 5 km beyond the limits of the subdivided area in March, April, May, and in November as well dropped peak cattle densities to be about 80 / km$^2$, and populations persisted, ending the simulation with abundances on-par with the simulation when cattle were distributed evenly (Figure 21, "5 ac, 5 km"), although average abundance was lower. Wildlife populations generally varied inversely with livestock populations, so that the current situation and with livestock distributed evenly, the wildlife populations were similar (Figure 21). When livestock were confined to the subdivided area, wildlife populations increased dramatically, but populations were relatively constant when livestock ranged beyond the subdivided areas (Figure 21).

With PHEWS enabled, pastoral decision making led to livestock being bought and sold. Trends in livestock TLUs were qualitatively similar to those when PHEWS was disabled (Figure 21). Livestock were somewhat more abundant when evenly distributed across the landscape, but again the populations declined more rapidly in drought than when staged grazing is used. When livestock were confined to the subdivided area, abundances declined markedly (Figure 21, "5 ac"). Allowing livestock to use areas within 5 km of subdivided areas in March, April, May, and November allowed the livestock to persist, but the number of TLUs at the end of the simulation was two-thirds its initial value (Figure 21). Wildlife populations increased steadily when livestock were confined to subdivided areas, or areas with 5 km. Attributes in Eselenkei households (Table 6) tell a similar story, with resources similar when staged grazing and an even distribution of livestock across the landscape are used, but dramatically fewer livestock when they are confined to the subdivided area in the wet season. Household food security is somewhat better when livestock are allowed to graze within 5 km of subdivided areas during the wet seasons (Table 6). Table 7 shows results averaged across livelihood types, but divided into wealth categories, poor, medium, and rich. Results are more variable for poor households (Table 7), which have fewer resources to use to buffer the stresses they face, but the overarching pattern is similar to the average across wealth categories (Table 6).

The abundance of livestock in the Imbirikani model that were distributed evenly across the landscape failed to build to the same level as in the control (Figure 22, "Subdivided" versus "Current", with similar responses with livestock sales disabled or enabled). Limiting livestock to settled areas that included the existing pipeline for three months a year caused their abundances to be lower still. In contrast, when livestock were allowed to use areas within 5 km of the settled areas, their abundances increased markedly (Figure 22, "5 ac pipe, 5 km"). The effect of subdividing areas around the newly constructed pipeline on livestock was to increase their abundance in one set of simulations. When animals were confined to the subdivided areas with the new pipeline in place, the livestock abundance increased slightly or remained the same (Figure 22, "5 ac pipe" versus "5 ac new pipe"). In contrast, allowing animals to use areas within 5 km of the newly constructed pipeline, and other settled areas, yielded abundances well above those using the existing pipeline.

Attributes of household food security are fairly similar across the simulations in Imbirikani Group Ranch (Table 6). When the area was fully subdivided or when livestock were using only subdivided areas in the wet season, food security was lowest. In contrast, livestock per person was highest when animals used the subdivided areas and nearby grazing lands. Adding the new pipeline increased livestock per person when animals used the subdivided area only, but allowing the animals to use the areas within 5 km of the subdivided lands increases food security only marginally.

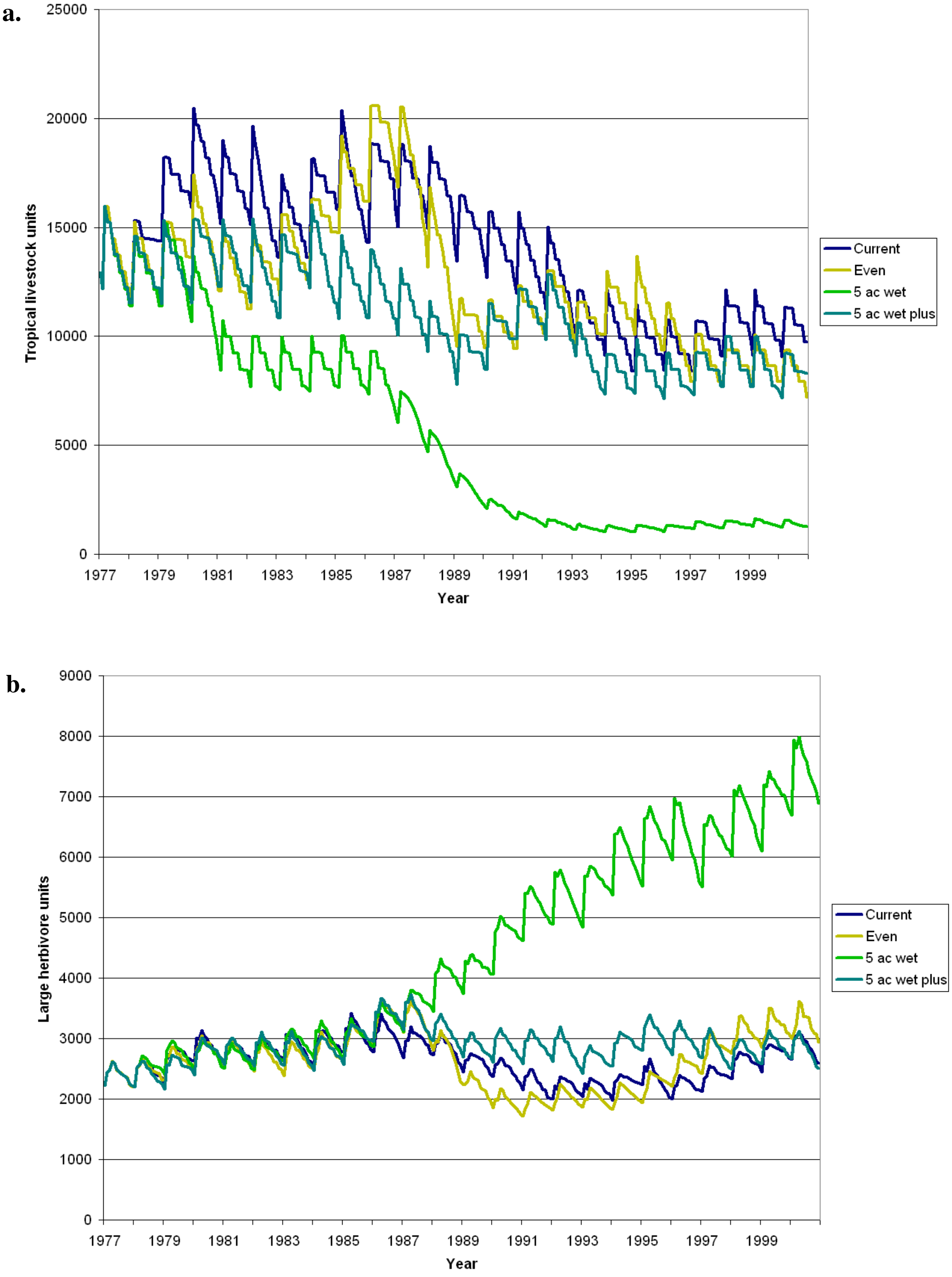

**Figure 17**. Livestock (a) and wildlife (b) population trends in Eselenkei Group Ranch, with livestock sales disabled. The simulations represented: current conditions with staged grazing ("Current"); grazing distributed evenly, simulating complete subdivision ("Subdivided"); grazing within the subdivided 5 ac parcels during the long wet season ("5 ac wet"); and grazing within the subdivided areas plus areas within 5 km, in the long wet season and peak of the short wet season, November ("5 ac wet plus"). Livestock and wildlife populations are combined into single metrics using units representing 250 kg biomass.

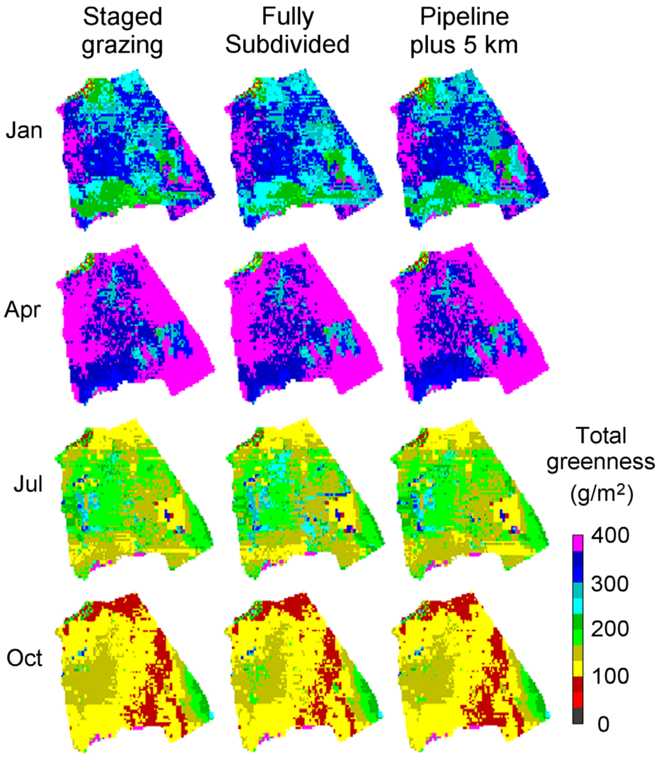

**Figure 18**. The distribution of total green biomass in Imbirikani Group Ranch in selected months of modeled year 1978, with currently employed staged grazing, animals distributed within a fully subdivided group ranch, and animals using areas around the existing pipeline and areas within 5 km of the pipeline during the wet season.

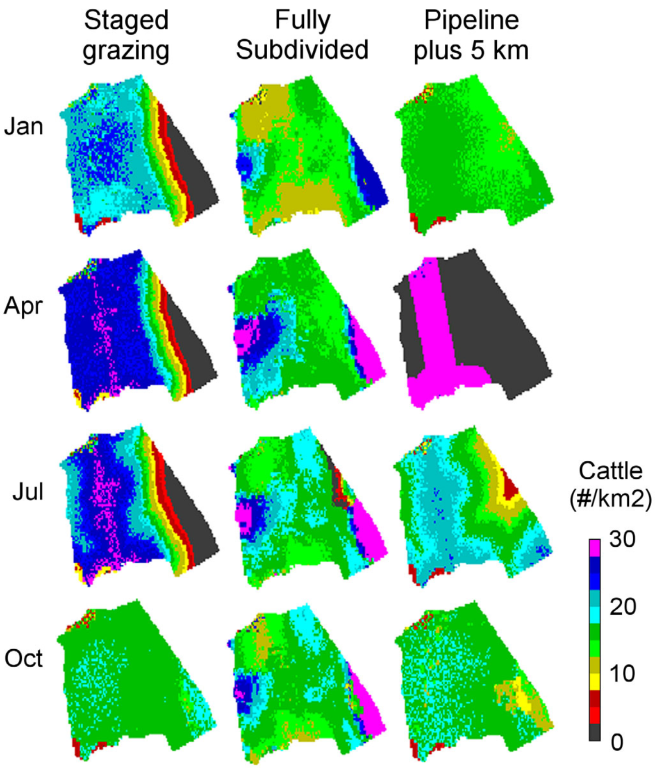

**Figure 19**. The distribution of cattle in Imbirikani Group Ranch in selected months of modeled year 1978, with currently employed staged grazing, animals distributed within a fully subdivided group ranch, and animals using areas around the existing pipeline and areas within 5 km of the pipeline during the wet season.

In the Imbirikani Savanna model, 742 ha (1,834 ac) are in irrigated agriculture (based on GPS locations around the parimeters of the areas). From that, 917 (1,834/2) of the estimated 5504 Imbirikani Group Ranch members were allocated 2 ac parcels of irrigated agriculture within and near the southern swamps. The remaining 4587 ranch members were allocated 5 ac parcels in a region suitable for rain-fed agriculture in the Chyulu Hills. The resultant area of the Chyulu Hills in agriculture was 22,935 ac (4,587 x 5 ac), or 9,282 ha (Figure 23). In the force map that limits movements of livestock, the large area of rain-fed agriculture was set to 30% suitability, matching the value for irrigated agriculture. The decreased use represents limited availability to livestock, but some use of areas between fields and the use of field stubble. Adjustments were made to the PHEWS parameters and simulations conducted. However, results from simulations with PHEWS enabled are not shown. We found that allocating irrigated lands based on group ranch membership and the area of swamps led to 17% (917 of 5504) of the members being allocated irrigated lands. In surveys by BurnSilver, she identified about 62% of households in Imbirikani doing irrigated agriculture. Overall, subdividing 9,282 ha of the Chyulu Hills did not have a significant affect on livestock populations when sales were disabled (Figures 21, 24), although cultivating those lands did decrease wildlife populations (Figure 21).

## Conclusions

An overwhelming result from these analyses is that household livestock cannot be supported on 5 ac parcels around developed areas for the three months of the wet season. Densities exceed the capacity of the parcels to support the animals.

In Imbirikani, evenly distributed livestock populations were one-third those when staged grazing is used, as expected (Boone et al. 2005). This result suggests that our methods were reasonable, but bodes poorly for fully subdivided group ranches. However, these results showed less dramatic declines in animal numbers than in our previously published work. Animals could still move about freely on the landscape, whereas in Boone et al. (2005) and Thornton et al. (2006) they were restricted to parcels, but the direction of change is the same and magni-

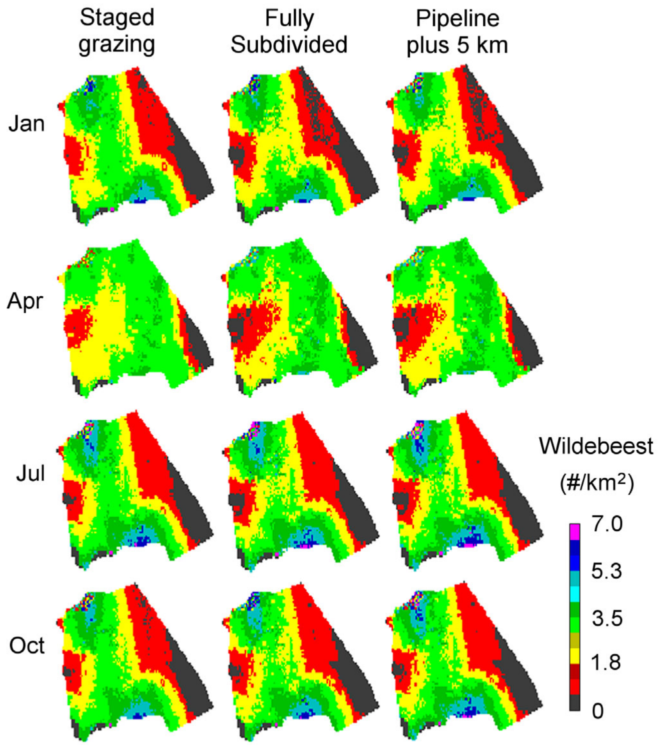

**Figure 20**. The distribution of wildebeest in Imbirikani Group Ranch in selected months of modeled year 1978, with currently employed staged grazing, animals distributed within a fully subdivided group ranch, and animals using areas around the existing pipeline and areas within 5 km of the pipeline during the wet season.

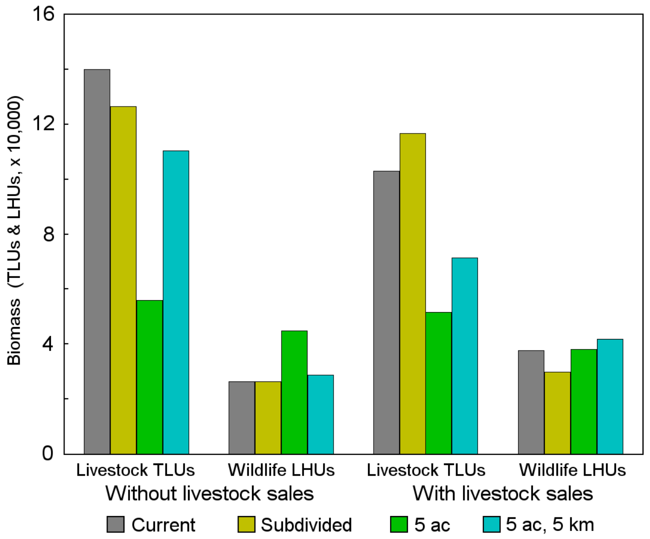

**Figure 21**. Livestock and wildlife abundance in Eselenkei Group Ranch, with and without livestock sales. The simulations represented: current conditions with staged grazing ("Current"); grazing distributed evenly, simulating complete subdivision ("Subdivided"); grazing within the subdivided 5 ac parcels during the long wet season ("5 ac"); and grazing within the subdivided areas plus areas within 5 km, in the long wet season and peak of the short wet season, November ("5 ac, 5 km"). Livestock and wildlife populations are combined into single metrics using units representing 250 kg biomass.

tude of change similar. However, in Imbirikani, the population declines are confounded with the loss of a grazing reserves when livestock are distributed evenly. Relatively low livestock and wildlife populations when grazing the entire area, relative to staged grazing, lends credence to the idea that animals using these areas are grazing reserves during the wet season, reducing forage availability during the dry season when the grazing reserves would be intended to provide forage for livestock (see Scenario 2).

Taken as a whole, our simulation results suggest that a pathway to subdivision that has been suggested, with people owning 5 ac parcels near developed areas but able to graze within about 5 km of the subdivided area, is reasonable. Group ranch members would agree to graze additional communal lands during the drier eight months of the year, and graze areas near their own parcels during the wet months (March, April, May, and November). Ungulate populations may be somewhat lower than in the current staged grazing, but the advantages of ownership of group ranch lands would be gained. For example, members could rent their lands to other members' use, buy or sell parcels, or use their parcels as collateral for loans. However, the benefits of communal land use would also be maintained, specifically the flexibility to move in times of drought and the maintenance of grazing reserves.

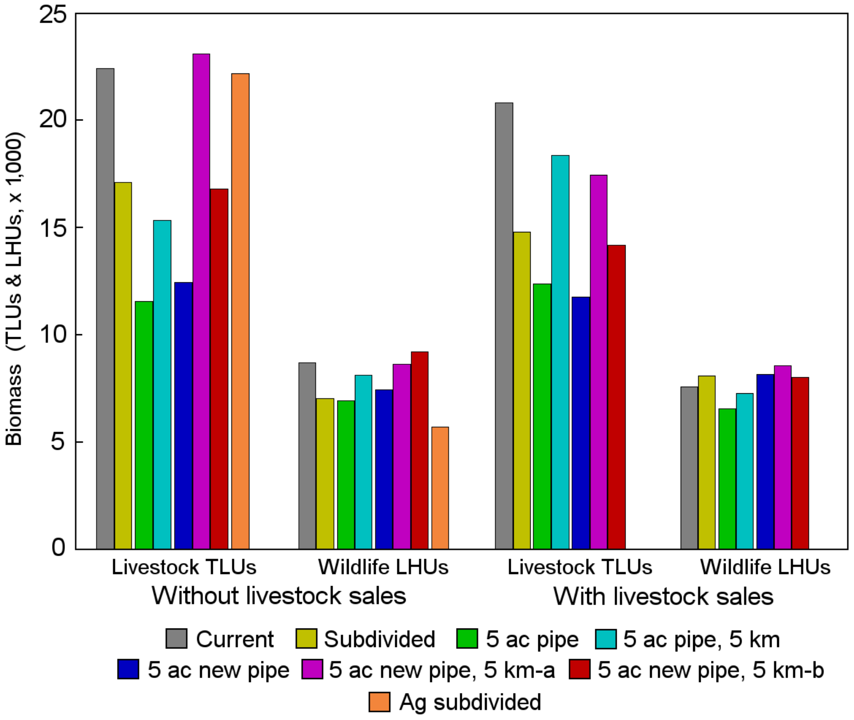

**Figure 22**. Livestock and wildlife abundance in Imbirikani Group Ranch, with and without livestock sales. The simulations represented: current conditions with staged grazing ("Current"); grazing distributed evenly, simulating complete subdivision ("Subdivided"); grazing within the subdivided 5 ac parcels around the existing pipeline during the long wet season ("5 ac pipe"); grazing within the subdivided areas plus areas within 5 km, in the long wet season and peak of the short wet season, November ("5 ac pipe, 5 km"); grazing within the subdivided 5 ac parcels around the existing and new pipelines during the long wet season ("5 ac new pipe"); grazing within the subdivided areas plus areas within 5 km, in the long wet season and peak of the short wet season, November ("5 ac new pipe, 5 km-a"); grazing within the subdivided areas plus areas within 5 km in the long wet season only ("5 ac new pipe, 5 km-b"); and grazing with agricultural areas subdivided into small parcels ("Ag subdivided"). Livestock and wildlife populations are combined into single metrics using units representing 250 kg biomass.

**Table 6**. Effects on households under different pathways to subdivision in Eselenkei and Imbirikani Group Ranches. Results are the average of the three values reported for poor, medium, and rich households.

| | **Staged grazing** | **Evenly distributed** | **Wet season, subdivided areas** | **Wet seasons, subdivided areas + 5 km[a]** |
|---|---|---|---|---|
| **Eselenkei** | | | | |
| Selling income (KSH) | 167,232 | 146,205 | 134,062 | 177,428 |
| Average cashbox (KSH) | 6943 | 7078 | 5220 | 5969 |
| Own food (%) | 40.4 | 41.3 | 27.4 | 36.6 |
| Livestock (TLUs per AE) | 3.28 | 3.68 | 1.66 | 2.36 |
| Gifts/Relief (%) | 5.90 | 4.87 | 10.03 | 6.80 |
| **Imbirikani** | | | | |
| **Existing pipeline** | | | | |
| Selling income (KSH) | 490,335 | 482,501 | 472,828 | 488,121 |
| Average cashbox (KSH) | 159,208 | 155,373 | 151,773 | 156,076 |
| Own food (%) | 66.7 | 64.3 | 63.1 | 66.2 |
| Livestock (TLUs per AE) | 5.27 | 3.78 | 3.13 | 4.65 |
| Gifts/Relief (%) | 1.63 | 2.07 | 2.20 | 1.77 |
| **All pipelines** | | | | |
| Selling income (KSH) | - | - | 475,612 | 486,003 |
| Average cashbox (KSH) | - | - | 150,292 | 155,285 |
| Own food (%) | - | - | 63.4 | 66.0 |
| Livestock (TLUs per AE) | - | - | 3.01 | 4.41 |
| Gifts/Relief (%) | - | - | 1.97 | 1.73 |

[a] – Livestock used the communal grazing in the long and short wet seasons. In analyses not shown in the table but included elsewhere, use in the short wet season (November) was removed, and livestock and food security declined.

**Table 7**. Effects on households under different pathways to subdivision in Eselenkei and Imbirikani Group Ranches. Results are for poor, medium, and rich households. The current conditions are represented by "Staged grazing," animals distributed throughout the ranch by "Evenly distributed," use of wet season subdivided areas "Wet season, subdivided" and areas within 5 km during the wet season, "Wet season, subdivided + 5 km."

| | | Gifts (%) | Income (KSH) | Cash holdings (%) | Own food (%) | TLUs/AE |
|---|---|---|---|---|---|---|
| **POOR** | | | | | | |
| **Eselenkei** | Staged grazing | 8.7 | 105,472 | 13,376 | 32.18 | 1.24 |
| | Evenly distributed | 6.8 | 75,232 | 13,369 | 32.72 | 1.38 |
| | Wet seas., subdiv. | 12.4 | 80,366 | 11,774 | 20.89 | 0.63 |
| | Wet seas., subdiv.+5 km | 9.1 | 122,722 | 12,442 | 27.96 | 0.90 |
| **Imbirikani** | Staged grazing | 2.0 | 579,753 | 222,786 | 65.88 | 1.96 |
| | Evenly distributed | 2.5 | 580,519 | 220,179 | 61.99 | 1.41 |
| | Wet seas., subdiv. | 2.9 | 568,058 | 217,445 | 59.16 | 1.16 |
| | Wet seas., subdiv.+5 km | 2.4 | 580,847 | 220,910 | 64.75 | 1.73 |
| **New pipe** | Wet seas., subdiv. | 2.4 | 575,155 | 217,363 | 59.94 | 1.12 |
| | Wet seas., subdiv.+5 km | 2.4 | 578,529 | 220,184 | 64.23 | 1.64 |
| **MEDIUM** | | | | | | |
| **Eselenkei** | Staged grazing | 5.4 | 187,049 | 1877 | 41.81 | 2.82 |
| | Evenly distributed | 4.6 | 163,355 | 1898 | 43.18 | 3.13 |
| | Wet seas., subdiv. | 10.0 | 146,082 | 1125 | 27.87 | 1.42 |
| | Wet seas., subdiv.+5 km | 6.6 | 202,956 | 1519 | 36.81 | 2.06 |
| **Imbirikani** | Staged grazing | 1.8 | 393,877 | 103,037 | 66.61 | 4.44 |
| | Evenly distributed | 2.3 | 386,858 | 99,837 | 63.69 | 3.20 |
| | Wet seas., subdiv. | 2.4 | 376,751 | 96,823 | 62.90 | 2.64 |
| | Wet seas., subdiv.+5 km | 1.8 | 392,853 | 100,618 | 66.32 | 3.92 |
| **New pipe** | Wet seas., subdiv. | 2.2 | 379,837 | 95,687 | 63.02 | 2.55 |
| | Wet seas., subdiv.+5 km | 1.7 | 391,011 | 100,072 | 66.08 | 3.72 |
| **RICH** | | | | | | |
| **Eselenkei** | Staged grazing | 3.6 | 209,174 | 5576 | 47.25 | 5.79 |
| | Evenly distributed | 3.2 | 200,030 | 5967 | 47.94 | 6.52 |
| | Wet seas., subdiv. | 7.7 | 175,739 | 2761 | 33.47 | 2.92 |
| | Wet seas., subdiv.+5 km | 4.7 | 206,606 | 3946 | 44.9 | 4.12 |
| **Imbirikani** | Staged grazing | 1.1 | 497,374 | 151,802 | 67.58 | 9.41 |
| | Evenly distributed | 1.4 | 480,126 | 146,102 | 67.21 | 6.73 |
| | Wet seas., subdiv. | 1.3 | 473,674 | 141,050 | 67.16 | 5.60 |
| | Wet seas., subdiv.+5 km | 1.1 | 490,664 | 146,700 | 67.57 | 8.31 |
| **New pipe** | Wet seas., subdiv. | 1.3 | 471,843 | 138,825 | 67.12 | 5.36 |
| | Wet seas., subdiv.+5 km | 1.1 | 488,470 | 145,599 | 67.55 | 7.88 |

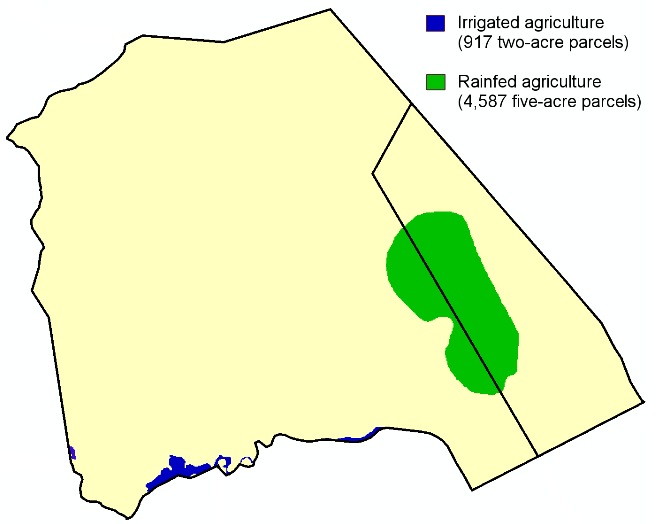

**Figure 23**. Subdivision within Imbirikani Group Ranch where some of the 5504 ranch members received 2 ac parcels of irrigated agriculture, and the remainder received 5 ac parcels in the Chyulu Hills.

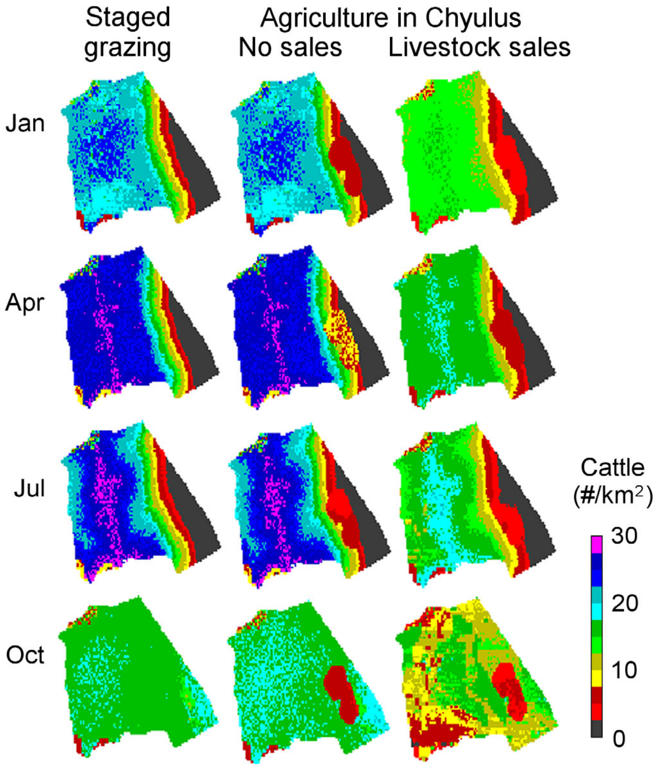

**Figure 24**. The distribution of cattle in Imbirikani Group Ranch in selected months of modeled year 1978, with currently employed staged grazing, agriculture represented in Figure 22 in place and sales (i.e., PHEWS) disabled, and with agriculture and sales in place.

## DIVERSIFICATION IN SOUTHERN KAJIADO DISTRICT, KENYA

Areas of Kajiado District, Kenya, have residents who are impoverished relative to the rest of Kenya. Many residents earn less than US $16 per month (reviewed in Thornton et al. 2006a, citing GoK 2003). They make use of some locally-produced foods not represented in government statistics, but in general, Maasai are food insecure. Rapid human population growth, increased incidents of drought, and immigration have amplified insecurity. Land tenure changes (see Scenario 3) have reduced livestock mobility on the landscape (Kristjanson et al. 2002, Boone et al. 2005), and households have been sedentarized, in part to tend crops and to access services. These changes mean that pastoral households are less flexible in their responses when drought does occur.

Based on detailed surveys conducted by BurnSilver from 1999 to 2001 and summarized, households from six study areas were classified into one of eight livelihood categories. All households raised livestock. Some households included members who earn wages or owned some type of business, such as food or craft sales, or the sale of charcoal or services. Households also participated in agriculture, with some doing rain-fed agriculture on the brush-grasslands of Kajiado, some doing rain-fed agriculture on the slopes of Mount Kilimanjaro around Loitokitok Town, and others doing irrigated agriculture. The observed pattern of livelihood strategies is a product of historical land use, resources available to residents (e.g., irrigation water), and opportunities. How residents may modify their livelihood strategies to improve their well-being, bearing in mind the constraints they face, is of interest to us. We proposed the scenario described in Box 4.

### Adjustments to Scenario Proposed

Our analyses under this scenario directly address diversification within southern Kajiado District, Kenya. However, this scenario was altered the most of the four analyzed. Analyses under the other three scenarios have highlighted some strengths and shortcomings of the PHEWS model. To fully address diversification in Kajiado for Scenario 4, we had proposed that PHEWS be updated so that households were more spatially explicit and to allow families to transfer between livelihood types (echoing that household strategies are not static through time). In the coarse of these analyses being completed, a US National Science Foundation project (SES-0527481) to K.A. Galvin, Boone, Thornton, and others has been funded. Under that project, we are constructing a detailed agent-based model of households, which will be joined with the SAVANNA model and applied to southern Kajiado District and other sites. The logic within PHEWS forms a foundation for the agent-based model, but the households within the new model will be more adaptable than PHEWS. We therefore did not invest time into modifying PHEWS to address this scenario. Also, some of the diversification pathways we proposed in the scenario are now known to be inappropriate or unbounded. For example, expanding agriculture will benefit Kajiado residents, but all of the costs inherent in that expansion – complex negative feedbacks – are not well represented in PHEWS, and so an optimum area in cultivation cannot be calculated.

We believe an important negative feedback in expansion of cultivation is the landscape itself. Water in the swamps form the foundation of irrigated agriculture in the Amboseli Basin, and those swamps that are not already in conservation areas, in principle, could be put into agriculture. Residents from Loitokitok and neighboring areas also cultivate on the slopes of Mount Kilimanjaro that have been cleared of trees, using the higher rainfall of that area to sustain crops. Areas appropriate for cultivation that are within Kenya (versus the higher slopes across the border in Tanzania) are limited (Campbell et al. 2005). Lastly, rain-fed agriculture within the Amboseli Basin is a risky proposition, with a successful crop only every few years when rainfall is adequate, but again that agriculture could be expanded (e.g., see Scenario 3). We estimated increases in each of these types of cultivation, and used modeling to quantify how much of an increase in Maasai well-being may be expected.

This focus soley on agriculture and its contributions to household economies is a departure from the original scenario proposed (Box 4), but is appropriate. Agricultural expansion is relevant to this area, given the process of subdivision already described (e.g., potential subdivision in Imbirikani for rain-fed and irrigated plots), plus the overriding expectation of cultivation contributing greatly to the well-being of houseehold.

### Model Adaptation

Areas appropriate for irrigation are already essentially fully allocated in southern Kajiado District, Kenya. We estimate that there are no more than 5% additional lands that can be irrigated with the water currently available. In modeling for the entire study area, the 3820 households cultivated 1800 ha in irrigated crops in 2000. A 5%

**Original Scenario 4. Diversification in Southern Kajiado District**

**Goals:** To identify potential pathways for diversification within the livelihood groups defined by BurnSilver using cluster analyses. Identify how the options for diversification vary across the landscape, and perhaps how they vary for wealth levels.

**Pathway:** PHEWS must be made more spatially explicit, and to allow families of a given livelihood to transfer to another livelihood type.

**Scenarios:** Examples only are shown. They include:

1. Eselenkei Group Ranch, income or wages needed from small business or external employment will be calculated;
2. Imbirikani Group Ranch, the acreage needed in cultivation to supply food will be calculated. We will explore how the balance of main crops (e.g., maize, beans) and specialty crops (e.g., tomatoes, onions) affect expected income;
3. Olgulului/Lolorashi Group Ranch, we will assess if intensified livestock trade can offset losses, plus acreage needed for highland rain-fed agriculture;
4. Osilalei Group Ranch, coping mechanisms may not be as critical, because prior analyses suggest effects of subdivision on livestock capacity will be minimal, and many options are available to residents (e.g., livestock raising, rain-fed agriculture, business, employment).

**Possible types of results:** Specific pathways people may follow in the different study areas will be described. Overall, it may be evident that the diversification pathways people may use are specific to given areas, but there may be commonalities as well. How much must people need to gain from diversification to offset the effective losses people feel now in TLUs, associated with human population growth? How much to do even better?

**Notes:** People are aware of the hardships, and to some degree the trade-offs. They seek help in setting balances in their diversification. How should analyses be prioritized? How can education be included?

increase yields 1890 ha in irrigated crops. Similarly, much of the area of Loitokitok appropriate for cultivation is being used for that purpose. Campbell et al. (2003) found that forests on the slopes of Mount Kilimanjaro declined from 646 ha in 1973 to 417 ha in 2000. Based on inspection of high resolution satellite images (Boone et al., In press), we estimate that roughly another 20% in agriculture in the Loitokitok region is the maximum that can be expected. In the control model, 530 ha are in Loitokitok cultivation. A 20% increase in that cultivation would yield 635 ha. Land is available for rain-fed agriculture throughout the district, but many areas are not suitable for cultivation. Few households in Osilalei and Eselenkei raise only livestock or only livestock plus a business and wages, so most families there are already cultivating plots. People of southern Imbirikani mostly do irrigated agriculture. Any new rain-fed agriculture will come from the Lenkesim, Emeshenani, and northern Imbirikani communities, but some of these communities are on dry landscapes. Further, shortages of labor will prevent the households modeled from cultivating large swaths of land. Here, we assume that rain-fed agriculture may increase by 30%, from 900 ha in the region to 1170 ha.

These increases in cultivation were added to the six study sub-areas in proportion to the observed areas already cultivated. The area each family cultivated remained similar in these simulations. Instead, some families that own only livestock in one analyses, or livestock and a business in another, were altered so that their livelihoods included cultivation. For example, in the base model, 6% of 3820 households did cultivation in the Loitokitok region, summing to 530 ha, or about 2.31 ha per household. About 275 households would cultivate 635 ha (see above) at that rate, which is 7% of 3820 after rounding. Those who irrigate comprise 29% of the total households (17% with livestock and irrigation plus 12% with livestock, businesses, and irrigation). Increasing that to 30% of the total households irrigating yields a 5% increase in area cultivated. Lastly, 36% of households practice rain-fed agriculture on 0.65 ha each. To increase the area in cultivation by 30%, 54% of the total number of households, or 2063 households, would each cultivate 0.65 ha of land.

## Results and Interpretation

The original eight livelihood approaches and their distributions throughout the study area are shown in Table 8a, condensed from extensive field work conducted by BurnSilver in 1990-2001. To address the scenario in the modeling system, agriculture was increased (1170 ha rainfed, 1890 ha in irrigation, and 635 ha in Loitokitok rainfed agriculture). We then altered the relative proportions of households doing agriculture. In the first case, households that were wholly pastoralists (L) were shifted to be agro-pastoralist (LR, LI, or LK) to yield the appropriate quantity of each type of cultivation. There were too few pure pastoralists in the study area; when all pastoralists were converted to agro-pastoralists, there was still too little land in cultivation. We therefore converted some business-pastoralists (LB) to agro-pastoralists as well (Table 8b). In the second case, business-pastoralists were assigned to agro-business-pastoralist categories (LBR, LBI, or LBK) (Table 8c).

Results from simulations suggest that very modest improvements in the livelihoods of Kajiado residents are possible through increased cultivation. Here the focus is on the average well-being of all households within the study area. Example responses include the monetary value of supplemental gifts that households required, coming from friends and family or from aid agencies (Figure 25a), the proportion of households' food that they produce (Figure 25b), the number of livestock per household member (Figure 25c).

These analyses suggest that options available to residents to improve their well-being cannot rely only on increased cultivation. In addition, livestock populations have been relatively stable for several decades (de Leeuw et al. 1998), though still fluctuating in drought and wet years. Simulations indicate that the capacity of the region to support livestock and wildlife is in a fragile balance (Toxopeus 2000), and sizeable increases in livestock populations are unlikely without intensive management, which is not foreseen in the near future. We estimate that most of the areas where irrigated agriculture is possible in southern Kajiado are already in production, so agriculture with reliable returns is unlikely to expand greatly in the study area (unless deep well irrigation and other intensive agricultural practices are used). Of course, individual Maasai

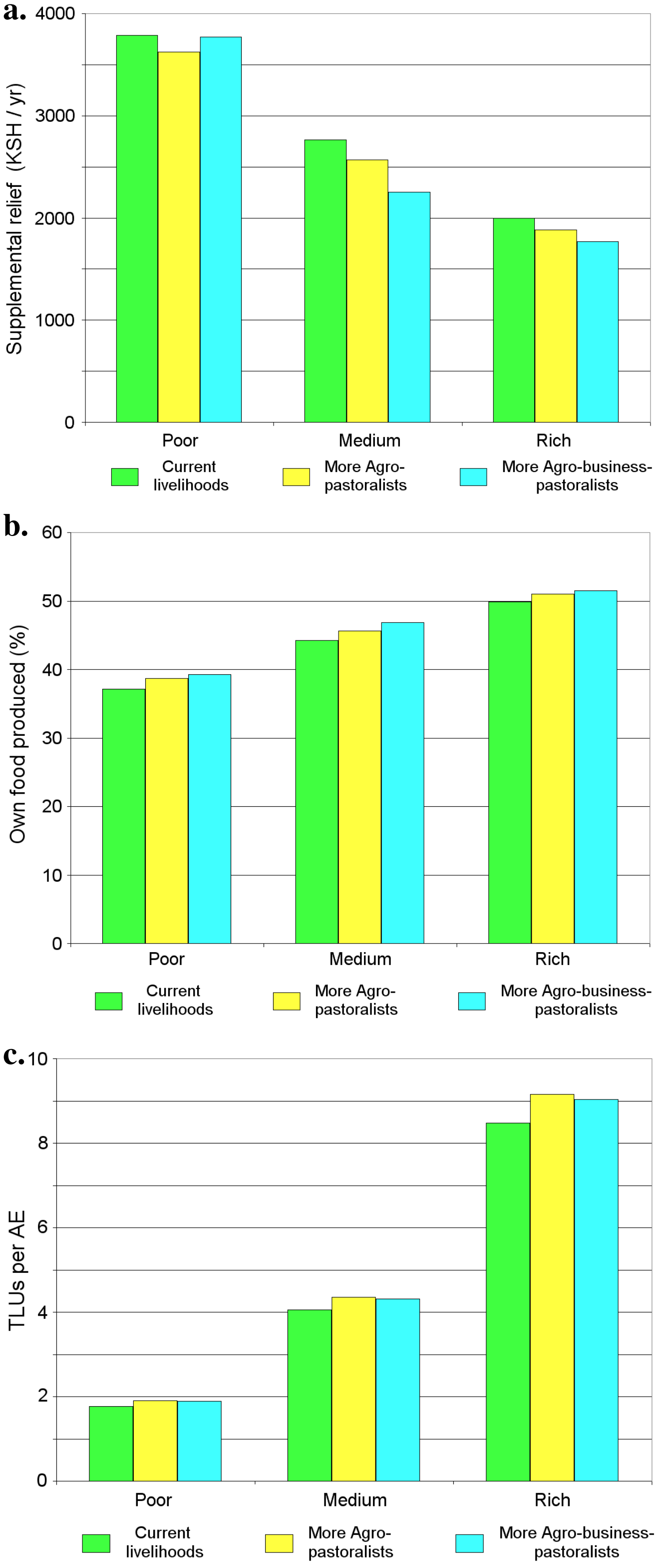

**Figure 25**. Selected metrics of human well-being for poor, medium, and rich households under current conditions, with pastoralists switched to agropastoralists, and with pastoralists with businesses switched to agropastoralists with businesses. Metrics are a) gifts or supplemental foods needed by households, b) the proportion of their food needs each households produced, and c) tropical livestock units per adult equivalent.

**Table 8**. Changes made to the percentages of households in eight livelihood strategies in regions of the study area. The a) original values where modified to shift b) livestock-only households to livestock and agriculture households (with some also doing business shifted as needed), and c) livestock-and-business households shifted to include agriculture. Values shown are percentages of households in each category, and each column sums to 100%. Abbreviations used are for livestock raising (L), irrigated agriculture (I), rain-fed agriculture (R), agriculture along the slopes of Mount Kilimanjaro in Loitokitok Town (K), and owning a business or earning wages or salary (B). These codes are combined to represent household livelihoods. For example, all households owned some livestock. The Lenkisim area is in southern Eselenkei Group Ranch, and the Emeshenani area in in Olgulului/Lolorashi Group Ranch, north of Amboseli National Park.

**a.**

| Livelihood strategy | Osilalei | Eselenkei | Lenkisim | Emeshenani | N. Imbirikani | S. Imbirikani | Total |
|---|---|---|---|---|---|---|---|
| L | 0 | 4 | 51 | 43 | 15 | 4 | 15 |
| LB | 0 | 5 | 38 | 19 | 26 | 6 | 14 |
| LI | 0 | 8 | 4 | 14 | 17 | 57 | 17 |
| LR | 68 | 53 | 2 | 0 | 5 | 0 | 24 |
| LK | 0 | 1 | 2 | 6 | 3 | 0 | 2 |
| LBI | 1 | 6 | 0 | 5 | 23 | 30 | 12 |
| LBR | 31 | 22 | 2 | 1 | 3 | 0 | 12 |
| LBK | 0 | 1 | 1 | 12 | 8 | 3 | 4 |

**b.**

| Livelihood strategy | Osilalei | Eselenkei | Lenkisim | Emeshenani | N. Imbirikani | S. Imbirikani | Total |
|---|---|---|---|---|---|---|---|
| L | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LB | 0 | 0 | 31 | 9 | 13 | 0 | 7 |
| LI | 0 | 8 | 4 | 15 | 17 | 56 | 17 |
| LR | 68 | 61 | 59 | 51 | 32 | 10 | 46 |
| LK | 0 | 2 | 3 | 7 | 4 | 1 | 3 |
| LBI | 1 | 6 | 0 | 5 | 23 | 30 | 12 |
| LBR | 31 | 22 | 2 | 1 | 3 | 0 | 11 |
| LBK | 0 | 1 | 1 | 12 | 8 | 3 | 4 |

**c.**

| Livelihood strategy | Osilalei | Eselenkei | Lenkisim | Emeshenani | N. Imbirikani | S. Imbirikani | Total |
|---|---|---|---|---|---|---|---|
| L | 0 | 4 | 51 | 43 | 15 | 4 | 16 |
| LB | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| LI | 0 | 8 | 4 | 14 | 17 | 57 | 17 |
| LR | 68 | 53 | 2 | 0 | 5 | 0 | 24 |
| LK | 0 | 1 | 2 | 6 | 3 | 0 | 2 |
| LBI | 1 | 7 | 3 | 6 | 24 | 30 | 13 |
| LBR | 31 | 25 | 34 | 18 | 27 | 5 | 23 |
| LBK | 0 | 2 | 4 | 13 | 9 | 4 | 5 |

may improve their well-being by acquiring a greater proportion of livestock within the study area, or a greater proportion of the area cultivated. But overall, food production from these sources seem almost maximized, without intensified management. Gains by one member of the community will imply losses for other members in the region (or their emigration). Residents of southern Kajiado must find other means to improve their well-being, such as through wage labor or business. Greater revenue from community conservation enterprises or conservation-based revenue sharing are additional options. Many challenges still exist in both guaranteeing higher levels of community-based conservation income and ensuring that the distribution of these benefits to community members is equitable.

We have not addressed how agriculture within southern Kajiado could be managed to increase production per unit cultivated. Agro-pastoralists could improve their well-being if they grew more food for their use or for sale on the land they cultivate and with the water they now use. In these analyses, we also did not directly link changes in the area of cultivation to potential changes in ungulate populations. That work requires a relatively high resolution map of agriculture for an area (e.g., Boone et al. 2006), which we have not created for this area. These analyses are intended to be illustrative rather than predicting, more so than in Scenarios 1 through 3, and highlighting what we believe are limited options available to Kajiado Maasai seeking to improve their well-being.

## Conclusion

As in many pastoral areas, human population growth is a concern in southern Kajiado District, many residents are poor, and resources such as livestock production and agriculture are having to support more and more people (Thornton et al. 2006a). Unfortunately, options available to residents in southern Kajiado to increase production from livestock and agriculture appear limited. Modeling suggests that the well-being of residents can be only modestly improved by increases in area cultivated, and dramatic increases in livestock populations are unlikely, especially if declines to wildlife populations are to be avoided. Agricultural production may be increased through intensified management (e.g., additional fertilizers, mechanization, and improved crops). Similarly, livestock production may be increased through intensified management, such as improved veterinary practices. Small-scale explorations are being made in intensified production. For example, pastoralists in the region are judging the usefulness of improved livestock breeds (see Scenario 1). However, nothing suggests large-scale intensification of livestock or agricultural production is on the horizon. Our results indicate that residents of Kajiado will need to increase their reliance on other forms of livelihood diversification beyond agriculture, to improve their well-being. The data of BurnSilver for Amboseli and researchers working in other pastoral areas of East Africa show that these trends are present, although pastoralists still rely on their livestock to a great degree.

## THE JUNE 2006 DISSEMINATION MEETINGS

A series of five community meetings were held between June 14 and June 23, 2006 in the Amboseli area to disseminate results from the most recent round of modeling scenarios undertaken under the *Reto-o-Reto* project. The form of these integrated assessments are detailed in previous sections of this report. This section will focus specifically on the dissemination meetings during which results were given out to local community members; their format, the attendance and relevant questions and feedback that emerged from them.

The five locations for the meetings were: Kalesirua (S. Imbirikani), Ilmabateni (N. Imbirikani), Inchakita (Emeshenani), Lenkisim town and Eselenkei. S. BurnSilver and R. Solonga Supeet led the dissemination team, however they were joined by D. Nkadinye (ILRI) for the two meetings in Eselenkei and Lenkisim, and Leonard Onetu for one meeting (Eselenkei). The meetings were open to all interested community members. Personal invitations went out to group ranch committee members and area chiefs and transportation was arranged for these individuals when necessary. The duration of each meeting ranged between 1.5 hours in Lenkisim, and 3+ hours in Eselenkei (where discussion of the results continued long after results had been given out). Approximate attendance at the meetings was as follows:

| | | |
|---|---|---|
| Kalesirua: | 70 | (including 20 women) |
| Ilmabateni: | 80 | (including location chief, group ranch Secretary and Treasurer) |
| Inchakita: | 55 | (including 3 group ranch committee members) |
| Lenkisim: | 45 | |
| Eselenkei: | 80 | (including group ranch Chairman, Treasurer and Secretary) |
| Total: | 280 | |

All five meetings followed the same general format, however some results were more pertinent than others in certain areas (e.g., the water distribution results were not presented in Eselenkei Group Ranch or at Inchakita). Modeling results for 3 of the 4 modeling scenarios were complete (breed strategies, subdivision and water distribution), but BurnSilver also reported economic diversification results for each area from her research in place of modeled results for question 4 (cultivation and well-being). Each meeting began with an extensive introduction during which BurnSilver explained the process the project had followed to develop the current set of research questions. The emphasis here was on linking the focus group meetings that had taken place in January of 2005 with the development of integrated assessment scenarios and the modeling results that we were there to present. It is no exaggeration to say that we received many nods of agreement as we explained that the questions we asked, and the scenarios we explored came directly from the concerns of community members.

### Breed Change

This part of the meetings began with discussion of a poster that depicted the degree to which the change from pure zebu shorthorn to either Boran or Sahiwal cattle had occurred by 2001, for different age/sex classes of animals across the study areas (Figure 26). The results on which this figure is based came from the research of S. BurnSilver. The poster was very effective in generating discussion, because it highlighted clearly the differences in the degree to which people were transitioning towards dependence on the larger cattle breeds, which in turn stimulated people to talk (animatedly!) about the tradeoffs and dangers involved in making this change. So for instance, the figure showed that households in Osilalei and Eselenkei were much further along in integrating the "bigger cows" into their herds, while in Emeshenani, only a few households had begun to buy improved bulls. People had asked during the January 2005 focus groups "What is the right mix of improved animals for our herds?", and "What if we go too far in integrating these big cows into our herds, and then a drought comes and they can't walk?" The modeling results suggested that there was a middle ground (between 40-60% improved breed cows), that pastoralists should aim for in transitioning to the big cows, and this meshed strongly with the thoughts of many people at the dissemination meetings. They stated that the goal was to only interbreed to a point where the strengths of the zebu cows were maintained, but the benefits of the bigger cows were also gained – *and* where cows were still able to 'walk' when they needed to. The point that had come through strongly during the focus groups – that local pastoralists are essentially "experimenting" with the improved breeds – came out again in comments during the dissemination meetings. This is a critical caveat for researchers to keep in mind, because regardless of whether we believe that greater dependence on improved breed animals is risky in such a highly variable environment – or a positive for producers – the process is currently underway for pastoral households to identify where that 'balance point' is. If people go too far past that balance point there will be negative repercussions for household well-being. However, no one is more aware of these con-

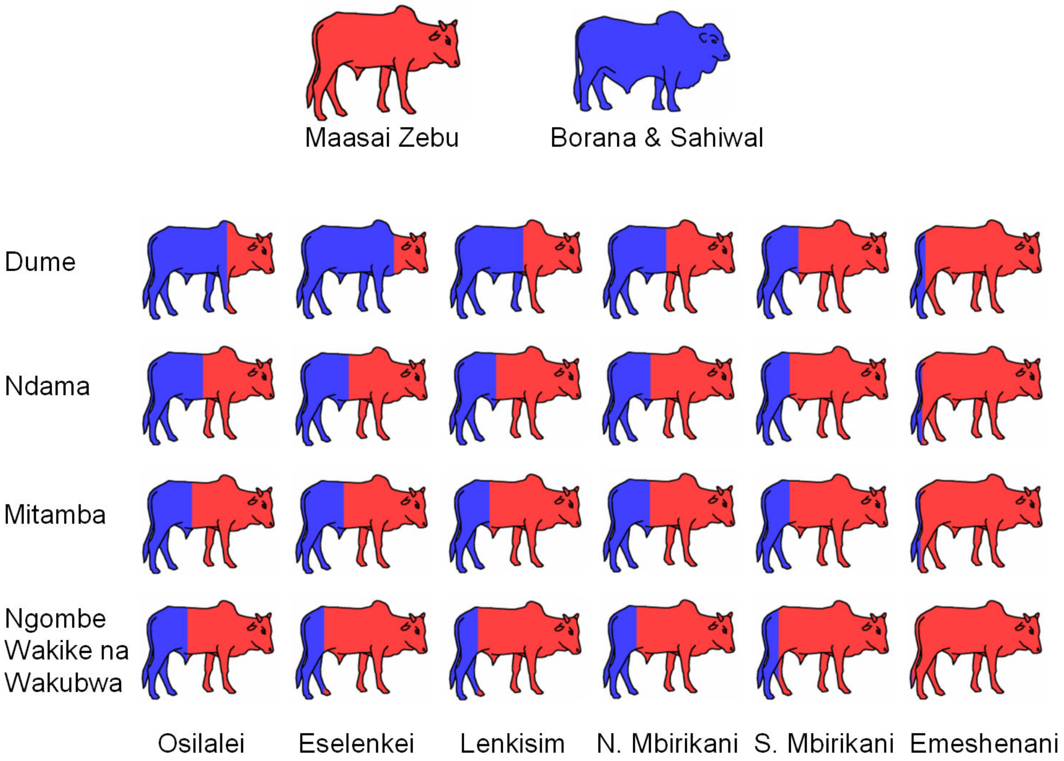

**Figure 26**. A poster used in dissemination meetings that portrays the ratio of Maasai Zebu and Borana and Sahiwal cattle in six study areas. The kiSwahili on the chart translates as: Dume - Bulls; Ndama - Calves; Mitamba - Heifers; Ngombe Wakike na Wakubwa - Cows.

cerns that producers themselves. This issue has emerged as a critical one, and one where there would be room to connect producers to researchers concerned with the question of interbreeding in the future.

## New Water Pipeline in Imbirikani

Results from the pipeline modeling scenarios for Imbirikani were presented based on a large poster similar to Figure 7 (page 15). The 2005 focus group meetings had highlighted perceptions (optimistic ones) that the new pipeline could be critical to; 1) improving livestock production on the group ranch, and 2) could relieve the crowding of people and animals experienced along the current pipeline (e.g., a zone of permanent settlements that is heavily used). The results regarding the new water pipeline at Imbirikani seemed to be particularly timely, as the pipeline spur was half-finished at the time we disseminated results, and the group ranch was embroiled in a process of trying to figure out how the new water source would be managed. We do not use the word "embroiled" here lightly, as it was clear during the meetings that how to use the pipeline, and when to open and close the new water source(s), was being hotly debated throughout the group ranch. Questions after the dissemination meetings suggested that the scenario of putting tanks every 5 km along the pipeline spur that were open at specific times, was less of an option in the minds of group ranch members than the scenario under which one large tank at the terminus of the new spur was available to livestock. Our conclusion that having water at the terminal tank available to livestock at all times posed substantial risk to the traditional system of staged grazing and maintenance of the Chyulu Hills as a grazing reserve, received many up-and-down nods during the meetings. The Location Chief at the Ilmabateni meeting stood up and took the floor after our presentation was done, and used the time to talk about what criteria the group ranch members should use in deciding when to open and close the new tank for use. The implication we drew from both Imbirikani meetings was that people are well-aware that the new terminus water source will have to be managed closely, although there was no consensus yet on how it should be done. Again, the value of our results was not so much in the specifics (e.g., under "x" scenario, livestock populations would decline by 28% over "x" years), but instead in the discussion of directional trends and tradeoffs associated with the different options for management of the new water – *which had initially come from community members themselves*.

### Subdivision

Results of the subdivision modeling scenarios were discussed based on two large posters (similar to Figure 14 on page 25 and Figure 16 on page 28) which illustrated what subdivision would look like on Eselenkei and Imbirikani group ranches under the different scenarios that group ranch members had laid out during the 2005 focus groups. These analyses were not undertaken for Olgulului/Lolarashi Group Ranch, however we still presented the posters and discussed the subdivision results at the Inchakita meeting. We found that these posters were a *very* powerful tool in illustrating what it would mean for every member of each group ranch to have their own, individual parcel. The comment from one *Mze* (i.e., elder) when we explained the subdivision map for Imbirikani was that "we would all die if we had to stay in those tiny, little places." It was our strong impression that this was the first time that group ranch members had actually seen what their group ranch would look like post-subdivision. BurnSilver and Supeet had met with Nkadinye prior to leaving for Amboseli to identify some effects of subdivision that Kitengela producers have been wrestling with (an area in Kajiado south of Nairobi in which Nkadinye is an expert). His point was that while yes, everyone now had their own piece of land, there were other issues that had emerged that continued to pose serious challenges for producers. For example, once the group ranch committee is dissolved, the need for people to work together does not go away, but there is now no mechanism for people to organize effectively. There are few people more eloquent or articulate than D. Nkadinye, and he was an absolutely invaluable addition to the dissemination meetings in Lenkisim and Eselenkei for this reason. The results of the subdivision scenarios that we presented were useful because they illustrated that neither the path nor the effects of subdivision are currently set in stone. The impression may be that subdivision is "inevitable," but while the classic pattern under which subdivision in Kajiado has occurred so far [e.g., divide the group ranch size by the number of group ranch members and this dictates (ideally) the size of an individual's parcel] still remains the dominant mode of thinking about how to move forward, the results of these scenarios illustrated that there are other options that members could explore *if the political will is present.* Questions that emerged at the end of the meetings in Imbirikani particularly, suggested that the scenario under which people have their small parcels near the pipeline plus access to a 5 km area during the wet season, followed by using the remaining open rangelands in stages, resonated most strongly with those present. However, the main value of these meetings was again to stimulate a more informed debate regarding options over and beyond each member receiving their own, finite parcel.

### Diversification Pathways and Pastoral Well-being

The modeling results for this scenario were not complete at the time of the dissemination meetings. However, the topic of economic diversification had emerged as important during the 2005 focus groups. The question people were asking was, "We know that people are trying new activities, but what activities are bringing the greatest benefits to people?" BurnSilver did some basic analyses of her household economic data to partially address this question. The results she gave out at the meetings are presented in Table 9. Listed values are annual averages based on the combinations of activities that households are pursuing across each of the study areas. The idea of "averages" and "gross household income" were used in the discussion, but were defined using analogies to bring them into a local frame of reference. BurnSilver went through the combinations of activities and associated income values for each study area, and made comparisons between study areas as well. The take home message was that currently a majority of pastoral households are engaged in activities beyond livestock production, and those who are adding additional activities to their livelihood strategies are (on average) doing better (e.g., have a higher annual gross income) than those who are pursuing only livestock activities. Some households are *very* diversified, and these few households are doing extremely well compared to less-diversified households. The types of activities that households are trying depends on location (e.g., access to certain kinds of resources) and also the investment/resource base that individual households have on which to base their diversification decisions. So for example, richer households have a different diversification trajectory than poorer households. However, a caveat added to these results was that in spite of the emerging importance of additional economic activities, livestock still formed the economic foundation (yielding over 50% of income) for the vast majority of households across *all* the study areas. This last result seemed to resonate strongly with those present at the meetings. In other words, livestock are still important (for many reasons, both cultural and economic) whether someone is an agropastoralist in the swamps, or is living in a more traditional pastoral area north of the park.

**Table 9**. Average gross income (Kenyan shillings) from different combinations of activities. Numbers of households comprising surveys in each category are in parentheses.

| **Activity Combinations** | **S. Imbirikani** | **N. Imbirikani** | **Emeshenani** | **Lenkisim** | **Eselenkei** |
|---|---|---|---|---|---|
| LS | 24,990 (2) | 59,990 (6) | 68,297 (9) | 32,690 (8) | 48,720 (11) |
| LS + Milk | | 64,540 (1) | 91,179 (2) | | |
| LS + OFF | | 250,670 (12) | 109,661 (8) | 92,960 (16) | 121,870 (11) |
| LS + AG | 35,840 (11) | 141,260 (1) | 63,638 (3) | | 69,230 (2) |
| LS + Milk + OFF | 158,620 (4) | 240,450 (2) | 118,154 (1) | | 181,230 (1) |
| LS + Milk + AG | | 80,920 (1) | | 159,460 (1) | |
| LS + AG + OFF | 87,150 (8) | 156,590 (7) | 234,396 (5) | 196,070 (1) | 140,630 (4) |
| LS + AG + Milk + OFF | 168,420 (4) | 255,150 (3) | 111,723 (1) | 411,530 (2) | |

LS= livestock, Milk= selling of milk, OFF= business, salaries, or petty trade activities, AG= consumed or sold value of agricultural products.

## Overall Conclusions and Policy Considerations

Results from each of the land-use intensification scenarios we addressed contributed insights to how lands may be managed in southern Kajiado District. This report demonstrates the utility of integrated assessments to quantify the direction and magnitude of changes expected under different land use or policy decisions. That said, we cannot consider the results from the scenarios we addressed equal in their usefulness. Some policy or land use decisions are very well suited to being addressed using the tools available to us, and some less so. Two of the scenarios (Scenarios 2 and 3) provided clear alternatives for the timing of use of new water sources and pathways to subdivision in Eselenkei and Imibirikani Group Ranches. Scenario 4 illustrated the limited potential for dramatic increases in areas cultivated in southern Kajiado to improve human well-being. Our contribution that suggests to pastoralists appropriate mixes of Maasai Zebu and improved cattle in their herds is less clear. Many of the traits expected to differ between Zebu and improved breeds were captured in ecological modeling (e.g., Table 1), and our modeling suggests that herds composed of 40% to 60% improved cattle are most appropriate for semi-arid group ranches. However, the results were variable, and some relationships, such as water needs and disease risks, were either missing or coarsely represented in the model. Moreover, issues of cultural preferences and some economic efficiency considerations were not represent in our household model. That said, the results did highlight effectively that a full transition toward owning improved breeds was not possible in these dryland environments, and that a moderate (40% to 60%) mixing of Maasai Zebua and improved animals was the ideal strategy. These results showed that the Emeshenani area was on the low end of suitability for these bigger, slower, less mobile animals which is a validation of our approach. These results were also received positively by community members, and led to substantial back-and-forth discussions of the tradeoffs associated with the improved animals during dissemination meetings.

Residents of Kajiado and the policy makers that support them should strive to diversify livelihoods. Expansion of cultivated areas and of livestock populations appears limited. Yet population growth and possibly subdivision will further strain the food security of southern Kajiado residents. Educational opportunities should be enhanced, to allow residents to earn wages and expand their livelihood options. Instruments may be put in-place, such as micro-loans, to promote the creation of small businesses. Entrepreneurial training may aid in the success of existing and new businesses. Efforts to increase crop production on the lands already in cultivation and to increase growth rates and sales of livestock may improve the well-being of Kajiado residents, with minimal risk to wildlife populations. Better marketing options for pastoral products would also improve the ability of producers to benefit from intensified livestock production strategies.

Modeling indicates that adding a water source to the Chyulu Hills near Imbirikani Group Ranch and allowing its unlimited use will degrade the grazing reserves of this critical area. Should water sources be opened along the new pipeline and allowed to be used anytime, the areas normally used in staged grazing will be degraded, and livestock and wildlife populations will decline. Closing the water sources in the wet season did not dramatically change the results. However, allowing the water sources to be used only when the preceding months were dry (< 75 mm rainfall) allowed many thousands more livestock to be supported on the area in simulations. Areas were held in grazing reserves as they currently are, but were available to livestock in difficult times, and without high travel costs to access water. Again, during dissemination meetings at Imbirikani Group Ranch, these results were greeted with the response, “Yes, this is what we were thinking, that the new tank could not be open all the time.” Group ranch committee members can judge dryness based on weather station results or qualitative judgments. If an adaptive management approach that allowed use of the water sources only during dry periods was culturally acceptable, modeling suggests more animals could be supported on Imbirikani Group Ranch than if the new water sources were available all the time.

This effort and past modeling has demonstrated that complete subdivision of Eselenkei and Imbirikani Group Ranches would be ill-advised. If parcel owners use their lands exclusively, livestock can fail to find adequate forage, lose condition, and die. In analyses where livestock were distributed evenly across the ranches, livestock populations were similar to those currently in the ranches. However, with animals unable to move about more freely, more livestock died during droughts. If these ranches are divided into individual parcels, group ranch committees should promote policies that support grazing associations, discourage fencing of parcels, or otherwise promote shared use of the land. Our modeling validated that the subdivision scenario identified by group ranch members was an effective alternative, namely that each ranch member receive a small parcel within the permanently settled areas of the group ranches, and graze their animals within 5 km of those parcels during the wet season, and use other areas communally in staged grazing during other months. Results suggest that livestock populations would be on-par with current populations, wildlife populations would not markedly change, and human well-being would be maintained. In addition, ranch members would gain the benefits of land ownership within the group ranch, such as the right to improve individual parcels with permanent housing and use their lands as collatoral for loans.

The southern Kajiado social- and ecosystems are changing rapidly. In the future, the area will support more humans (Thornton et al. 2006a), there will be increased variability in weather (e.g., CA 2006), what may be longer growing seasons (Thornton et al. 2006b) with its increase in the forage and agricultural base but also in diseases, and rapid diversification of livelihood strategies is ongoing (BurnSilver, In prep.). Integrated assessments like those done here help identify specific policy instruments that will improve conservation and human well-being under these rapidly changing conditions.

## ACKNOWLEDGEMENTS

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