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Modelling the impacts of group ranch subdivision on agro-pastoral households in Kajiado, Kenya

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Abstract

Pastoral communities in East Africa are facing considerable challenges arising from shifts in land tenure policy from communal to individual landholdings and high human population growth rates. Over the last 30 years, livestock-to-human ratios have generally declined to levels that will no longer support pure pastoralism. Many Maasai have thus diversified into cultivation, wage labour, and small businesses. Livelihood expectations are rising, with concomitant increases in the need for cash. We describe the modification of PHEWS, a simple rule-based model that tracks cash flow and calories in agro-pastoral households. We use it, coupled to Savanna, a sophisticated ecosystem model, to quantify some of the effects of subdivision and land fragmentation on household livestock numbers and on food security. For the group ranches simulated, model outputs indicate that subdivision results in substantial reductions in livestock numbers, partially because households have to sell more animals to generate the cash needed, with serious long-term consequences on herd sizes and food security. If subdivision occurs, even to parcels as large as 196 km^2, livelihood strategies may need to be modified to maintain current levels of household well-being. Model results have been discussed

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in community meetings in southern Kajiado, but more work is needed on communication mechanisms to utilise more effectively the results of imperfect but useful integrated assessments of complex problems concerning land use and human well-being.

Keywords: Savanna; Household model; Kajiado District; Subdivision

1. Introduction

Pastoral communities in East Africa are facing considerable challenges arising from shifts in land tenure policy from communal to individual landholdings and high human population growth rates and in-migration rates (Galaty, 1994; Kristjanson et al., 2002). These and other factors have led to expansion of cultivation and growth in the number of permanent settlements, sedentarisation, and diversification of land-use activities around wildlife conservation areas, which have contributed to more human–wildlife conflicts (Western, 1982; Ellis et al., 1999). Some of the consequences of these changes are declining ecological, economic and social integrity of rangelands because of fragmentation of landscapes, declining rangeland productivity, truncated wildlife migratory corridors, declining wildlife populations and diversity, and cultural and economic diversification arising from immigration (Gichohi et al., 1996; Ellis et al., 1999).

In East Africa, pastoralists and wildlife have co-existed for tens of thousands of years. Today income from wildlife and tourism is an important livelihood option for some pastoral communities. The threats posed to the conservation of wildlife are thus intimately linked with low and variable income levels, and with the increasing poverty and food insecurity being witnessed in these areas (Kristjanson et al., 2002).

In the Maasailands of East Africa, the linkages between pastoral communities and the wider national economy continue to grow. The roots of this exist in the history of land tenure and policy changes in these areas. Briefly, communal trust land became freehold title land through adjudication from the late 1960s to the 1980s in Kenya, in an environment in which private tenure was considered to be a foundation of economic growth (Bekure et al., 1991). This paved the way for the formation of group ranches, because many Maasai feared that land adjudication would adversely affect the territorial integrity of Maasai rangelands (Rutten, 1992; Kimani and Pickard, 1998). Fifty-two group ranches were incorporated, encompassing 75% of Kajiado District (Bekure et al., 1991; Rutten, 1992). While pastoralists never bought into the foundations of commercial livestock management, continuing to manage their herds largely based on subsistence strategies and movement of their livestock across group ranch boundaries when climatic conditions demanded it, group ranches did stimulate the public and private development of livestock infrastructure (water points, pipelines, stock dipping tanks) as well as human infrastructure (schools, health care centers, and shopping areas) (BurnSilver, 2005).

Before group ranch incorporation was complete, however, dissolution of group ranch titles and subdivision of rangelands into private parcels for registered members began. This occurred for various reasons, including problems associated with group ranch management and concerns of younger members over long-term access to resources. Kenyan government policy initially did not support subdivision because of concerns that individual parcels would not be economically and ecologically viable (Bekure et al., 1991), but by the early 1980s this had changed, primarily because of a feeling that the process was too far along to avert. By 1990, forty of the original 52 group ranches had subdivided or were in the process of doing so (Rutten, 1992; Kimani and Pickard, 1998).

At the same time, the population of pastoral districts was growing rapidly because of both natural population growth and dramatic increases in numbers of immigrant agriculturalists. The population of Kajiado District in 1979 was 149,000, of which 63% were Maasai, while by 1999 it was over 306,000 (GoK, 2001). The livestock population has remained relatively constant over this period, and livestock-to-human ratios in general have declined to levels that will not support pure pastoralism. Many Maasai have thus diversified their activities into cultivation, wage labour, or starting some type of small business. Livelihood expectations are rising, in terms of education, clothes, and foodstuffs, with concomitant increases in costs of production and in the need for cash. Cash needs are generally met through livestock sales; a gradual increase in offtake levels has been observed, although offtake rates continue to fluctuate dramatically according to drought cycles (Rutten, 1992; Kristjanson et al., 2002).

Against this background, we carried out work under a project called POLEYC (Policy Options for Livestock-based livelihoods, and EcosYstem Conservation). The objective of POLEYC was to provide useful information to decision makers (both pastoralists themselves and national policy makers) regarding the potential advantages and disadvantages associated with specific management options in areas of East Africa where there is conflict or potential conflict between wildlife and pastoral land use. The goal was to promote management options that balance the needs for wildlife conservation, human well being and ecosystem sustainability. In this paper, we outline a coupled ecological and household model for Kajiado District, Kenya. We present and discuss the results of various scenarios run with the model whose aim was to quantify in broad terms some of the impacts at the household level of subdivision of group ranches and restricted access to grazing resources, primarily with regard to household cash flow and food security.

2. Kajiado District, Kenya

Kajiado District is a semi-arid landscape in the shadow of Mount Kilimanjaro, with extensive bushlands in the northern part of the district and bush and grasslands to the south. The study site is the southern portion of the district. To the east are the Chyulu Hills, containing the Chyulu Hills Conservation Area. The grassy slopes of the hills are important dry-season grazing areas for livestock owned by resident

Maasai. West of the Chyulu Hills, a pipeline runs from north to south, transporting water from the slopes of Mount Kilimanjaro to areas around Nairobi. The pipeline is an important water source for people, livestock, and wildlife. To the south are swamps that provide critical short-term grazing for livestock and wildlife and water for pastoralists; the swamps also support irrigated cultivation at their margins. Kajiado District contains Amboseli National Park, in the south-central part of the study area. Amboseli is a small (392 km^2) conservation area encompassing several swamps fed by underground springs flowing from Mount Kilimanjaro. Wildlife disperse into lands used by Maasai for grazing livestock during the wet season, then congregate in Amboseli to access the permanent water sources in the dry season. Semi-arid areas such as Kajiado District are characterized by variable rainfall within and between years, including recurrent droughts. The CV of annual rainfall from 1969 to 1998 was 27% (Boone et al., 2005). In the past, Maasai pastoralists were mobile, relying upon moving their livestock over very large areas of land to access adequate forage and water resources.

Kajiado District is characterized by high levels of poverty. Recent sub-district level poverty estimates show that Kajiado District has areas with higher rates of poverty than the Kenyan national average (53%), on a headcount basis (GoK, 2003). In addition, the poverty in Kajiado tends to be relatively deep (many people are substantially below the rural poverty line of KSh 1239 or about US$16 per adult equivalent per month). It should be noted that this poverty measure is based on a consumption basket of both food and non-food items that are considered to meet the basic needs of most Kenyans. Consumption items such as blood from livestock or locally gathered roots and berries, that have traditionally been a part of the Maasai diet, are not captured, and so the actual consumption levels may be slightly underestimated for pastoral communities. There is substantial spatial heterogeneity in poverty rates in Kajiado. Location-level (fourth administrative unit below the national) poverty rates range from 11% to 68%. In 21 out of 45 of Kajiado's Locations, over 50% of the population is living below the poverty line, and three Locations have poverty rates above 60%.

3. Methods

The POLEYC project sought to carry out an integrated assessment balancing land-use needs in this area. As part of the work, multiple workshops were carried out in which Maasai, land managers such as members of the Kenya Wildlife Service, conservation scientists, and other stakeholders were asked to identify what they considered to be the most pressing land-use issues. The issues defined by the different interest groups overlapped to a considerable extent. Landscape fragmentation and sedentarisation were the issues of greatest concern to participants – subdivision is a contentious and hotly debated issue. Many participants felt that subdivision is inevitable – the political, tenurial, and social pressures to subdivide are simply too great to withstand. Accordingly, much of our effort at integrated assessment concentrated on the issues of landscape fragmentation and sedentarisation, focusing on mimicking the potential effects on pastoral well-being and livestock of confining herding households to successively smaller and smaller land areas. Other issues of concern voiced at the workshops included livestock disease and conflicts between wildlife, livestock, and humans. Further work is currently being carried out on modelling disease and wildlife issues. In the scenarios described here, however, disease pressure was assumed to be constant.

3.1. The Savanna model

An extensive programme of field-based studies was undertaken in southern Kajiado, in part to provide information for model validation and calibration. These studies were supplemented by analyses of remotely sensed data. We used the Savanna Modeling System to quantify effects of fragmentation on livestock and wildlife. Savanna is a spatially explicit computer simulation model that predicts forage production and quality based upon spatial data layers and settings that describe how plant populations grow (Coughenour, 1993). It was originally developed for pastoral areas of northern Kenya, and has subsequently been adapted and applied in other areas of East Africa, the USA, Asia, and Australia. In Savanna, populations of livestock and wildlife are modelled, including their growth, reproduction, and nutritional state (Ellis and Coughenour, 1998). Boone et al. (2002) provide an example of the use of Savanna from nearby Ngorongoro Conservation Area (NCA) in northern Tanzania, and Boone and Coughenour (2000) describe the model in some detail. Depending on the situation being modelled, Savanna can represent either strong or weak links between grazing animals and vegetation. Given that it is a process-based model, Savanna should be able to contribute to the ongoing debate concerning equilibrium and disequilibrium in rangeland systems (see, for example, Illius and O'Connor, 1999; Sullivan and Rohde, 2002), but in the debate itself, it is essentially neutral. In the Kajiado application of Savanna, seven plant functional groups are simulated: palatable grasses, palatable forbs, unpalatable grasses and forbs, swamp vegetation, palatable shrubs, unpalatable shrubs, and deciduous woodlands. Nine animal functional groups are simulated: wildebeest, zebra, buffalo, grazing antelope, browsing antelope, elephant, cattle, sheep, and goats. Grazing antelope include Grant's gazelle, Thomson's gazelle, impala, kongoni, oryx and waterbuck. Browsing antelope include eland, great kudu, lesser kudu, and gerenuk. Details of the Savanna application for Kajiado, and issues relating to input data and calibration, are given in Boone (2003) and Boone et al. (2005).

3.2. The household model

Joined to the Savanna model is PHEWS (Pastoral Household and Economic Welfare Simulator). This household model was originally developed and calibrated for the NCA, and the construction and use of that version is described in Thornton et al. (2003). The situation in Kajiado District is very different from NCA; households are generally much more diverse in their economic activity, and they tend to be much better linked to local markets. PHEWS still tracks the flow of cash and dietary energy in agro-pastoralist households using a simple set of rules, but it had to be extensively adapted for Kajiado, primarily in relation to some of the rules used and to being able to handle a larger number of household types. The next sections summarise the structure of the model.

3.2.1. Household types

The study area was the southern part of Kajiado District (Fig. 1). Detailed field work in 1999 and 2000 was carried out in four of the group ranches in the region (Osilalei, Eselenkei, Olgulului/Lolarashi, and Imbirikani), across six study areas: Osilalei (OS), Eselenkei (ES), Lenkisim (LE), Emeshanani (EM), South Imbirikani (SI), and North Imbirikani (NI) (BurnSilver, 2005). Subsequently, the entire study area was divided into six areas that were deemed to be similar to these group ranches in household practices (the Lenkisim area corresponding to the southern portion of Eselenkei Group Ranch, and the Emeshanani area corresponding to Olgulului/Lolarashi Group Ranch and the areas to the west and south of Amboseli National Park, Fig. 1). Another area was added to these six, the Loitokitok slopes, where households practise relatively extensive highland rainfed agriculture on the slopes of Kilimanjaro. Many households with plots on the Loitokitok slopes have livestock elsewhere in the study area.

The decision making unit in the model is the extended household associated with one *olmarei*, corresponding in Maasailand to a male head of household and his dependents (i.e., wives, children, married sons and their families). This approach was used because the variation within the next unit up in the hierarchy, the *boma*, which describes multiple *olmarei* living together in one compound, would have been excessive. Thus in what follows, the word "household" refers to the household of one Maasai elder, and there may be multiple extended households per *boma*.

From her field data, BurnSilver (2005) identified five basic household economic activities:

- All households have some livestock (L). This may be all that some households do.
- Some households engage in additional economic activities that are summarised in the model under the rubric "livestock trading", denoted B (for Business).
- Some households engage in rainfed agriculture, growing mostly maize and beans for home consumption (R).
- Some households have irrigated plots of land near the pipeline or in the swamps, where they may grow maize and beans, potatoes, and vegetables such as onions and tomatoes, primarily for sale (I).
- Other households have access to agricultural land on the slopes of Kilimanjaro, which is here referred to as Loitokitok agriculture (K).

The survey results of BurnSilver (2005) suggested that these five basic economic activities (L, B, R, I, K) could be combined in various ways to produce eight clusters of household type in the study area. In the model, the household types are modelled in an additive way. Each of the five activities is treated at three levels of intensity to correspond with three wealth levels (poor, medium and rich), and then these are combined to form the 24 household types (8 strategies $\times$ 3 wealth levels) that the

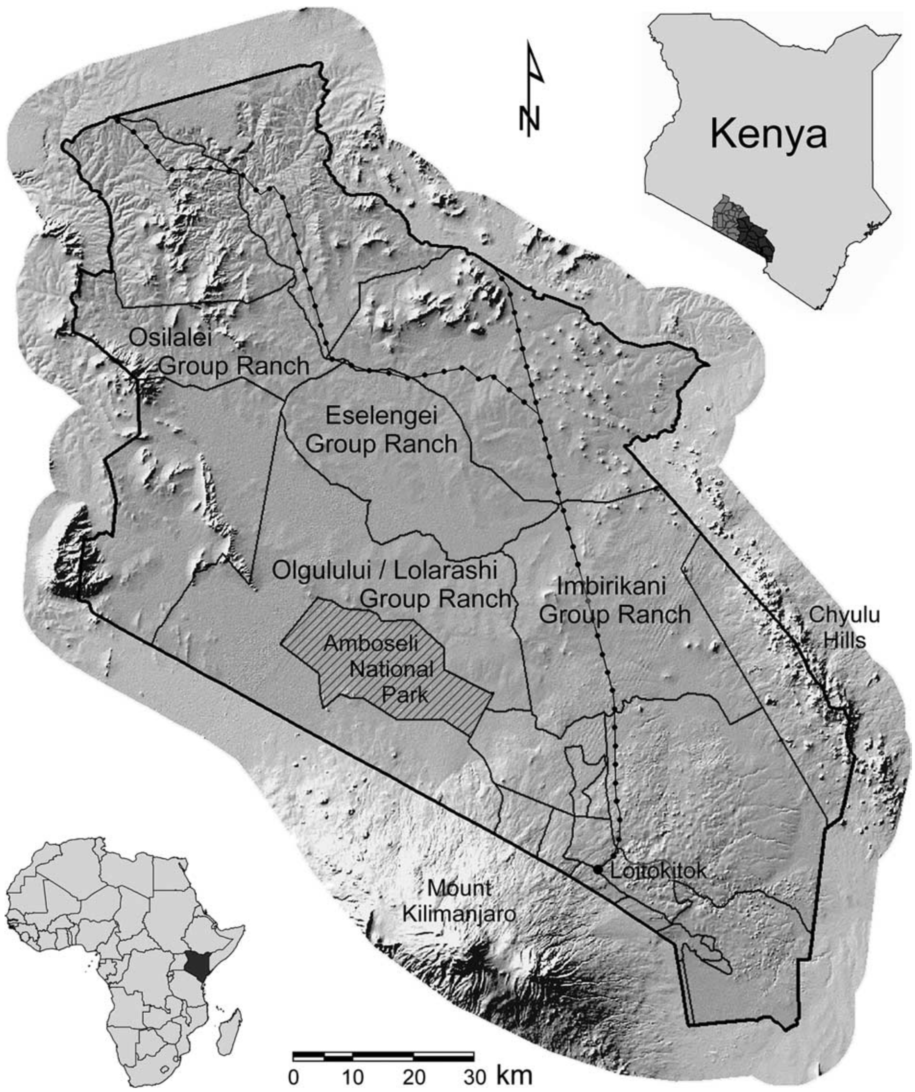

Fig. 1. The study area, showing the location of group ranch boundaries. Topography is in shades of gray; the pipeline is shown as the spotted line; location of the study area and the entire Kajiado District are shown in insets.

model currently handles. These are shown in Table 1, with relative proportions of each household type in each of the six study area. Thus the Osilalei-like area is made up of 68% LR households (livestock and rainfed-agriculture), 1% LBI households (livestock, business and an irrigated plot), and 31% LBR households (livestock, business and a rainfed plot). The relative proportions of household types in each of the six focal study areas as identified by BurnSilver (2005) are assumed to be the same throughout the whole study area.

Table 1
Distribution of household types (percentages) in the six study areas in southern Kajiado District (data and analysis from BurnSilver, 2005)

Household type	Study area						
	Osilalei	Eselenkei	Lengisim	Emeshanani	North Imbirikani	South 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	2	0	12
LBK	0	1	1	12	8	3	4
Total	100	100	100	100	100	100	100

L, livestock; B, business; I, irrigated agriculture; R, rainfed agriculture; K, Loitokitok slopes agriculture.

It should be noted that PHEWS is still not a spatially explicit model. A poor livestock-only household in Osilalei is, in the model, no different at the start of any simulation run from a poor livestock-only household in Eselenkei. The mix of household types differs between areas, and thus the weighted results of the model are spatially explicit in that sense. This is a limitation that will be addressed in future versions of PHEWS, and is discussed further below. A further limitation of this version of PHEWS is that no transition from one household type to another is possible, i.e., if a household is classified as "poor" at the start of a simulation, then it remains poor for the duration of the run. This limitation is also being addressed in subsequent versions of the model, so that households can evolve through time, in terms of the livelihood options that the households engage in.

In terms of the number of people per household, in the model this is stratified on the basis of wealth level. BurnSilver (2005) found an average of 20.7 people per household and 13.8 adult equivalents (AE) for rich households, 14.4 and 9.9 AE for medium households, and 9.8 and 6.8 AE for poor households, and these numbers are used in the model. The model needs age–sex distributions to calculate caloric requirements. As there was insufficient detailed information on age–sex distributions, we adjusted the distributions (in seven categories: those under 2 years of age, from 2 to 6 years, 7 to 12 years, males 13–17, females 13–17, adult males, adult females) to match the household data of BurnSilver (2005). It is noteworthy that the proportion of infants and children under 6 years of age in these households is generally much greater in Kajiado (55–61% of the household, depending on wealth level) than in Maasai households in NCA, where detailed sex–age data were collected (37–48%, depending on wealth level) (Thornton et al., 2003). Currently, the number of members in each household is kept constant throughout a simulation run of the model.

BurnSilver's (2005) survey data indicated that, based purely on livestock holdings, 23% of households were classified as rich, 29% as medium, and 48% as poor. Using the 1999 census data for Kenya (GoK, 2001) and estimates for the number of people on group ranches, we estimated that there were just under 52,000 in the study area in

1999. This is necessarily approximate, as the census administrative boundaries do not coincide with the group ranch boundaries. With this population, and the above wealth proportions and household size, this gives a total of 3820 households in the study area (defined as above), with a mean size of 13.6 people per household.

3.2.2. Household access to resources

In PHEWS, input data to specify household resources are specified on the basis of the proportion of those resources used by rich, medium and poor households. This allows the number of households in the landscape to be varied without having to rebalance the input data for each of the 24 household types. A certain amount of trial and error was required to fully specify all household types. For example, consider the size of rainfed plots for households with this resource. Given 3820 households in the landscape, and multiplying by the appropriate proportions of wealth levels, this equates to a total of 900 ha of rainfed land in the study area. The survey data indicated that rich households have rainfed plot sizes of 0.95 ha (BurnSilver, 2005), and this plot size was used for rich households in the model. The same process was gone through for all land types and to estimate herd sizes by wealth level. In most cases, resource levels by wealth level in PHEWS compare closely with the household survey data, except for the number of sheep and goats per household. The cause of this disparity is not known, but may be due to problems in the total livestock population estimates used in Savanna, which were derived from aerial surveys (Boone et al., 2005) and/or in the household survey data. Livestock numbers in the model were chosen so as to match the total livestock population estimates used in Savanna (some 235,900 cattle; 99,400 sheep; and 106,700 goats).

Taking all this information together, household characteristics are shown in Table 2, by household type (i.e., by set of livelihood strategies).

3.2.3. Household food security

PHEWS tracks calories in households. The rules determining the make-up of diets are similar to those described in Thornton et al. (2003), but there is only limited information concerning household diets in Kajiado, so the rules here are dependent to some extent on those applying to Maasai households in NCA. Households, depending on their activities and resources, will at various times of the year have access to the following:

Table 2
Land resource and herd size characteristics by wealth level and livelihood strategy for the control run

Household type	Herd size (number)			Plot size (ha)		
	Cattle	Sheep	Goats	Irrigated	Rainfed	Loitokitok
Poor	16.7	8.1	8.7	0.7	0.5	1.6
Medium	53.2	26.9	28.9	0.7	0.7	2.4
Rich	166.5	62.2	66.8	1.1	0.9	3.2

1. Milk produced by their cattle herds.
2. Tea and sugar, which in Maasai culture together make up a significant proportion of caloric intake; these have to be purchased, of course.
3. Meat produced by their own herds.
4. Their own maize and beans produced from agricultural plots.
5. Their own vegetables, provided that these are grown and not all of them are sold.
6. If they have money, households can purchase maize or other sources of calories.

If households do not have adequate cash, then household intake either has to be reduced that month, or the calories have to come from sources external to the household. In what follows, these are called "external" calories, and may refer to gifts from friends and relatives, animal or grain exchanges, or drought relief. The proportion of external calories in the diet of the household is a key output of the model, and is used as an indicator of food security in model results.

In the model, the above list is the order in which calories are treated. For each month, the household caloric requirement is calculated, based on the age–sex ratios, the number in each group, and the caloric requirement for each group. As for the NCA model, we used 80% of the WHO values (WHO, 1995), except that recent nutritional data of Galvin (personal communication) indicate that adult females are somewhat better off in Kajiado than in NCA. We thus increased the adult female requirement to match that of a young female to take account of this (i.e., from 1741 kcal per day to 1943 kcal per day). No distinction in made in dietary preferences between age–sex categories.

Milk production from cows in the model is calculated according to the condition of adult lactating females, to a maximum of 1.2 l per day in the wet season and 0.6 l per day in the dry season. There is a great deal of uncertainty concerning Maasai milk offtake as reported for human consumption, but the values are certainly in the range reported (see Bekure et al. (1991), for example), and are rather higher than those found by BurnSilver (2005).

Tea and sugar calories make up a significant proportion of the diet in Maasai households. BurnSilver (2005) estimated the amounts spent on tea and sugar in the survey, and these are stratified by wealth level – from KSh 142 per AE per month for poor households to KSh 153 per AE per month (US$1.85–2.00) for medium and rich households. If there is not enough cash in the household to purchase tea and sugar in any month, then (as for the case of NCA, where they make up about 8% of all calories in all households) it is assumed to be donated to the household (Galvin and Thornton, 2001).

Meat calories come from dead or dying animals that are edible (i.e., that did not die of anthrax or other diseases that render the animal inedible), and from probabilistic slaughter that is set as an input, with a fixed probability each time period. This reflects the fact that Maasai households kill animals for ceremonial or festive purposes periodically.

Cropping is divided into three commodities: maize, beans, and vegetables, which are represented in the model by tomatoes and onions. All of these may be for home consumption or for sale, or some mixture of the two. Depending on the land

Table 3
Cropping characteristics in agricultural plots in southern Kajiado (data from BurnSilver, 2005)

	% of area in maize	% maize sold	% of area in beans	% beans sold	% of area in vegetables	% vegetables sold
Rainfed plots	50	20	50	20	0	–
Irrigated plots	25	0	10	0	65	94
Loitokitok plots	48	20	52	20	0	–

resources available to households, these cropping enterprises are operated at different levels of intensity, with different levels of inputs. Table 3 shows the cropping and consumption patterns used in the model, slightly simplified from the data collected by BurnSilver (2005). Share cropping in areas of irrigated cultivation is common. To take account of this and its impact on household income, crop prices in the model are appropriately modified. For example, BurnSilver (2005) found that 13% of total households are engaged in rainfed share cropping, so given that 50% of rainfed beans are sold, the price expectation per household for beans is 94% of the market price.

If households still need calories, then these are purchased, if there is enough cash in the household. If not, then as much maize is purchased as is possible. The calorie needs still not met are the external calories referred to above, and these calories would normally come from gifts and exchanges, and in drought situations, from government relief sources. In any case, the amount of external calories needed each month is a useful and sensitive indicator of household food security.

3.2.4. Crop management

In the model, there are two cropping seasons per year, from September to December and from March to June. In terms of assigning crop inputs on a household basis, it can be expected that there will be wealth-level differences between households (i.e., richer households could be expected to spend more on crop inputs than poorer households). The survey data, however, showed enormous inter-household variability in this regard. Accordingly, the survey means were used as a guide, and crop input expenditures (on seed, fertiliser, etc.) were assigned that were plausible, given total household income, and that increased according to wealth. These costs were also increased according to intensity of production: total costs for rainfed plots were lower than for Loitokitok plots, which were themselves somewhat lower than for irrigated plots.

The survey data also indicated considerable inter-household differences in yields. In PHEWS, for simplicity, crop yields are linearly related to rainfall over the growing season. From the survey, average maize yields for rainfed, irrigated and Loitokitok plots were 606, 1245 and 1722 kg per ha, respectively (BurnSilver, 2005). Ramp functions were fitted to match these means to rainfall received. As noted above, produce prices are adjusted for share cropping arrangements. At harvest, the appropriate portion for sale is sold off immediately. For crops that are home consumed, the harvested crop is available to the household in diminishing proportions over the subsequent three months. While it is to be expecte that maize prices will generally increase in seasons of low rainfall and/or low maize production, thus far we have not been able to find adequate local price data from Kajiado that would enable this effect to be simulated realistically. In addition, no account is taken of the labour, time and energy that households put into cropping. Even though plot sizes are generally small, in relation to the average number of people in the household, further development of PHEWS will need to deal with labour issues.

3.2.5. Livestock management

All households have recurring monthly veterinary costs. The survey data were used to calculate these directly, and amount to KSh 670, 975 and 1460 per month (US$8.70, US$12.70 and US$19.00) for poor, medium and rich households, respectively.

Animals are sold in relation to a cash need. In each iteration of the model, the expected need for cash is calculated for the coming three months, and this is offset against expected income and the existing cashbox. The initial choice of three months was somewhat arbitrary as a household medium-term time horizon, but subsequent sensitivity analysis showed that model results changed very little whether this was one month, three or six. For a small cash need (defined currently as less than KSh 1200 or about US$15.60), a sheep or goat is sold. If the cash need is larger than KSh 6000 (about US$80), a large ruminant is sold and, following the results of the survey, a sheep or goat is bought at the same time. The survey data were also used to set up rules concerning what type of animal to sell or buy, and cumulative probability functions were constructed for buying and selling animals, in terms of the livestock categories simulated in Savanna (pre-weaning, immature male and female, mature male and female). For example, if an animal is purchased, the probability is 0.3 that it is a mature female sheep, and 0.7 that it is a mature female goat.

3.2.6. Cash flow

Cash flow is tracked in each of the 24 household types each month. Income arises from any wage income, livestock trading, and other business; and from any sale of milk, of crops, and of livestock. The survey data indicated that, generally, milk is sold by households involved in irrigated agriculture and that are in close proximity to non-livestock owning immigrants who are also settled near the swamps, and then sales occur only in the wet season. This is taken into account in PHEWS. Wage income was calculated from the survey data and transformed to a per AE basis. This varies by wealth level, and in the model is fixed between different household types of the same wealth level. Livestock trading income was also calculated from the survey data, and again varies by wealth level. Monthly sources of expenditure include tea/sugar, crop inputs, veterinary inputs, and general expenses including school fees.

All households' cash flow is calculated each iteration, and spare cash sits in a cashbox for consumption in subsequent time periods. Costs and prices were taken from data collected in late 2002 and early 2003 from a number of markets in Kajiado (K. Kimani, personal communication), and the values used in the model are averages that hide considerable variability.

3.3. Scenario analysis

Once PHEWS had been linked to Savanna, some calibration was carried out. Given the considerable uncertainty associated with many of the input data, and partly because of the large number of household types, calibration was carried out in relation to two premises. First, all households would occasionally have to sell animals at some stage, and some would have to sell many in order to meet their expenditure objectives. Second, all household cash flows were to oscillate between reasonable limits, but no household's cash levels were to fall to zero and stay there, nor were they to increase upwards continually. Thus it was important that household expenditures balanced household income fairly closely. The major "instruments" with which to calibrate the model were the thresholds for defining cash needs (large and small), and the monthly general expenditure (including school fees) per household per month.

Calibration was carried out in relation to the "baseline scenario". This was essentially a control run that attempted to simulate current conditions. The control run was simulated over 24 years, using weather from 1977 to 2000, at a resolution of 2.5 km^2. "Resolution" refers to the size of individual pixels that Savanna uses in its simulations. The original calibration of Savanna for the entire study region was done at the same resolution (Boone et al., 2005).

To investigate the broad impacts on households of different subdivision options available to decision makers, we carried out a series of scenarios for four of the group ranches in the study region: Osilalei, Eselenkei, Imbirikani, and Olgulului/Lolarashi. Their locations are shown in Fig. 1. Runs were done over 24 years as before, initially at a resolution of 1 km^2. As the areas being simulated were subsections of the entire study area, we were able to increase the resolution of the run compared with the baseline (a major constraint to the feasibility of higher-resolution model runs is the time required for their completion – typically one to two hours per simulation).

We then ran a scenario to investigate the option of maintaining intact grazing blocks within group ranch territories as an alternative to straightforward privatisation of group ranch territories. To do this, an area of 196 km^2 within each group ranch was randomly chosen (from about 12% to 36% of the land area of each group ranch), and household density and resources were recalculated to match the baseline situation. The simulation was then run over 24 years as before, but this time with only 196 km^2 of land available for grazing to the number of wildlife, cattle, sheep and goats scaled linearly based on area. This process was replicated five times for each group ranch, and the results averaged.

Although the finest scale of resolution possible for Savanna is 1 km^2 (100 ha), this is four times the average parcel size that most households could expect to receive during subdivision. For the 1-km resolution scenarios outlined above, household densities and household resources were recalculated for each group ranch, based on a household density coverage derived from satellite images and ground truthing. Thus the only differences with the control run was the resolution of the Savanna simulations and the grazing resources available to livestock and wildlife – these were much reduced, in effect. As noted above, PHEWS (though not Savanna) in these runs was operating on aggregated areas, and the reason that subdivision effects were visible at the household level was because of their impacts on the ecology of the system, and hence on livestock.

Pastoralists in southern Kajiado see the Chyulu Hills (Fig. 1) as a key resource for pastoralists for dry-season grazing, and this importance crosses group ranch and Maasai territorial boundaries (BurnSilver, 2005). Yet, one of the subdivision options being considered by decision makers in Imbirikani group ranch is to parcel out areas of the hills for highland rainfed agriculture, similar to that which is being carried out in the Loitokitok area (BurnSilver, 2005). The Chyulu Hills cover some 25,000 ha. In the control run, livestock across the region had access to these hills for three months per year. We also ran a scenario with the model that prevented livestock having any access to these hills all year round.

Finally, we carried out a series of simulations to look at the viability of households dealing with the loss of the Chyulu Hills grazing lands by increasing the size of their cropping plots. In these runs, the size of rainfed plots for LR and LBR households was successively increased, to see what impact this might have. It should be noted that there are no prospects for increasing the size of irrigated plots in the region, as all the swampland and irrigated land is already being used. Scenarios were run for the standard plot size (as shown in Table 2: 0.5, 0.7 and 0.9 ha for poor, medium and rich households, respectively, or a total of 900 ha for the study region), and for doubling, trebling and quadrupling these plot sizes.

Savanna and PHEWS can produce a great deal of output, but the major outputs of interest for the household model were the average percentage of external calories (as defined above) per month over the 24 years of each run, the number of TLU per AE in the household and how this changed during the course of the run, the overall average percentage of food produced by the household (livestock and cropping), and the overall percentage of consumption satisfied (i.e., the average monthly proportion of desired household cash expenditure that could be met by the household). Despite the fact that in some important respects, PHEWS is not fully dynamic (households cannot evolve from one type to another through the accretion of wealth, for example, and household numbers are static), these metrics are all highly sensitive to simulated conditions, and integrate a great deal of information from each simulation, while at the same time hiding much of the temporal variability that occurs within any simulation run. Although wildlife herds were being simulated during all runs with Savanna, and these were interacting with the livestock herds, the results below concentrate on household impacts. Wildlife benefits and interactions are not dealt with explicitly here, although these issues are being addressed through other modelling activities.

The results of the scenario analyses carried out with Savanna-PHEWS were subsequently presented to stakeholders in Kajiado in the middle of 2003, through a series of community meetings, with scenario results translated into Maa, the Maasai language.

4. Results

4.1. The control run

For the control run, the total cattle, sheep and goat herd sizes fluctuated as shown in Fig. 2. The strong wet-dry season response is particularly noticeable. Results of the household model are shown in Table 4, stratified by wealth level, and weighted by household type. The results show clearly that most households needed some external calories at some stage during the simulation. For most households, the call on these occurs in specific months, and the proportion, even for poor households, is not great. This can be compared with the situation in NCA, where external calories accounted for approximately 15% of all calories in poor households (Thornton et al., 2003).

To give an idea of the variability of model output in any run, Fig. 3 shows the observed annual rainfall for the base weather station, the simulated fluctuation in cattle numbers in a poor, livestock-only (L) household, and the simulated annual proportion of external calories in the household, averaged across months. In such a household, the monthly proportion of external calories varies considerably; for the control run, during the months of February and March, for example, the household was free of any calls on external calories, while the mean proportion needed in May was 21%. As might be expected, there are no simple relationships between rainfall, simulated cattle numbers and proportion of external calories in Fig. 3, although some association can be seen between the very low (observed) rainfall in 1983, which may have resulted in the reduced cattle numbers simulated in the household in 1984 and 1985, and a sharp increase in the average monthly proportion of external calories to 10% simulated for 1985 and 1986.

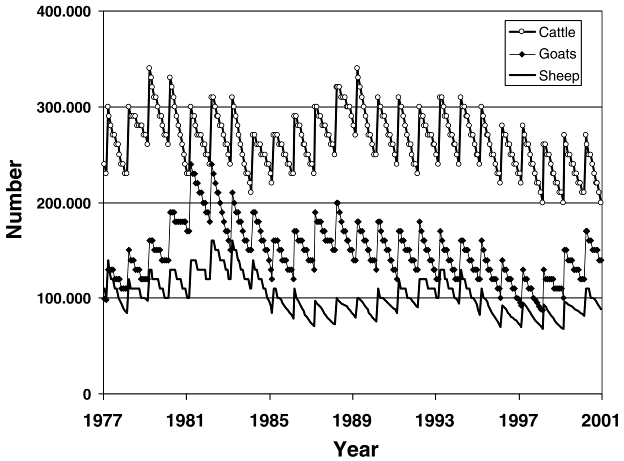

Fig. 2. Simulated evolution of total herd sizes for cattle, sheep and goats, control run, 1977–2000, southern Kajiado.

Table 4
Results of the control run over 24 years, weighted by relative occurrence of household types

Household wealth	Dietary makeup, %						Sales income[a], KSh per year	Food purchases[b], KSh per year	Own food available, %	Average TLU per AE
	Milk	Own crops	Meat	Other, including sugar	Purchased grain	External (i.e. gifts, relief)				
Poor	14	6	12	8	54	6	6,112	10,077	32	1.9
Medium	24	4	12	9	48	3	9,364	8,417	40	4.3
Rich	30	5	12	9	43	2	8,357	9,294	46	9.0

US$1 ≈ KSh 77 in late 2003.
[a] Average total sales of milk, crops and livestock per year.
[b] Average annual expenditure on food per household.

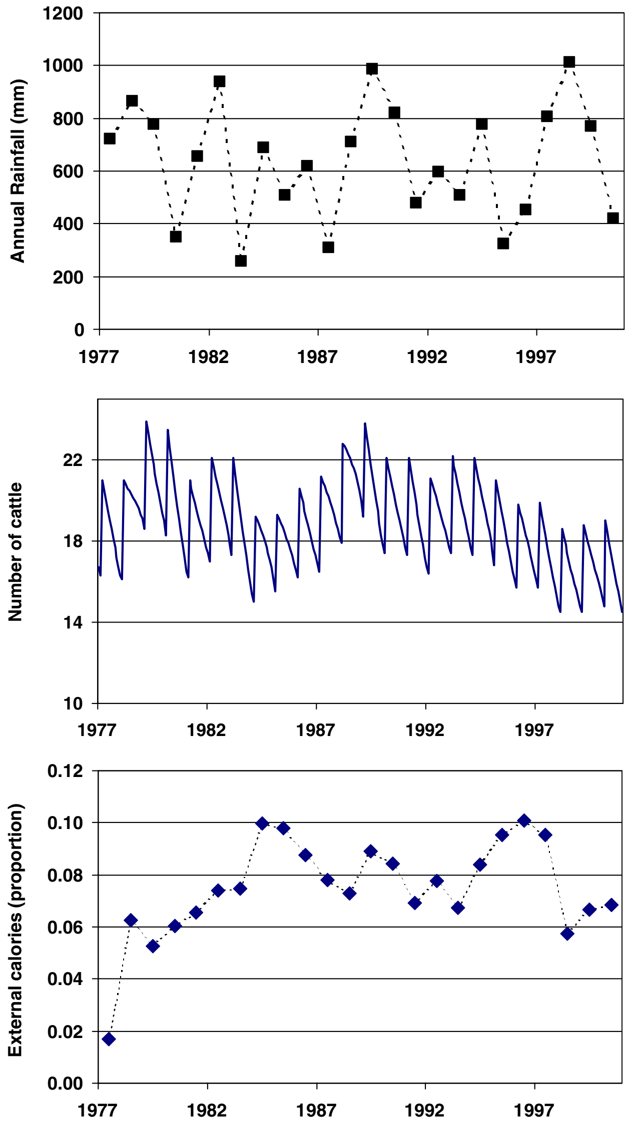

Fig. 3. Control run, poor livestock-only (L) household. Top: Observed annual rainfall at the Savanna base weather station (Makindu, Kajiado District), 1977–2000. Middle: Simulated monthly evolution of number of cattle in the herd. Bottom: Simulated average annual external calories as a proportion of all household calories.

For all households in the landscape, between 30 and 46% of calories are home-produced. It is only the rich households that could in theory sustain a purely pastoral way of life, with TLU per AE at about 9. Most households do other things, as herd sizes are simply not large enough to sustain the large numbers of people per household. Poorer households have to spend more income, in absolute terms, on food to satisfy their caloric requirements.

In general, the more diversified the household, in terms of the activities undertaken, the better off the household. Table 5 tabulates household indicators for the control run stratified by wealth, broken down by whether the household is engaged in one, two or three economic activities. The proportion of external calories decreases, and the proportion of consumption satisfied increases, as the portfolio of household activities gets larger. The same indicators are shown in Table 6 broken down by type of cropping. Interestingly, rainfed cropping appears to have a slightly adverse impact on long-term household food security, in terms of the proportion of external calories required. This is because rainfed cropping in Kajiado is highly risky, and despite the expenditure of cash on crop inputs each year, returns (in terms of household food calories) in some years will be very low or zero. Irrigated cropping has a highly beneficial impact on household well-being, with Loitokitok rainfed cropping somewhere in between these two extremes, as Loitokitok yields, though still highly variable, are generally higher than the lowland rainfed yields. Model results suggest that the option of not cropping at all (29% of households) slightly outperforms rainfed cropping, in terms of the two indicators shown, because the business activity in half of the non-cropping households provides income that can be spent on food and other items; and although some home-grown calories are foregone in livestock-only households, the risk associated with crop inputs failing to produce any cash or calories for the household is avoided.

4.2. Broad impacts of group ranch subdivision on households

In a series of runs with the Savanna model without the household model, Boone (2003) found that about the same numbers of livestock could be supported on 196-km^2 parcels as on intact group ranches, ecologically speaking. Model experiments with smaller subdivided areas showed that livestock numbers can decline substantially. For example, when Eselenkei group was fragmented into 1 km^2 parcels, 25% fewer livestock could be supported on the entire group ranch, compared with

Table 5
Impact of diversification on key household indicators, control run over 24 years, weighted by relative occurrence of household types

Household wealth	One economic activity (L)		Two economic activities (LI, LB, LR, LK)		Three economic activities (LBI, LBR, LBK)	
	External calories in the diet, %	Proportion of consumption satisfied, %	External calories in the diet, %	Proportion of consumption satisfied, %	External calories in the diet, %	Proportion of consumption satisfied, %
Poor	8	95	6	97	4	100
Medium	4	98	3	98	3	100
Rich	2	98	2	99	2	100

L, livestock; B, business; I, irrigated agriculture; R, rainfed agriculture; K, Loitokitok slopes agriculture.

Table 6
Impact of different types of cropping on key household indicators, control run over 24 years, weighted by relative occurrence of household types

Household wealth	No cropping (L, LB)		Rainfed cropping (LR, LBR)		Irrigated cropping (LI, LBI)		Loitokitok cropping (LK, LBK)	
	External calories in the diet, %	Proportion of consumption satisfied, %	External calories in the diet, %	Proportion of consumption satisfied, %	External calories in the diet, %	Proportion of consumption satisfied, %	External calories in the diet, %	Proportion of consumption satisfied, %
Poor	7	97	9	97	2	100	5	99
Medium	4	99	5	98	1	99	3	99
Rich	2	99	4	98	0	100	1	98

L, livestock; B, business; I, irrigated agriculture; R, rainfed agriculture; K, Loitokitok slopes agriculture.

the situation in which the ranch was not subdivided. The basic reason for this effect is that livestock in larger areas benefit from access to widely dispersed grazing patches consisting of different vegetation communities, which are exposed to heterogeneous weather effects (Boone et al., 2005). However, this effect is highly dependent on the inherent productivity of the area being subdivided. For the more productive group ranches such as Osilalei, for example, simulated impacts of subdivision had relatively little impact on carrying capacity.

The results of running simulations for four group ranches using Savanna and the household model are shown in Fig. 4. For the four group ranches simulated, the entire-area 1-km runs show substantial reductions in livestock numbers (TLU per AE, middle graph of Fig. 4), compared with the control run for the entire study area. Livestock numbers declined essentially because households had to sell more animals to satisfy their cash needs, with concomitant deleterious long-term impacts on herd sizes and subsequent cash flow and food security. The parcel simulations for all group ranches show that TLUs per AE were declining even further; in most cases, cattle and sheep numbers (and productivity) were declining, while goat numbers were increasing, but the net result for TLU per AE was a sharp decrease. Subdividing the land into 196 km^2 parcels is not a viable option in any of these group ranches; livestock numbers eventually fall, the proportion of external calories that households need then increases, and the proportion of consumption satisfied falls markedly. Model results suggest that the livelihood strategies that are employed by households would have to change considerably (or household numbers would have to be drastically reduced) to maintain current food security levels and to stabilize current household herd sizes in 196 km^2 parcels.

While these general trends apply to all four group ranches, the effects of subdivision between group ranches differ markedly. Osilalei, at the high end of the rainfall gradient for the region, appears to show the least impact of subdivision, relatively speaking – external calories do not exceed 15% for all households, but even so, herd sizes are declining. The impacts of subdivison in Eselenkei, on the other hand, are considerable, and after 24 years, the households have long since become unviable. These differences arise because of differences in the intrinsic productivity of the group ranches simulated; the more productive group ranches, such as Osilalei and Imbirikani, are generally more ‘‘resilient’’ to subdivision, but even for these, if the amount of grazing land is reduced too much, then all succumb to crashing livestock populations. These results illustrate the fact that subdivision may have different impacts in different areas, depending on specific household and ecological characteristics. The process of, and expectations associated with, subdivision thus need to be flexible.

4.3. The effect of restricting dry-season access to key grazing resources

When access to the Chyulu Hills by livestock was prevented all year long, simulated livestock numbers decreased and TLUs per AE for all households declined. At the same time, there was an increase in the call by all households on external calories, slightly increased livestock sales to try to compensate for reduced household

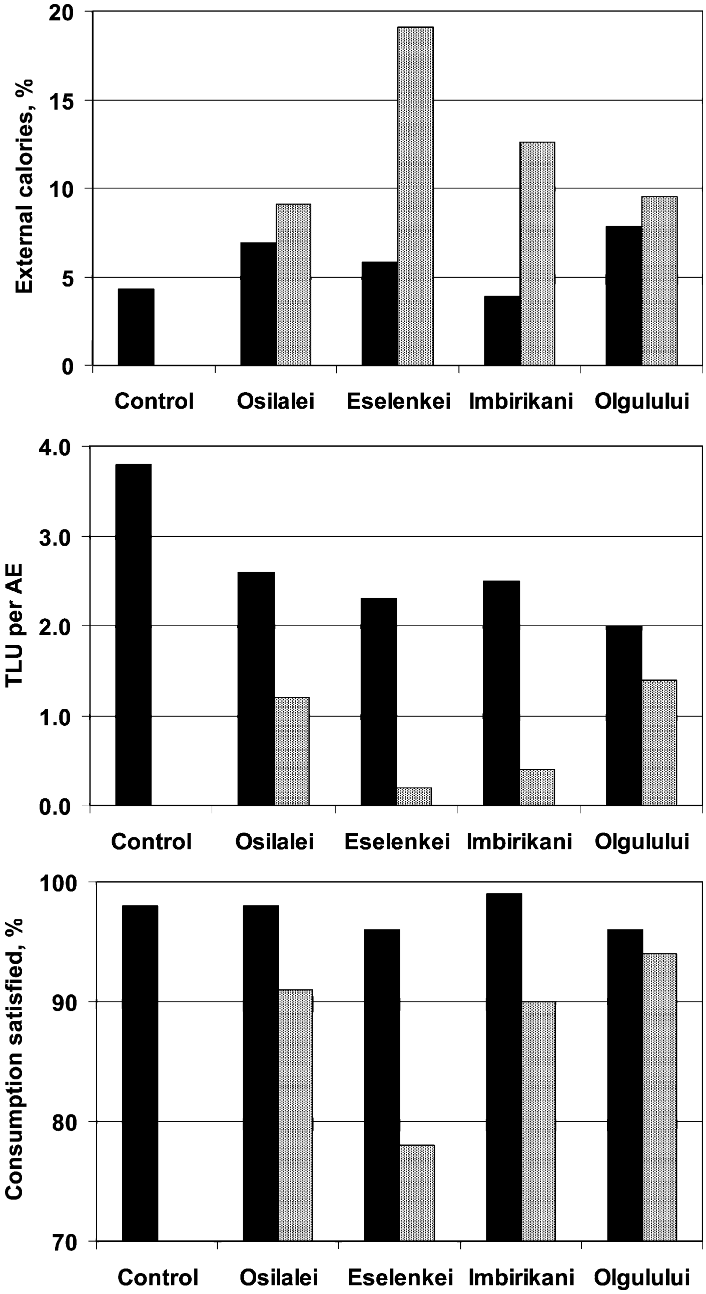

Fig. 4. Impacts of subdivision: simulated effects on three household indicators, weighted by relative occurrence of household type and by wealth category, for Osilalei, Eselenkei, Imbirikani and Olgulului GRs (black bars), and for five replicates of randomly chosen areas of 196 km^2 within each GR (shaded bars), over 24 years.

Table 7
Impacts of loss of Chyulu Hills dry-season grazing on LR and LBR households, and the effects of increasing the size of rainfed plots as a compensatory measure. Simulations over 24 years, results weighted by relative occurrence of household types

Rainfed plot size	Poor households				Medium households				Rich households			
	Difference, external calories (%) vs control run	Difference, proportion of own food (%) vs control run	Difference, TLU per AE vs control run	Sum of squared differences	Difference, external calories (%) vs control run	Difference, proportion of own food (%) vs control run	Difference, TLU per AE vs control run	Sum of squared differences	Difference, external calories (%) vs control run	Difference, proportion of own food (%) vs control run	Difference, TLU per AE vs control run	Sum of squared differences
Standard	+2.0	−1.6	−0.2	6.6	+0.5	−1.9	−0.5	4.1	0.0	−1.4	−1.0	3.0
Double	+3.4	−3.4	−0.6	23.5	+1.0	−4.1	−1.4	19.8	+0.4	−2.3	−3.1	15.1
Triple	+0.1	+0.6	−0.2	0.4	+0.5	−0.1	−0.4	0.4	−0.3	+0.7	−1.0	1.6
Quadruple	+0.8	+0.6	−0.4	1.2	+0.3	−0.1	−0.9	0.9	0.0	+1.1	−1.9	4.6

incomes, and thus a general decline in household well-being. Model results agree with the assessment of pastoralists, that access to the Chyulu Hills for three months per year as a grazing reserve is of considerable importance to the long-term stability of the system and to household well-being. Without it, model results suggest that the number of cattle and sheep that could be supported would decline dramatically.

For the simulations that investigated the viability of households dealing with the loss of the Chyulu Hills grazing lands by increasing the size of their cropping plots, results are shown in Table 7, in terms of the differences (positive and negative) between key household indicators for these runs compared with the control run. Results are weighted for the relative occurrence of the two household types that engage in rainfed cropping (LR and LBR). Also shown for each wealth level are the sum of the squares of these differences for the four scenarios. This sum of squared differences is used here simply as a single indicator of differences between each scenario and the control run, a value closer to zero implying scenario results that are generally more in accord with those of the control run. There is some variability between household wealth levels, but model results suggest that if rainfed plots are three times the size used in the control run, then the proportion of external calories, proportion of own food, and TLU per AE are reasonably close to their control run values (i.e., the squared differences shown in Table 7 are minimised).

These results suggest that loss of key dry-season grazing resources can be overcome for some household types by increased areas of highland rainfed cropping (although as noted above, this option does not exist for expansion of irrigated plots), but this would not compensate pastoralists in areas (i.e., Osilalei, Eselenkei) who use the Chyulu resources at critical times of the year and have no alternative access to other areas where highland agriculture is possible. It should be noted as well that there will almost certainly be implications for household labour resources relating to the management of larger plots. As noted above, this is an aspect that is not currently handled in PHEWS, and it is likely that the benefits of this compensation have been somewhat over-estimated. Labour might very well have to be hired by the household to manage larger plots, and this may have disproportionate impacts on cropping input costs.

5. Conclusions

In spite of its various limitations, Savanna-PHEWS appears to behave plausibly in relation to the control run and a variety of scenarios it was used to address. As was noted in the case for NCA (Thornton et al., 2003), the "validity" of PHEWS still remains to be demonstrated, strictly speaking, although the validation of this type of model is extremely difficult. It may be more useful to view model validity as the ability to provide food for thought for those concerned with the situation being modelled. Although the community meetings in 2003 at which these results were presented provided positive feedback (there was general agreement that the model results presented made some sense), we need to do much more work on identifying effective communication strategies, so that a process involving this kind of integrated assessment is driven as much as possible by local needs, its results communicated more widely, the work then re-assessed in terms of stakeholder feedback, and finally integrated into the decision making of local and regional planners and policy makers, if this is appropriate.

Based on the survey data collected that were used to set up the household model, and for the group ranches simulated, model results showed that for all runs with subdivided areas, substantial reductions in livestock numbers occurred, mostly through households having to sell more animals to generate the cash needed, and this having a deleterious long-term impact on herd sizes and subsequent cash flow and food security. If subdivision were to occur even to parcels as large as 196 km^2, and parcel owners insisted on exclusive use of their lands, then model results suggested that livelihood strategies would have to change to maintain current levels of household well-being. In fact, of course, diversification of pastoral livelihoods is an increasing trend already documented by many researchers working with pastoral groups (see, for example, Little et al., 2001; Nduma et al., 2001; Kristjanson et al., 2002; Thompson, 2002). Model results also underlined the fact that loss of key dry-season grazing resources could have serious household repercussions. Some households could compensate for this loss by increasing the area cropped, but there are many households for whom this would not be feasible.

In Kajiado, subdivision seems to be inevitable, but it is clear that more information is needed on the likely ecological and household impacts that may result, so that if there are deleterious effects, these can be ameliorated through appropriate action. Such action could take the form of encouraging group ranch members to form grazing associations, or promoting the development of other economic activity that can provide other options for agro-pastoralist households that are faced with declining livestock numbers and productivity. Model results have highlighted the fact that the impacts of subdivision are not the same in all circumstances, but differ in relation to particular household and ecological characteristics. This shows clearly that the process of subdivision needs to be flexible and adapted to local conditions.

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