Integrated Modeling and Assessment for Balancing Food Security, Conservation and Ecosystem Integrity in East Africa

Final Report to the GL-CRSP
Socio-Economic Modeling Component, 1997-2000

IMAS Project

Natural Resource Ecology Laboratory

ILRI
INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE

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Integrated Modeling and Assessment for Balancing Food Security, Conservation and Ecosystem Integrity in East Africa

GL-CRSP

Final Report, Socio-Economic Modeling Component, 1997-2000

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Summary

East Africa contains areas with the greatest large mammal biodiversity on the planet. These areas are key natural resources for the economic development of the region. They are also key areas for pastoralists who have co-existed with wildlife for millennia, so far we know. Increasing populations, conflicts between wildlife and cattle, and the growth of agriculture, are all placing great pressure on these lands. This GL-CRSP project was designed with a small component to develop a pastoralist socio-economic model that could be linked to the Savanna ecosystem model. In this way, options and scenarios could be investigated for their impacts not only on the ecosystem but also on pastoralist households and their welfare.

The activities of this subcomponent concentrated on two of the case study regions: Ngorongoro Conservation Area (NCA), northern Tanzania, and Kajiado District, southern Kenya, areas with very different specific problems but that share common problems relating to pastoralism, wildlife conservation, and agriculture. A socio-economic household-level model was constructed and calibrated for NCA, and a range of scenarios were simulated. The model, named PHEWS (Pastoral Household and Economic Welfare Simulator Model) produced results to show that all households depend on outside sources of calories. Pastoralist welfare in NCA, even with small amounts of agriculture allowed, is not internally sustainable at current human population levels. If realistic population growth rates are imposed for the next 15 years, then the household food security situation deteriorates markedly. The model suggests that the introduction of agriculture in 1991 in NCA occurred at a time to make a substantial improvement in householders' welfare, by reducing the dependence on "outside" purchased [a1]grain at a time of rapid population growth. By the late 1990s, these welfare gains would have been overtaken by human population growth rates in excess of 6% per year. From a household welfare perspective, banning agriculture is not an option: poor households would now [a2]nownowbe dependent for nearly one quarter of their calories from gifts and relief. Doubling the area of agriculture per household was shown to have a highly beneficial impact on the food security of poor and medium households. This doubling would still amount to only 0.6% of the land area of NCA. If pastoralists are to continue as part of the landscape of NCA, then allocating increased amounts of agricultural land seems an effective mechanism for improving household food security for the less well-off. The model shows that the NCA pastoralists are susceptible to drought; in the immediate term, household food security is severely compromised, but there is also the longer-term impact on livestock numbers, where livestock numbers have to be built up in the aftermath of drought. The model also indicates that various productivity-increasing interventions can have beneficial impacts on household welfare.

Activities for the Kajiado case study to date have largely concentrated on surveys to collect the socio-economic data with which to modify PHEWS for the greater levels of market integration found there and with which to calibrate the model. A set of scenarios have been defined, and these will be run and analysed in the coming months. Longer-term objectives are (1) to combine the various modifications of PHEWS into a comprehensive socio-economics model that can cover the spectrum from subsistence livestock keeping to commercial ranching systems, and (2) to develop and apply a regional socio-economics model to problems of population growth, climate change and land-use impacts on the trade-offs involved between wildlife conservation, human activity, food security, and poverty alleviation.

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1 Introduction

The project "Integrated Modeling and Assessment for Balancing Food Security, Conservation and Ecosystem Integrity in East Africa", was founded on the notion that there is a need to establish a more appropriate and sustainable balance between food security and natural resource conservation in the pastoral regions of East Africa. Ecologically unsound livestock development schemes, coupled with increased human population densities have often led to overgrazing and environmental degradation with resultant negative impacts on wildlife [a3]. The result for pastoral populations has been a decline in economic welfare and chronic states of undernutrition. Alarming decreases in livestock and wildlife over the last two decades suggest that rangeland carrying capacity has declined, possibly because there has been progressive rangeland degradation, resulting from excessive livestock densities and restricted livestock movements. Unfortunately, there are few data that conclusively show either a decline in range production or that livestock densities are too high.

The Integrated Modeling and Assessment System (IMAS) is based upon an existing spatial-dynamic ecosystem model (Savanna), which was originally developed for a pastoral ecosystem in northern Kenya. The model simulates plant growth responses to soil, weather, and herbivores; foraging, energetic status, and population sizes of both wild and domestic herbivores. The modeling objectives of the GL-CRSP research for the project were to develop a user interface, a human ecology/economics component, and animal disease components. The overall goal was to be able to predict interactions between livestock and wildlife in terms of spatial-dynamic competition for forage and disease transmission and effects. The modeling work, as well as the IMAS field studies, were designed to quantify the impacts of land tenure, enterprise scale, population increases and conservation policy on four objective functions: pastoral welfare, livestock production, wildlife, and ecosystem integrity.

The original plan was to implement the IMAS at three sites: Ngorongoro Conservation Area, Tanzania; Kajiado District, Kenya; and the Lake Mburo National Park in Uganda. It was envisaged that regional analyses would be conducted to identify areas of high and low conflicts between pastoralists and wildlife, the economic costs of conflicts and the benefits of their solutions, and appropriate policies for mitigating and preventing unfavorable pastoral-wildlife interactions in an era of rapid land use changes, human population growth, and modernization. For various reasons, this plan could not be implemented in full in the time available. This report describes project work for the Tanzanian and Kenya case studies only, as no socio-economic work was carried out in Uganda during this phase.

2 CRSP Project Activities

Year 1: 1997-98

Work was initiated in early 1998 on the socio-economics module for Savanna. Various design criteria were drawn up: a rule-based approach was decided upon, building upon a previous model of similar processes built by Drs Coughenour and Swift at NREL a number of years previously. The major reason for a simple, rule-based approach as that the 1998 study site, NCA, has a low level of market integration, and it was felt that the traditional western economic paradigm would probably not be very relevant. The rule-based framework developed, however, is flexible enough to be used for systems with much more market integration. A second reason for a simple, rule-based approach was that the setting up of rules and parameterisation of the model to produce plausible behaviour is much more easily achieved in situations of data paucity. The initial working hypothesis was that three land classes by three wealth strata would be sufficient to capture much of the household-level variation in NCA, necessitating nine distinct household models. The working out of this hypothesis is described in subsequent sections of this report.

As noted above, the original Swift-Coughenour model of pastoral households was used as a starting point. Simple household cash accounting needed to be built into the model, as well as rules covering the flow of dietary energy in the household. Initial coding was done to produce a stand-alone model that could run off Savanna output files. Eventually, the socio-economics module, named PHEWS (Pastoral Household and Economic Welfare Simulator) was integrated within the Savanna model proper.

Also during year 1, collaboration with the Agricultural Economics Department at the University of Nairobi was initiated. Various options were investigated, in terms of mechanisms for linkage. At that stage, three areas of collaboration were identified:

1. A study of pastoralist household decision-making processes, with a focus on the cropping decision. With information from the household level, analysis would involve a rule-based approach, to complement the Savanna modeling work for NCA. This work would also involve other household decisions and GIS analysis, in terms of looking at livestock movement, acquisition of forage, and location in the landscape in terms of relation to markets and access to infrastructure, for example.

2. A study of the distribution of pastoralists, wildlife, livestock, and tourists in Kajiado, and information on land-use, working towards the prospect of estimating the potential regional benefits from tourism and the potential for wildlife in the district.

3. A study of the economics of commercial ranching in Kajiado. This would involve the production of a fairly detailed economic model of a typical commercial ranch, possibly built around the ILRI herd simulation model. Ranches of different characteristics such as size could also be investigated, to compare and contrast them in terms of productivity and profitability.

We hoped to implement some or all of these areas with the help or one or more graduate students. Given the nature of the MSc cycle at Nairobi University (some 6 months available for a thesis project only every other year), and the relatively small number of MSc students, this was not possible. Instead, these areas above were addressed in different ways, including short-term consultancies with personnel in the Agricultural Economics Department, University of Nairobi. A large amount of information was provided for model building. This work is described and summarised below.

Year 2: 1998-99

Year 2 of the subproject saw work continue on the socio-economics module for the Savanna model, largely through travel, both to the USA and to Kenya. The simple rule-based model was constructed and tested using data from previous studies and from the field work carried out in NCA during 1997 and 1998 in part supported under this GL-CRSP project. At this stage, the model, dealing with three household wealth strata in NCA, was still being run in a stand-alone mode. Work started on linking it to Savanna output files. By this time, most of the decision rules in the model were predicated on the basis that the household has a target quantity of Tropical Livestock Units per person and a target cash income rate per month per person in the household.

In preparation for the Kenyan case study application of Savanna and the socio-economic module, some initial field work was undertaken in Kajiado in June-August 1999. This work was performed by Professor S Mbogoh and Dr K Munei, Department of Agricultural Economics, University of Nairobi, together with technical assistants. A survey was undertaken of the group ranches surrounding Amboseli National Park, with two objectives:

- To update existing knowledge about the economics of ranching compared with alternative income-generating activities, including ranchers' perceptions of the economic impacts of wildlife on ranching in these areas.
- To initiate collection of input data with which to parameterise the socio-economic module linked to the Savanna rangeland model.

Details of this survey work, and the major outputs, are reported below.

Year 3: 1999-2000

PHEWS, the socio-economic household model for NCA, was completed and tested, and then fully integrated within the Savanna Modeling System. This was done largely through two trips from Kenya to the USA for a total of nearly 4 weeks in 2000. During these times, a set of scenarios was drawn up, that PHEWS and Savanna together would be used to investigate, and these were run and analysed. Results are reported below (see Section 3.6).

PHEWS was also to be adapted for Kajiado in Kenya (the second project site), a much more market-orientated production system. Work progressed on this, but stopped at the end of the project.

Collaboration with the Agricultural Economics Department at the University of Nairobi continued, and involved a study of the economics of commercial ranching in Kajiado and the impacts of subdivison on household food security in the wildlife dispersal areas round Amboseli National Park. This work was designed to complement other CRSP-supported socio-economic and ecological work being carried out in the same area, and was aimed at providing more detailed information for parameterising the socio-economic model. Some details on the surveys are presented in Section 4 below.

3 Development of PHEWS and its application to NCA

3.1 Background

Ngorongoro's spectacular landscape encompasses highlands, forests, and grassy plains. Central to the Ngorongoro Conservation Area is the Ngorongoro Crater, formed by the explosive collapse of an ancient volcano. The 250-square-kilometer (97-square-mile) crater is internationally renowned for its rich wildlife and spectacular scenery and supports one of the last populations of the endangered black rhinoceros in Tanzania. The Conservation Area's short grass plains are the wet-season grazing grounds for much of the Serengeti's migratory herds of wildebeest, gazelle, and zebra. The highlands provide important habitat for rhinoceros, elephant, and buffalo. Ngorongoro is also located in the cradle of humankind. Two of the world's most famous archaeological and paleontological sites, Olduvai Gorge and the Laetoli Footprint Site, are in the Conservation Area.

Prior to 1960, Maasai people had free access to the Conservation Area and to the adjacent Serengeti plains. In 1960, they were evicted from the Serengeti, and, in 1974, they were evicted from the Ngorongoro Crater. By 1995, about 42,000 Maasai lived in the Conservation Area, where they continued to graze cattle in non-restricted areas and to farm to a limited extent. The Maasai population, growing at about 3 percent a year, remains largely impoverished, with most households earning less than $10 a month.

The status of wildlife in the Ngorongoro Conservation Area is mixed. The population of black rhinoceros, the most threatened large mammal there, declined from more than 100 in the 1960s to 12 in 1995 and is on the verge of extinction. In response, the Ngorongoro Conservation Area Authority imported two black rhinoceros from South Africa in 1998, with hopes that interbreeding would not only expand the population but also contribute to a more robust gene pool. The lion population also suffers from a lack of genetic diversity that may be harming the animals' health and fertility. Other animal species listed as threatened or endangered by the World Conservation Union include the wild dog, the African elephant, and the cheetah.

On the other hand, the wildebeest population, as well as that of other large herbivores, remains healthy. There are currently about 900,000 wildebeest in the Serengeti migratory herd, up from 240,000 in 1960. About one-third to one-half of these migrate into the Ngorongoro Conservation Area. The wildebeest increase followed the eradication of rinderpest, a disease fatal to wildebeest and cattle. The wildebeest population competes with other wildlife species and cattle for grazing land.

Perhaps the biggest change underway in the Ngorongoro ecosystem is the conversion of rangeland to farmland. In 1992, a ban on cultivation was temporarily lifted. As a result, within three years, 85 percent of Maasai were cultivating small plots of land. Their modest harvests of maize, beans, and potatoes meant fewer households were forced to sell their cattle to survive. The number of reproductive animals sold dropped from 47 percent to 1 percent. People were adopting cultivation as a means of maintaining their cattle and pastoral way of life.

However, Maasai were not the only ones to take advantage of the change in policy. In addition to small-scale farming by Maasai, government and Conservation Area employees, schoolteachers, hospital workers, shopkeepers, and other non-indigenous residents working in the Area also farm. Their farms are larger, averaging about 1.6 hectares (4 acres), and tend to grow crops for sale rather than subsistence. In addition, outsiders are settling in the region exclusively to farm. Their large-scale agriculture is putting more and more land under cultivation, yet agriculture still makes up less than 1% of the land area. In 1997, the ban on farming was lifted completely. Now, wildlife managers are struggling to understand how this change will affect conservation.

Once Savanna was parameterised for NCA, then it could be used to answer some of these questions associated with wildlife-livestock-human interactions. What was needed in addition to Savanna was a household model that could, at the same time, indicate changes in household welfare while such changes were occurring. Such information could then be used by the Ngorongoro Conservation Area Authority, pastoral development groups, and local and regional wildlife conservation groups, in the quest to assess tradeoffs between wildlife, livestock and pastoralist wellbeing.

3.2 Model Design

As noted above, early in the project perhaps the major design criterion to be elucidated was that a rule-based approach should be used. Two factors in particular influenced this decision: the low level of market integration in NCA, meaning that standard economic models were unlikely to be appropriate, and the recent building and testing of simple, top-down models that seemed to offer substantial benefits with respect to the simplicity of the model processes and relatively short development time, while still providing useful information to the modeller and other users. Work on a very simple dynamic land-use model was reported in Thornton and Jones (1997) with developments in Thornton and Jones (1998) and Jones and Thornton (1999), and a similar model was applied in a real-world situation, looking at intensification of agriculture in response to livestock disease control programmes in central Ethiopia, in Reid et al. (2001). There are clear implications for being able to model land-use decisions simply, and there are very good prospects in the future of being able to link outputs from PHEWS and Savanna to provide useful insights.

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

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

We also hypothesised a hierarchy of goals at the household level. First, the household has to meet its food requirements. If there is a shortfall, then this is made up by recourse to various options, including the selling of an animal, if necessary. Second, the household is assumed to manage for T in terms of investment and disinvestment decisions -- these types of livestock purchases and sales can be considered different to the meeting of household food requirements. Third, there is discretionary consumption; after the first two goals have been dealt with, with consequent impacts on the cash reserves (purchase of food, for example), there may be a certain amount of cash left over for spending on various items. Considerable field work had been undertaken in NCA, planned in part to generate information with which to test these hypotheses within a simple model framework. Once tested and applied in NCA, the plan was to use the same basic structure for the Kenyan case study area, Kajiado, using data collected from surveys and existing secondary sources.

3.3 Model Description

PHEWS currently consists of approximately 1700 lines of FORTRAN code, and is compiled along with the rest of the Savanna model using version 4.0 of the Lahey Fortran 90 compiler (Lahey, 1997). The model currently treats three different household types, stratified in terms of wealth, which are taken to be somehow representative of households within each stratum. In the model, wealth relates to the number of livestock each household has, and these three household types are characterised by different numbers of people. Details are provided in the section on calibration below. Throughout, the term “household” refers to an adult male decision maker, his (usually multiple) wives and their children, and other family members living within such a grouping. The household thus refers necessarily neither to a Boma (a collection of houses around a livestock corral) nor to one house. This is the unit of analysis that was used in much of the primary data collection (see Galvin et al., 2001).

The model consists of a set of subroutines. The first of these, SEM_INIT, is used to initialise the model. It calculates initial herd numbers by household type, and generally sets up the various arrays and parameters that are needed. The major data input files are read, and starting numbers of TLUs, Adult Equivalents and the target ratios are calculated and stored.

For each iteration of time in the model (usually one calendar month), a series of calculations is gone through for each household type. The controlling subroutine, SEM_RUN, is called each iteration. It updates animal numbers, then updates the welfare ratios. If the particular month is a harvest month (as specified in the input data files), then a subroutine is called to calculate yields for maize and other garden crops based on 5-month total rainfall. Subroutine CASHFLOW is then called to update cash flow that month, by adding in what is sold and subtracting what is bought, other than food. Subroutine ENERFLOW is called to deal with household energy; sources of dietary energy are milk, maize (own or bought), dead animals, the occasional stochastic slaughter, and finally gifts or relief. If maize is purchased, and if milk is sold, then the cash boxes are updated. Subroutine LSTRADE is called to see if animals are sold or bought this iteration. Subroutine OUTPOUT is then called to output one record of output variables to the output files. If livestock numbers have changed in the model this iteration, through being sold or killed, then herd numbers are updated. Finally in each iteration, if spatial outputs are required (specified by the user), then these are written to the appropriate output files.

Once the run is complete, and all iterations have been finished, a subroutine SEM_OUTP is called, which summarises various cumulative and global variables.

The details of the cash flow, energy flow and livestock trading modules are described in more detail below.

Cash flow

Cash flow for each household type each iteration involves simple additions and subtractions from a cashbox . Sources of income and expenditures are listed in Table 1. Essentially, income is made up of any crop sales (the proportions of the crops sold for each household type are inputs demanded of the user), milk sales, wages and other sales plus gifts, Household expenditures are specified in terms of household goods each month, again specified as inputs by the user. If there is not enough cash to pay for all the projected expenditure, then household expenditure that iteration is pro rated if there is cash to meet at least 50% of projected expenditure. If there is less than this amount of cash in the household, then household expenditure that month is deferred, except expenditure on tea and sugar, which is paid for in cash (if there is enough) or they are assumed to be gifted to the household (if there is not enough).

Table 1 Cash flow in PHEWS

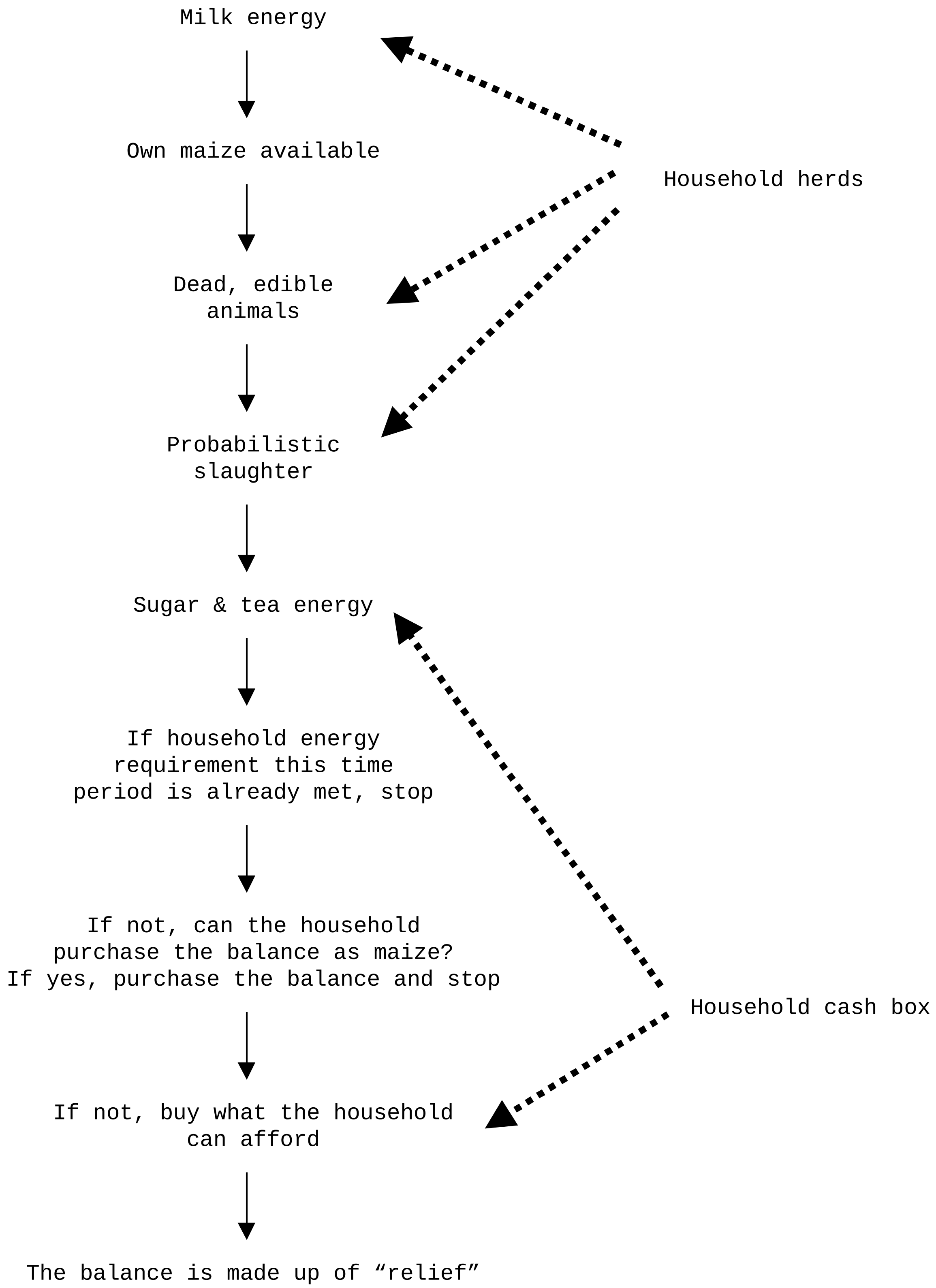
Flow	How treated in PHEWS
Cash in	
Livestock sales	See Table 3
Crop sales	Calculated as a household characteristic (% sold); the remainder is consumed by the household
Wages	From input file (Table 5)
Milk sales	Calculated a household characteristic (% sold), the rest is consumed in the household.
Other (gifts, crafts, etc)	From input file (Table 5)
Cash out	
Food purchases	Calculated from the food flow (see Figure 2). The balance of requirements is purchased if cash is available.
Household goods	From input file (Table 5)
Livestock purchases	See Table 3
Other payments out	From input file (Table 5), plus crop inputs

Energy flow

Energy flow in PHEWS is treated in a hierarchical fashion (Figure 1). Household energy requirements are calculated for the current iteration; these depend on the number of people in the household, the age-sex ratios, and the assumed calorific requirement for each category (see the section on calibration below). These energy requirements are met from the sources that are described below.

The energy available from milk is calculated. This depends on the proportion of the cattle herd milking this iteration, and milk production per animal is calculated from a ramp function that relates milk yield to body condition. The caloric content of this amount of milk is then calculated. Some may be sold; this is subtracted from the milk energy variable. The rest is available for consumption, although a ceiling is placed on the amount that can be consumed by the household in any one iteration.

Figure 1. The basic dietary energy flow hierarchy in PHEWS



Energy available from the household's own maize is then calculated for this iteration. At harvest, the total amount of maize harvested is stored in an array that makes the maize available over a four-month period from the harvest date, but in decreasing amounts (Table 2). The amount of "other" crops available to be sold is treated in similar fashion.

The next source of dietary energy is from animals that starve or are dying from "edible" diseases (i.e., not something such as anthrax). Meat energy is calculated from the number of dying animals in each iteration, modified by the proportion that cannot be eaten because of the nature of the disease.

Table 2 Crop harvesting in the model

	Proportion of harvest available to the household in:			
	Month of harvest	**Month of harvest + 1**	**Month of harvest + 2**	**Month of harvest + 3**
Maize	0.4	0.3	0.2	0.1
Other crops	0.25	0.25	0.25	0.25

An input data to the model is the probability that an animal will be slaughtered each iteration. This is to take account of households' needs for meat energy for ceremonial and festive occasions. For each household type, a pseudo-random number is drawn each iteration, and if

$$\mathbf{RN < pkill\ (mo, i)}$$

where **RN** is a uniformly distributed random number between 0 and 1, and **pkill (mo, i)** is the probability of slaughter in month **mo** for household type **i,** then an adult steer will be slaughtered (0.05 probability), an adult female goat (0.20 probability), or an adult male goat (0.75 probability). As for milk, a ceiling is placed on meat calories (12% of total calories) in each household for each iteration, to account for occasionally high livestock deaths.
Energy from sugar and tea is then taken into account, in relation to monthly input data.

The total energy from milk, home-produced maize, meat and tea and sugar is then summed, and compared with the household's requirement. If the total is less, then the household attempts to buy maize to cover the deficit. This amount of maize (to exactly cover the shortfall) is purchased if the household has sufficient cash reserves.

If the household does not have sufficient cash to purchase what is required, then as much maize as can be paid for is purchased, and any remaining shortfall is covered through an open-ended box that can be termed "gifts or relief (food aid)". In the rare cases where a household requires relief calories in any iteration and there may be some milk energy left over (after reaching the household's ceiling and selling the proportion allowed by the input data), then milk energy for that iteration can be increased up to a maximum of 50% of the household's requirement. Actual relief in the area is rare, so shortfalls in food supply are borne disproportionately by the adults, resulting in their having a particularly low nutritional status.

Livestock trading (purchases and sales)

Livestock purchases and sales are simulated using a simple matrix approach that specifies particular courses of action depending on the values of the TLU ratio and the cash ratio. We define the following:

TTLU = the target TLU per Adult Equivalent in the household
ATLU = the actual (at any time t) TLU per Adult Equivalent
TCL = the target cash income per Adult Equivalent per month
ACL = the actual (at any time t) cash income per month

The ratios ATLU/TTLU and ACL/TCL define an index of the severity (or otherwise) of the livestock and cash problems facing the household. For NCA, livestock purchases occur infrequently, so these do not really have to be dealt with. For livestock sales, goats are sold in the order: male, immature male; and female. In other words, if there are no males in the herd but the decision is still to sell, then an immature male will be sold, for example. If the sale of a large ruminant is indicated in the matrix, then a steer will be sold first, then a male. A sample decision matrix is shown in Table 3. A major activity in calibrating PHEWS was to adjust the ratio limits so that simulated livestock sales were reasonable and accorded with such survey data as we had access to that included information on livestock sales. This is returned to below.

Table 3. Idealised livestock trading matrix (SR = small ruminant, LR = large ruminant)

		ATLU / TTLU			
		> 1	**= 1**	**< 1**	**<< 1**
ACL / TCL	**> 1**	Buy SR	Buy SR	Buy LR	Buy LR
	= 1	0	0	Buy SR	Buy SR
	< 1	Sell SR	Sell SR	Sell SR	Sell SR
	<< 1	Sell LR	Sell LR	Sell LR, SR	Sell LR, SR

TTLU = the target TLU per Adult Equivalent in the household
ATLU = the actual (at any time t) TLU per Adult Equivalent
TCL = the target cash income per Adult Equivalent per month
ACL = the actual (at any time t) cash income per month

Input and output files

PHEWS is controlled through one input data file and parameterised through two other files. Control of whether PHEWS is run or not resides in SIMCON.PRM, one of the standard Savanna input files. This file controls a number of important parameters that describe a particular simulation run, including:

- ***ipmodl***, the flag that specifies whether PHEWS is run or not.
- ***mnths***, the number of months to run for this simulation.
- ***nystrt***, the year to start the simulation.
- ***iagric***, the flag that specifies whether to model agriculture and households.
- ***imgsoc***, a flag to control for spatial output of socio-economic data.

The parameterisation of PHEWS is done through AGRIC.PRM (a Savanna input file) and ECMOD.DAT. These are shown in Tables 4 and 5, respectively. PHEWS generates a

Table 4. Input data file AGRIC.PRM

```
2991     // houses   -- Number of households

0.00     // popgrow  -- Human population growth rate (An entry of 3.0
            represents a 3% growth rate per year).

.35      // ppoor    -- Proportion of poor households

.40      // pmod     -- Proportion of moderately weathly households

.25      // prich    -- Proportion of rich household

0.67     // hapoor   -- Hectares of cultivation per poor household (1.5
            acres/household, Smith and Lynn)

0.89     // hamod    -- Hectares of cultivation per moderately weathly
            household (Smith and Lynn)

1.42     // harich   -- Hectares of cultivation per rich household (Smith
            and Lynn)

2.0      // hmean    -- Mean houses per km2, for cells with houses. The
            maximum density will be Mean+2 SD

0.8      // hsd      -- Deviation in the number of houses per km2
```

Table 5   Input data file ECMOD.DAT

```
@HOUSEHOLD_VARIABLES---- GLOBAL

Random number seed        2217                     ix
Ad Eqs  1 <2 yrs          0.52                     adeqs (i)
        2 2-6             0.52
        3 7-12            0.85
        4 13-17 m         0.96
        5 13-17 f         0.96
        6 m               1.00
        7 f               0.86

TLUs    1 not weaned      0.24                     tleqs (i,1)
CATTLE  2 immature f      0.42
        3 immature m      0.42
        4 mature f        0.70
        5 mature m        0.85

TLUs    1 not weaned      0.10                     tleqs (i,2)
SHOATS  2 immature f      0.10
        3 immature m      0.10
        4 mature f        0.10
        5 mature m        0.10

Cal cont  1 milk           830                     calcon (i)
(kcal/kg) 2 meat          1720
          3 non-MZ        3500
          4 MZ            3700
          5 sugar etc     3950

@HOUSEHOLD_VARIABLES----  POOR  MIDL  RICH        j=1,3

Size                        10    17    19     hhsize (1,j) ! Total no. of HHs, % poor-mod-rich, cult. ha
Size std dev               5.4   9.7   4.7     hhsize (2,j) !      poor-mod-rich, are in AGRIC.PRM ******
```

(Table 5   Input data file ECMOD.DAT … continued 2/5

```
Prop of cattle nos         0.10  0.32  0.58     pronos (1,j) ! MUST add to 1
Prop of shoat nos          0.10  0.28  0.62     pronos (2,j) ! MUST add to 1

Age/sex 1 <2 yrs             28    25    22     agesex (i,j)
 HUMANS 2 2-6                20    16    15
   %    3 7-12               13    16    15
        4 13-17 m            07    12    11
        5 13-17 f            07    12    11
        6 m                  07    04    04
        7 f                  18    15    22

Proportion MZ %              70    70    70      propmz (j)
Proportion other crops       30    30    30      propot (j)

kcal per day      1        1052  1052  1052      kcalrq (i,j)
(by age/sex clss) 2        1720  1720  1720
     HUMANS       3        1720  1720  1720
                  4        1943  1943  1943
                  5        1943  1943  1943
                  6        2024  2024  2024
                  7        1741  1741  1741

@TIME DEPENDENT VARS----    JAN   FEB   MAR   APR   MAY   JUN   JUL   AUG   SEP   OCT   NOV   DEC

Hshld TLU target POOR       2.2   2.2   2.2   2.2   2.2   2.2   2.2   2.2   2.2   2.2   2.2   2.2    ttlu (i,1)
 (TLU/AdEq)      MIDL       3.3   3.3   3.3   3.3   3.3   3.3   3.3   3.3   3.3   3.3   3.3   3.3    ttlu (i,2)
                 RICH       9.0   9.0   9.0   9.0   9.0   9.0   9.0   9.0   9.0   9.0   9.0   9.0    ttlu (i,3)

Hshl CASH target POOR      2300  2300  2300  2300  2300  2300  2300  2300  2300  2300  2300  2300    tcl  (i,1)
 (T/mo/AdEq)     MIDL      2500  2500  5500  2500  2500  2500  2500  2500  2500  2500  2500  2500    tcl  (i,2)
                 RICH      3000  3000  3000  3000  3000  3000  3000  3000  3000  3000  3000  3000    tcl  (i,3)

Opportunistic    POOR      0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05    pkill (i,1)
slaughter prob   MIDL      0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05    pkill (i,2)
                 RICH      0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05  0.05    pkill (i,3)
```

(Table 5 Input data file ECMOD.DAT … continued 3/5

Income POOR	wages	0	0	0	510	190	300	0	0	0	0	0	0	income (i,1,1)
(T/mo/AE)	all sales	750	1073	5600	1020	1630	1750	1710	1730	1760	1250	1580	500	income (i,2,1)
	gifts	0	265	1130	286	0	100	280	240	176	0	0	235	income (i,3,1)
Income MIDL	wages	0	0	0	0	0	0	330	0	0	0	0	0	income (i,1,2)
(T/mo/AE)	sales	1580	830	2040	3000	2320	120	2730	2170	1610	1010	1350	1240	income (i,2,2)
	gifts	0	0	220	390	140	330	2210	1260	320	620	0	0	income (i,3,2)
Income RICH	wages	0	0	0	0	340	90	0	0	0	0	0	0	income (i,1,3)
(T/mo/AE)	all sales	5230	6340	6420	5070	1064	590	1270	2985	4700	4510	3900	5480	income (i,2,3)
	gifts	0	490	0	570	1920	480	210	110	0	40	690	810	income (i,3,3)
Milk kg/cow/day		0.8	0.8	1.5	1.5	1.5	0.8	0.8	0.8	0.8	0.8	1.5	1.5	miyl (i)
Milk sold % POOR		05	05	10	10	10	10	10	05	05	05	10	10	misold (i,1)
Milk sold % MIDL		05	05	10	10	10	05	05	05	05	05	10	10	misold (i,2)
Milk sold % RICH		05	05	10	10	10	05	05	05	05	05	10	10	misold (i,3)
Harvest flag		0	0	0	0	0	1	0	0	0	0	0	0	harv (i)
Milk price sell T/kg		160	160	160	160	160	160	160	160	160	160	160	160	milk (i,1)
Milk price buy T/kg		200	200	200	200	200	200	200	200	200	200	200	200	milk (i,2)
Tea/sugar cost T/kg		600	600	600	600	600	600	600	600	600	600	600	600	teapri (i)
Maize price sell $/kg		60	60	60	60	60	60	60	60	60	60	60	60	maize (i,1)
Maize price buy $/kg		70	70	70	70	70	70	70	70	70	70	70	70	maize (i,2)
Other crops sell $/kg		60	60	60	60	60	60	60	60	60	60	60	60	crops (i,1)
Other crops buy $/kg		70	70	70	70	70	70	70	70	70	70	70	70	crops (i,2)
Cattle 1	sell T	17000	17000	17000	17000	17000	17000	17000	17000	17000	17000	17000	17000	catpri (i,1,1)
Tz 2	sell T	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	catpri (i,2,1)
3	sell T	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	catpri (i,3,1)
4	sell T	45000	45000	45000	45000	45000	45000	45000	45000	45000	45000	45000	45000	catpri (i,4,1)
5	sell T	65000	65000	65000	65000	65000	65000	65000	65000	65000	65000	65000	65000	catpri (i,5,1)

(Table 5 Input data file ECMOD.DAT … continued 4/5

Cattle	1	buy T	22000	22000	22000	22000	22000	22000	22000	22000	22000	22000	22000	22000	catpri (i,1,2)
Tz	2	buy T	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	catpri (i,2,2)
	3	buy T	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	35000	catpri (i,3,2)
	4	buy T	55000	55000	55000	55000	55000	55000	55000	55000	55000	55000	55000	55000	catpri (i,4,2)
	5	buy T	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	catpri (i,5,2)
Shoats	1	sell T	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	shopri (i,1,1)
Tz	2	sell T	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	shopri (i,2,1)
	3	sell T	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	shopri (i,3,1)
	4	sell T	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	shopri (i,4,1)
	5	sell T	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	shopri (i,5,1)
Shoats	1	buy T	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	5000	shopri (i,1,2)
Tz	2	buy T	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	shopri (i,2,2)
	3	buy T	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	7000	shopri (i,3,2)
	4	buy T	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	shopri (i,4,2)
	5	buy T	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	shopri (i,5,2)
Cash out	1	tea-sugar	300	300	300	300	300	300	300	300	300	300	300	300	expend (i,1,1)
(T/AE)	2	livestock	0	0	0	0	0	0	0	0	0	0	0	0	expend (i,2,1)
POOR	3	h/h goods	1290	2420	2400	1250	1150	820	980	580	190	1070	1170	1420	expend (i,3,1)
	4	other	220	710	1320	1050	1230	1220	760	530	290	240	200	390	expend (i,4,1)
Cash out	1	tea-sugar	300	300	300	300	300	300	300	300	300	300	300	300	expend (i,1,2)
(T/AE)	2	livestock	0	0	0	0	0	0	0	0	0	0	0	0	expend (i,2,2)
MIDL	3	h/h goods	3140	2450	3660	2460	1940	1560	2650	1380	110	510	1340	2440	expend (i,3,2)
	4	other	730	2720	2570	3960	2920	2890	3720	2240	740	200	750	650	expend (i,4,2)
Cash out	1	tea-sugar	300	300	300	300	300	300	300	300	300	300	300	300	expend (i,1,3)
(T/AE)	2	livestock	0	0	0	0	0	0	0	0	0	0	0	0	expend (i,2,3)
RICH	3	h/h goods	1630	2700	2070	1600	2020	1610	1540	1340	1150	1300	1590	2190	expend (i,3,3)
	4	other	4480	3150	3380	3040	3790	3210	2640	2370	2100	2820	2840	1780	expend (i,4,3)

(Table 5 Input data file ECMOD.DAT … continued 5/5

```
@OTHER VARIABLES    ----

POOR sell-buy matrix         0     0     0     0     lsmat (i,1,1)
    + buy - sell             0     0     0     0     lsmat (i,2,1)
  1 shoat 2 cow/steer        0    -1    -1     0     lsmat (i,3,1)
                             0    -2    -2     0     lsmat (i,4,1)

MIDL sell-buy matrix         0     0     0     0     lsmat (i,1,2)
                             0     0     0     0     lsmat (i,2,2)
                             0    -1    -1     0     lsmat (i,3,2)
                             0    -2    -2     0     lsmat (i,4,2)

RICH sell-buy matrix         0     0     0     0     lsmat (i,1,3)
                             0     0     0     0     lsmat (i,2,3)
                             0    -1    -1     0     lsmat (i,3,3)
                             0    -2    -2     0     lsmat (i,4,3)

Max milk vs condition       0.0   0.1   1.0   1.0         ecmilk (2,2)
Max kg meat by class      17.80 42.40 42.40 74.2 95.9     ymeatx CAT
                            3.97  6.36  6.36 10.6 12.3    ymeatx SHO
Prop non-edible deaths      0.05                          percan CAT
                            0.05                          percan SHO
Meat yld vs condition       0.0   0.5   1.0   1.0         cndval (2,2)
Mz yield vs ppt mm        200.0   0.0 600.0   0.8         datamz (2,2)
```

variety of output files, detailing cash flows, energy flows, and general household indicators. The full set is listed in Table 6.

Table 6 List of output files generated by PHEWS

File Name	Contents
ANIM /P /M /R.OUT*	Household livestock herd details each iteration
DIET /P /M /R.OUT	Household dietary consumption each iteration
HOUS /P /M /R.OUT	Household variables such as welfare ratios each iteration
CASH /P /M /R.OUT	Household cash flows in and out each iteration
SUMMARY /P /M /R.LOK	Summary output file each iteration with major model variables
DUM.DAT	Debugging file
SEM_SUM.OUT	Summary statistics at the end of each run detailing cash and welfare levels for each household type
IMAGE4.IMG IMAGE4.HDR	Spatial variables that can be mapped by the Savanna Modeling System

* indicates that there are three files, ANIMP.OUT, ANIMM.OUT and ANIMR.OUT for the three household types: poor (P), medium (M) and rich (R)

3.4 Linkages to the Savanna model and to the Savanna Modeling System (SMS)

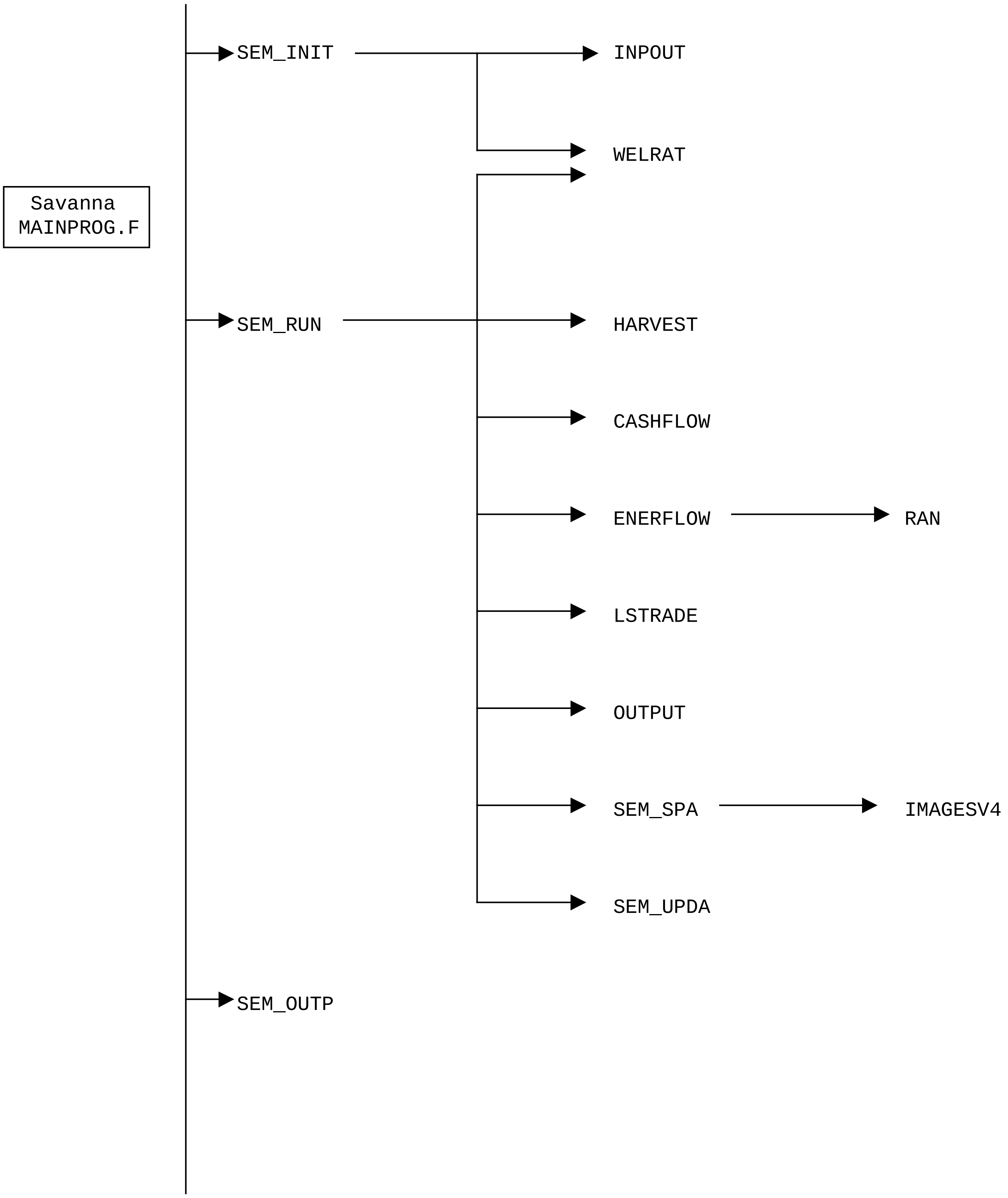
Most of the development of PHEWS was carried out in a stand-alone mode, i.e. the code was written and the module operated on a set of output data files generated by Savanna, but it was not necessary to run Savanna itself each time. Savanna is a very large and complicated model, and a 15-year simulation of NCA on a Pentium PC can take two to three hours, depending on the options that are set. Integrating PHEWS into Savanna was felt to be an important objective of this work, because clearly there are various feedbacks between the ecological components and the household components of the system that need to be taken into account, such as livestock condition and food available to humans. Integration is needed particularly if trade-off scenarios are to be examined using the IMAS (of which Savanna and the PHEWS module are part).

The size and complexity of the Savanna model itself (Coughenour, 1993; Ellis and Coughenour, 1998) made for a simple decision rule in terms of integrating the PHEWS module into it: it should be done as simply as possible, with no or little changes needed in the coding of Savanna. Fortunately, this could be achieved fairly simply, as the original “hooks” to the early Swift-Coughenour energy flow model were still in the code of Savanna. These simply had to be replaced with new calls to the relevant components of PHEWS. Figure 2 shows the arrangement of the subroutines and the way they are called from Savanna itself, in three parts: initialisation of PHEWS, running PHEWS each iteration, and summarising outputs at the completion of each simulation.

The modifications needed to the code of Savanna to effect this linkage were minor. The second part of the linkage was to ensure that the appropriate variables in Savanna were accessed by PHEWS and then passed back to Savanna, so that the important feedbacks were operating. An obvious example of one such feedback is what happens if an animal is sold, for example. Savanna keeps track of all animal herds, in terms of both size and composition (age:sex ratios), in terms of total numbers. PHEWS operates on the basis of household herds. Thus at the start of each iteration, PHEWS recalculates the herd size of livestock for each household type (rich, medium and poor); this has to be done each iteration, as animals will have died and been born since the previous iteration. If during that iteration in PHEWS, an animal is sold or purchased, then Savanna needs to be told that both the number of animals and the herd composition have been changed. At the end of each iteration in PHEWS, household herd numbers and composition are totalled and aggregated, and appropriate adjustments are made to Savanna’s variable arrays to reflect any changes. Thus if a adult female goat is simulated to be sold during that iteration in poor households, then the total goat herd is adjusted downwards by aggregating the total number of poor households and adjusting the number of animals in the appropriate age-sex cohort in the model. This information is then passed back to Savanna (in effect) for the next iteration of the ecological model run.

The variables that are currently used to link Savanna and PHEWS are the following:

Figure 2. Subroutine structure of PHEWS and linkage to Savanna



•

POPAGE(-,-,-): total herd numbers by age and sex. This information is used to help update animal numbers following changes (such as sales, purchases, etc).

- BRTHRTAGE(-,-): livestock birth rate by species by age. This is used to determine the number of lactating animals as part of the determination of milk yield in any iteration.

- COND (-): herd-level condition by species. Milk yield per animal in any iteration is related to body condition.

- PAGSX(-,-): number of animals by age/sex class. Used to update animal numbers following changes.

- DEATH(-,-): number of dead animals by species and age/sex class. Used in the determination of edible meat energy per household type per iteration.

- NAGEMX(-,-): maximum age by sex and species. Used in the animal numbers updating code.

- BODSIZ(-,-): maximum body size by species and age/sex class. Used in the determination of edible meat energy per household type per iteration.

- NUMRUN: number of run, if multiple runs. Used to control the frequency of summary output from PHEWS.

- SYSPPT: weighted average rainfall this iteration (mm). Used in the determination of crop yields in PHEWS.

These variables are generally “one-way” (i.e., PHEWS reads them but does not change their values), except POPAGE, which is updated and changed depending on buying, selling and slaughtering of animals, as outlined above.

The code in PHEWS itself runs very quickly, and currently it adds very little overhead to the operation of Savanna, either in time or in CPU resources required.

Links to the SMS

Savanna (with or without PHEWS attached) can be run in various ways. One way is by using the Savanna Modeling System (SMS). The SMS was originally developed (Coughenour, 1993) to provide a user-friendly Windows environment for editing input files to set up a scenario, running the scenario with Savanna, and then looking at the outputs of the scenario either spatially or temporally. PHEWS is now integrated with the SMS on the output side, so that model results from the socio-economics of the system can be graphed and mapped as required by the user, in exactly the same way as for the ecological outputs.

For temporal outputs, a wide range of variables from PHEWS can be graphed in the SMS. The output files ANIM, DIET, HOUS and CASH in Table 6 are all temporal output files that can be graphed, and a complete list of variables available for output is shown in Table 7. These variables are graphed by household type in SMS, but if comparisons are required for one variable between household types, then cutting-and-pasting with a suitable text editor and importation into a software package such as Excel for subsequent graphing is very straightforward.

One of the very attractive features of the SMS is the ability to map outputs spatially, and to be able to assess how spatial outputs change over time as well. A set of socio-economic outputs from PHEWS has been defined, and these are output to the mapping file IMAGE4.IMG (see Table 6) that can then be accessed by SMS for mapping. These spatial output variables are shown in Table 7 also. Modelled households are located in the landscape of NCA in a random fashion, depending on an underlying probability map for household location (Boone and Coughenour, 2000). Spatial variation arises because of two factors: differences in household density per pixel, and differences in the relative preponderance of rich, medium and poor households in NCA. Given data shortages, we hypothesized, following Lynn (2000), that NCA could be divided up into three distinct areas, based essentially on elevation: lowlands, midlands and highlands. It has been observed (Lynn, 2000) that the relative occurrence of poor, medium and rich households in each of these areas is different, although detailed data on these changes are not yet available. We thus hypothesised a set of relative household occurrences based on the following:

Table 7 List of output variables generated by PHEWS that can be graphed and mapped in the SMS

File	Variable	Temporal or Spatial Output
DIETP/M/R	• Household energy requirements, kcal • Milk consumed, proportion in diet • Maize consumed, proportion in diet • Meat consumed, proportion in diet • Sugar consumed, proportion in diet • Maize bought, proportion in diet • Relief consumed, proportion in diet	Temporal
HOUSP/M/R	• Cash reserves, Tz Sh • Own maize available, kg • Other crops available, kg • TLU welfare ratio • Cash welfare ratio • Actual TLUs • Adult Equivalents	Temporal
CASHP/M/R	• Cash reserves, Tz Sh • Net income, Tz Sh • Livestock purchase flag • Livestock sales flag • Crop sales, Tz Sh • Milk sales, Tz Sh • Other income, Tz Sh • Livestock sales, Tz Sh • Surplus milk sales, Tz Sh • Tea expenditure, Tz Sh • Livestock purchases, Tz Sh • General household item expenditure, Tz Sh • Maize purchases, Tz Sh	Temporal
ANIMP/M/R	• Cattle number in household herd • Percent female cattle in household herd • Percent adult cattle in household herd • Goat number in herd in household herd • Percent female goats in household herd • Percent adult goats in household herd • Sheep number in herd in household herd • Percent female sheep in household herd • Percent adult sheep in household herd	Temporal
IMAGE4	• Household density, number/km2*100 • Agriculture, ha/km2*10 • Net income, Tz Sh/1000 • Diet relief, % • Household maize availability, kg/km2 • TLU per Adult Equivalent, number*10 • Household's own food availability, % • Cash box, Tz Sh/1000 • Human population density, number/km2	Spatial & Temporal

- We classified 73% of the pixels in NCA as lowlands, 9% as midlands, and 18% as highlands;
- The weighted average of household type needed to match the overall figures shown in Table 4;
- Estimates were based on observations in the field.

As a result, we estimated that:

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

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

An even more flexible user-friendly and flexible modeling system has been developed, called SavView. At the time of writing, PHEWS had not yet been integrated into this system. Integration would allow considerable flexibility in setting up scenarios for running with Savanna and in mapping and graphing output.

3.5 Calibration of PHEWS

The above sections have detailed the structure of PHEWS. As noted in section 3.2, various reasons enjoined a simple rule-based approach to modeling pastoralist households. One important implication of this approach is that a certain amount of trial-and-error is required to calibrate such a model ("calibration" being taken to mean the process of parameterising the model). A second implication is that validation becomes a real problem, particularly in the situation where data are relatively scarce ("validation" being taken to mean the process of attempting to establish the appropriateness or otherwise of the model for one's particular purpose). In an ideal world, the modeller has at least two completely independent sets of data: one with which to parameterise the model, another with which to test it. Data scarcity is usually the norm, however, but in itself this is a major driving force for model simplicity. We return to the issue of validation at the end of this section.

To calibrate PHEWS for NCA, various sources of data were available. These included the following:

- Previous studies and surveys in NCA itself. These included sources such as Homewood et al. (1987); Homewood and Rodgers (1991); various papers in Thompson (1997); NCAA (1999); Galvin (1994, 1995, 1997, 1998); Galvin et al. (1994, 1999); Magennis and Galvin (2000).

- Previous studies and surveys of pastoralism in areas of northern Tanzania, southern Kenya and elsewhere. These included sources such as Bekure et al. (1991), and Dahl and Hjort (1976).

- Studies and surveys carried out in NCA as part of the GL-CRSP. These included Smith (1999) and Lynn (2000).

Two very practical issues drove the calibration. First, it was important to try to find some supporting evidence for all the input data shown in Tables 4 and 5, if not from NCA directly then from similar agropastoral systems elsewhere in the region. Second, the calibration of the household model was to be done using the identical Savanna inputs that produced the "control" run of Boone and Coughenour (2000) – i.e., a baseline run that could be used as a benchmark against which to judge other scenarios. This is returned to below.

There is a whole series of important data for setting up the model to run. One of these is the number of livestock species. This is a key parameter for the Savanna model, and the NCA application had 17 herds defined. Of these, three are of importance to the welfare of pastoralists: cattle, sheep and goats. Accordingly, PHEWS is currently parameterised for these three herds.

Another set of data that are key to the model relates to "current" (i.e. baseline) numbers of households and the numbers of animals per household. Data for NCA (NCAA, 1999) show a population of over 51,000 people in NCA in 1999. Human population growth in recent years in NCA appears to have been highly volatile. Fitting a linear regression to the data in NCAA

(1999) from 1970 indicates a growth rate of 8.3% per year, and a 2000 population estimate of 46,600 or so ($r^2 = 0.91$). This number is taken as the baseline population figure for the "control" run.

The proportion of poor, medium and rich households in NCA was estimated as 0.35, 0.40 and 0.25, respectively (McCabe et al., 1997b:291; Homewood, 1992:70; Potkanski, 1997). An issue of some uncertainty is the size of households (as defined above). The data of Smith (1999) indicate household sizes of about 14, 25 and 27 people per poor, medium and rich household, whereas other estimates are of the order of 10 persons or so (Bekure and Grandin, 1991; Kijasi et al., 1997). Our numbers are high because they reflect the actual number of people in the household at the time of interview. It is likely that the other published estimates relate to household size based on a man, his wives and their children only. For the control run, we assumed household sizes of 10, 17 and 19 persons per household, giving a weighted average of 15 persons per household. Given this average household size, this suggests a total of 2991 households in NCA for the control run.

In terms of the herd sizes for the three household types, Boone and Coughenour (2000) used totals of 116,000 cattle and 193,000 sheep and goats in NCA (data from Kijazi et al., 1997), goats outnumbering sheep by an estimated ratio of 3 to 2. To divide up the total cattle and smallstock population per household, we inferred household herd sizes from ratios found during field work (Smith, 1999), although some adjustments had to be made to preserve total herd numbers in relation to household numbers. An important point in PHEWS is that total livestock numbers are really the driving force for household herd sizes. As is clear from the results of scenario analysis (discussed below), if human population increases are imposed on NCA, then household sizes remain the same; the number of households increases; and household livestock herds of cattle, sheep and goats will decrease, since the same numbers of animals must go round more households. It is thus important to get the initial balances right between households and herd sizes. Characteristics of the three household types for the control run are shown in Table 8, together with an indication of the source of the data.

Table 9 shows sources for the other input data shown in Table 5, by category. There were some input data for which there are essentially no sources of information (either because of the way they are defined in the model, or because relevant information simply does not exist,

Table 8. Characteristics of household types used for the control run

	Poor Households	Medium Households	Rich Households	Sum or Weighted Mean	Source
Proportion of households in NCA	0.35	0.40	0.25	-	Homewood (1992); Potkanski (1997); McCabe et al. (1997b)
Number of households	1047	1196	748	2991	NCAA (1999); Smith (1999)
Cultivated land per household (ha)	0.67	0.89	1.42	0.95	Smith (1999); McCabe et al. (1997a)
Total land area cultivated (ha)	701	1064	1062	2827	Derived
People per household	12	17	19	15.0	NCAA (1999); Smith (1999)
Cattle per household	11	31	90	39	Smith (1999); estimated and derived
Smallstock per household	18	45	160	64	Smith (1999); estimated and derived
Total cattle	11,517	37,076	67,407	116,000	Kijazi et al. (1997)
Total smallstock	18,846	53,820	120,334	193,000	Kijazi et al. (1997)

Table 9. Sources of the input data in ECMOD.DAT (Table 5)

Data	Source
Adult equivalents	Bekure et al. (1991); Grandin (1988)
Tropical Livestock Units of cattle and smallstock by age:sex ratio	Bekure et al. (1991)
Caloric content of foods	Galvin (1985)
Household sizes, herd sizes	See Table 8
Human age:sex ratios	Smith (1999)
Percentage of land sown to maize	Smith (1999) and derived
Daily calorific requirements of pastoralists by age:sex ratio	Derived from Homewood (1992)
Household TLU and cash targets	Calibration variables
Opportunistic slaughter probabilities	Calibration variables
Income by household type	Smith (1999), slightly modified
Ceiling milk yields, kg per cow per day	Bekure et al. (1991)
Proportion of milk sold	Smith (1999)
Commodity prices	Smith (1999)
Expenditures by household type	Smith (1999), slightly modified
Sell-buy matrices	Calibration variables
Milk and meat yields as a function of body condition	Boone and Coughenour (2000)
Maize yields as a function of seasonal rainfall	Smith (1999), slightly modified

so far as we are aware). These then became critical variables for calibrating the model, and they included the household TLU and cash income targets, and the sell-buy matrices. As noted above, PHEWS has been calibrated for NCA, in the sense that it appears to produce plausible behaviour in relation to the control run. We show below that it also appears to produce plausible behaviour in relation to a wide range of scenarios inflicted on it. This does not mean that the model is in any sense "valid" (this, strictly speaking, has yet to be determined), but it is a very promising start. Indeed, there are no reasons why some highly specific fieldwork could not be designed to elicit information from pastoralists concerning their livestock trading decisions and household targets, but as yet this has not been done.

3.6 Scenario analysis

The NCA Control Model

Boone and Coughenour (2000) describe the control model, the idea of which is to model Ngorongoro as it is now. This control model included seven types of vegetation – palatable grass, palatable forbs, unpalatable herbs, palatable shrubs, unpalatable shrubs, evergreen trees, and deciduous woods. The changes in plants are modelled for a fifteen-year period, from 1973 to 1988. The control model simulates seasonal changes in total biomass, in response to the wet and dry seasons. Particularly dry periods, such as the late 1970s, yield less biomass than wetter periods, such as the early 1980s. Livestock populations change each year, as animals in the 17 herds die and are born, and over the long term, as dry and wet periods are experienced in NCA. In the control model, populations for migratory animals are set as a constant. The proportion of animals in NCA changes from month to month, but the total does not. The 17 herds in the control model are as follows:

Cattle	Migratory wildebeest
Resident wildebeest	Migratory zebra
Resident zebra	Buffalo in the crater area
Buffalo in the rest of NCA	Migratory grazing antelope
Resident grazing antelope	Goats
Sheep	Browsing antelope in the crater area
Browsing antelope in the rest of NCA	Elephant
Rhinoceros	Giraffe
Warthog	

The control model was used to calibrate the PHEWS module. Ecologically, the outputs of the control model are quite stable: animal populations rise and fall annually and in response to longer-term weather patterns of below-average and above-average rainfall, but basically the system is relatively stable. For calibrating PHEWS, the object was to end up with similar stability in terms of household welfare and household herd numbers. The control run was thus undertaken with no population increase imposed, and with the values of other inputs as shown in Tables 4 and 5.

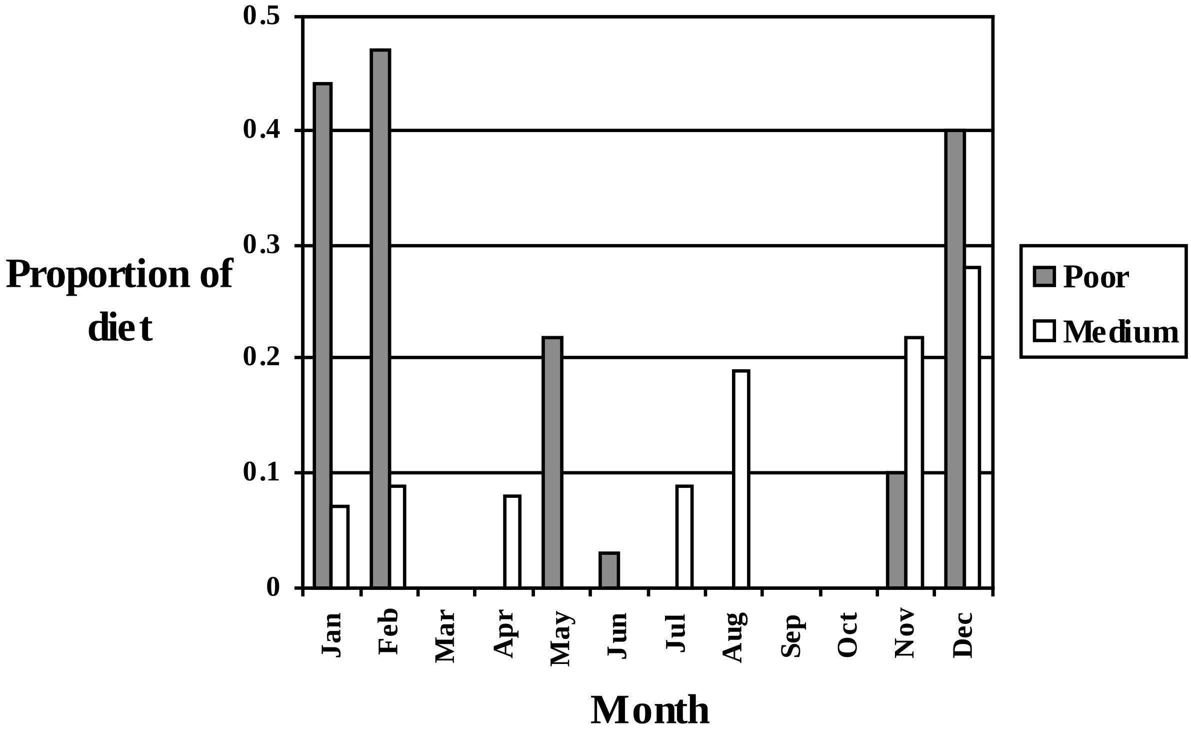
Summary results for the NCA control run are tabulated in Table 10. The first six rows of the table show the total percentage makeup of diet for the three household types. Total milk consumed refers to the milk that is produced by the household's own herd. The data of Galvin (1994) and others (e.g., Homewood, 1992) show clearly that the diets of the Maasai in NCA do not vary much depending on household wealth. Assuming that gifts/relief (the portion of the diet that cannot be produced by the household from animals or crops, and that cannot be bought with cash) are in milk, then the dietary figures from the control run indicate that NCA diets are made up of about 12% meat, 29% milk, and 56% grain, which accords well with the approximate 10:30:60 proportions for meat, milk and grain that other researchers have found (Homewood, 1992; Nestel, 19985; Galvin, 1992). A major indicator of household welfare lies in the percentage of gifts or relief. As might be expected, this changes sharply, depending on household wealth, from 13% of all dietary energy in poor households to zero for rich households. The problems that poor and medium households have are not surprising, given that these households have 1.07 and 1.65 TLUs per Adult Equivalent, on average. Even the rich households have only 4.40 TLUs per AE, which is well below the threshold of 6-8 that is often cited as a necessary requirement for sustainable pastoralism (Dahl and Hjort, 1976; Galvin et al., 2001).

The need for poor households to receive gifts or relief is highly seasonal, as might be expected. Figure 3 shows the average monthly relief figures for poor and medium households, and indicates that such households are clearly at serious risk of food insecurity during certain months, when the household's own resources can provide 60% or less of the energy requirements of the household members. Interestingly, there is an interaction between the time when households are most affected and household type. Poor households are, on average, particularly badly affected in December, January and February, while medium households are more affected in August, November and December. Medium households

Table 10. Summary output for the control run over 15 years for the three household types

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

Figure 3. Seasonality of the percentage of gift/relief calories in the diets of poor and medium households (control run, average of 15 years)



have larger herds and more area in crops compared with poor households, but they have more people than poor households (about 12 Adult Equivalents compared with 7) and thus greatly increased monthly caloric requirements.

The results in Table 10 also highlight differences in income and cash used to buy food by household type (these are totals over the 15 years of the simulation run). The average size of the cash box per month is shown in row 9. The standard deviation of these figures by household type shows huge variability; for poor and medium households alike, the CV is close to 100%, again underlining the vulnerability of such households to cash shortages and thus to food shortages as well. Again, as might be expected, the results show that the richer the household, the greater the percentage of food available from the household's own resources, although even rich households are dependent for 40% of their calories on outside sources.

It must be remembered that these results apply in a reasonably steady-state situation. Assuming that the calorie transfers via gifts and relief are actually occurring, then the control run describes a reasonably stable situation. Figure 4 shows the evolution of household herd sizes for rich households. There is substantial seasonal variation, but the overall trends in livestock numbers per household are fairly flat. This is not surprising, given that total numbers are cyclical but stable (Boone and Coughenour, 2000) and that the number of households is constant. Similarly, if the two ratios, actual TLUs per Adult Equivalent and cash income per month per Adult Equivalent, or the two welfare ratios (these as a proportion of the household's desired numbers of TLUs and cash income), are plotted over time (data not shown), no trends are apparent for any of the household types. In a typical simulation year, poor households in the control run are selling two or three goats for cash; medium households are selling three goats and a steer for cash, while rich households are selling three or four steers during the year for cash.

As an example of the spatial output that can be produced using SMS, Figure 5 shows household density in NCA for the first four months of the control run. The maps are identical, as there is no population growth in the control run.

In sum, the results from the control run for the household model show reasonable stability over a 15-year period, but sustainability of households and household welfare for the less

Figure 4. Evolution of herd numbers for rich households, control run -- screen capture from the SMS

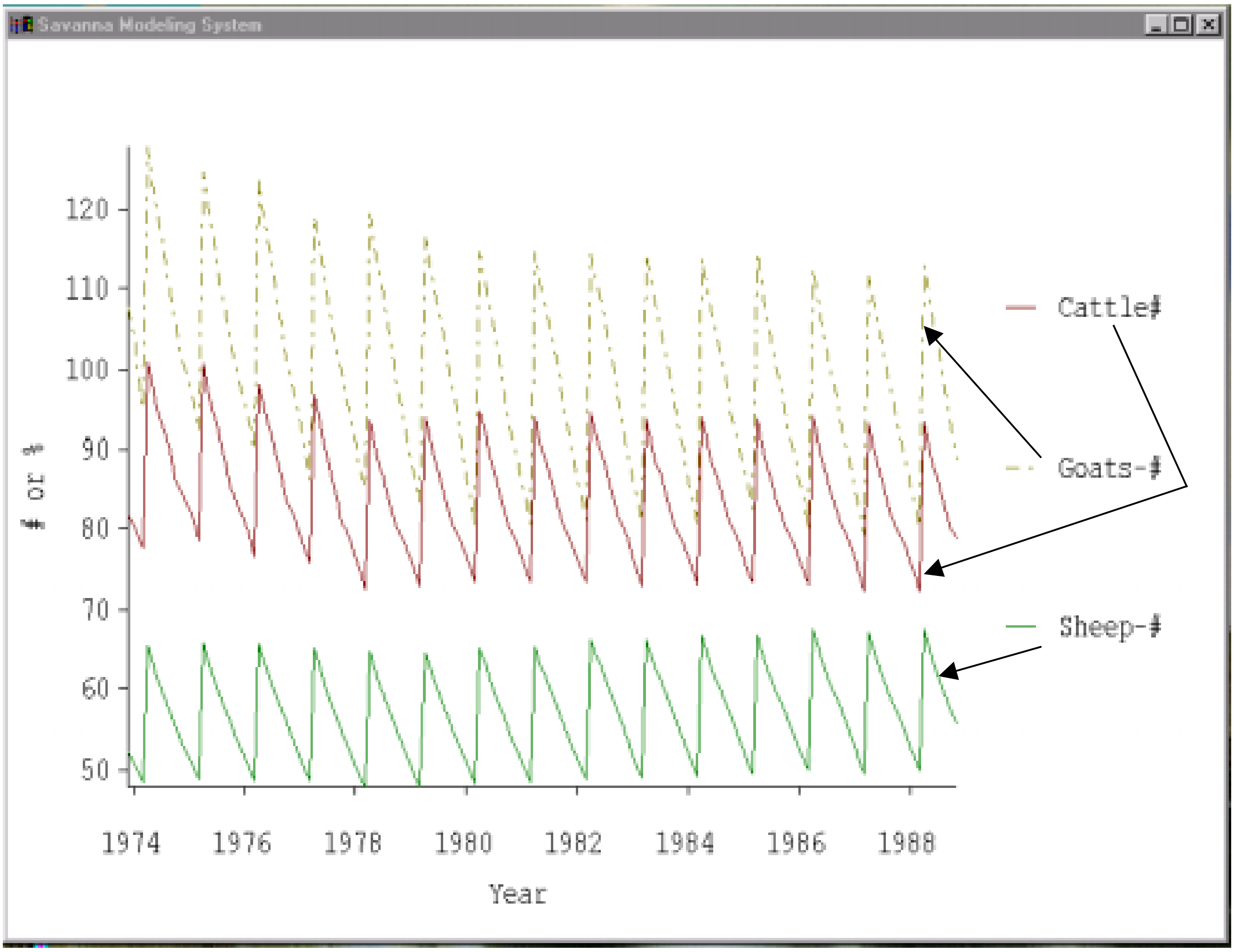
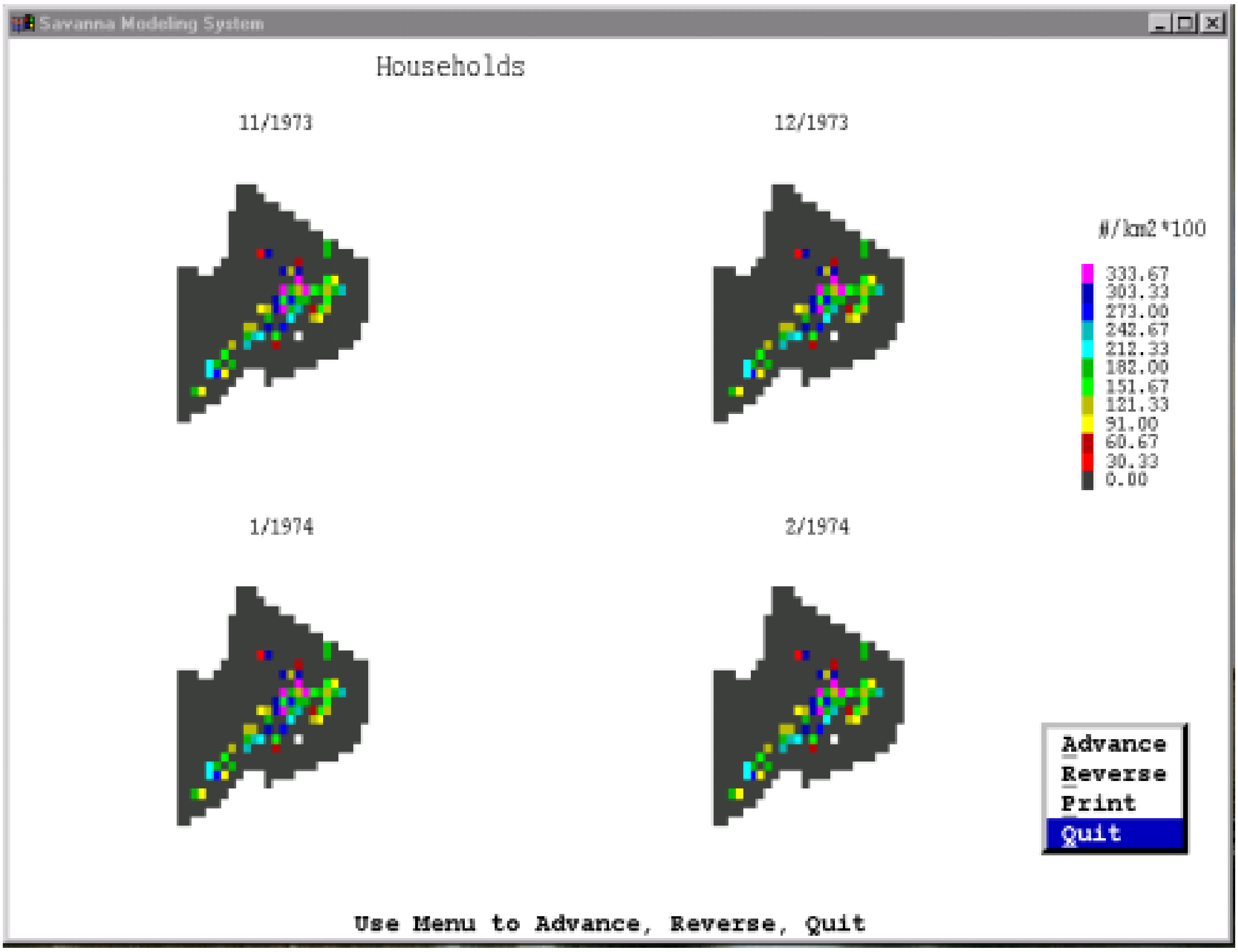


Figure 5. Household density in NCA for the first four months of the control run (households per square km * 100) -- screen capture from the SMS



well-off are still dependent on gifts and/or food relief. All households depend on “outside” food calories, which have to be purchased. The number of TLUs per Adult Equivalent for all household types is very low, and poorer households are very food- and cash-insecure. The control run shows clearly that pastoralist welfare in NCA, even with small amounts of agriculture allowed, is not even remotely internally sustainable at current human population levels. Even the basis for looking at a range of alternative scenarios, therefore, is of real concern.

Other scenarios

A range of other scenarios were run using Savanna and PHEWS. These are summarised in Table 11. Given the quantity of output that can be produced by the model, the subsections that follow attempt to distil the essential points arising from each scenario.

Scenarios 2 and 3: Population growth rates of 3% and 6% per year

These scenarios were identical to the control run, except that a human population growth rate of 3% per year was imposed, and then one of 6% per year. Table 12 shows three key summary indicators of household welfare, and for all household types, these are declining from the control run values. Figure 6 shows the evolution of household herd sizes for poor households under the 3% scenario. Livestock numbers are declining rapidly, as the number of households in the NCA is simulated to increase from 2990 to more than 4660 in the 15-year simulation period. The change in household food security, as measured by the proportion of relief in the diet, is shown in Figure 7 for both scenarios for poor households, in terms of the annual percentage of relief. A linear regression through these points shows an increase in relief of 0.34 % per year for the 3% scenario and a 0.75% increase per year for the 6% scenario. Figure 8 shows the changes in the TLU ratio (actual to desired) and the cash income ratio (actual to desired) for medium households. The former is declining, while the cash ratio oscillates around zero, but the variability of this is decreasing through time, apparently. Such households are caught in an increasing squeeze – fewer animals with which to feed the household, and fewer to sell for cash for grain, and no opportunities for increasing livestock numbers.

Table 11. Scenarios simulated with PHEWS and Savanna

Name	Description
1 CNTRL	Control run - same as the control run CNTRL in Boone and Coughenour (2000), over 15 years (as from 2001-2015), no population growth. The idea here is to look for long-term stability that can then be compared with other scenarios. This runs includes agriculture (0.67 ha for poor households, 0.89 ha for medium households, and 1.42 ha for rich households).
2 POPGR-3	As for the control run, but with 3% human population growth imposed for 2001-2015. This means an increase in population from 45,000 to some 70,000 during the simulation.
3 POPGR-6	As for the control run, but with 6% human population growth imposed for 2001-2015. An increase in population from 45,000 to nearly 108,000 during the simulation. Note that this rate is close to the current growth in numbers in NCA.
4 HIST-4A and HIST-4B	These are two scenarios designed to look at NCA in a historical perspective. For the first, the run goes from 1980 to 1990, with no Agriculture, using historical population of 14,600 in 1980 with a growth rate of 6% per year to arrive at 27,800 in 1990 (historically observed). The second run goes from 1991 to 1999, again with population growth of 6% per year, to end up in 1999 with 47,000 (observed). Agriculture is allowed for this period, again using the figures as for the control run. The object here is to compare and contrast changes in welfare with respect to population increase and the introduction of agriculture in 1991. Wildlife numbers are as assumed in the control run.
5 NOAG2015	This is as for the control run, but a 3% population growth rate is imposed, and no agriculture is allowed, for 2001-2015. The question being asked here is, given the current state of the system, and if agriculture was suddenly banned, how bad would things get for the pastoralists?
6 SUS2015	With no agriculture allowed, what are sustainable human population numbers to give reasonable welfare indicators? So how many people can NCA support with no agriculture, from a sustainable human welfare perspective? This is run as for the control, but with no agriculture allowed and a 1.5% population growth rate (to be realistic), so no huge in-migrations occurring (this is equivalent to a 25% increase in 15 years). We start with a purely hypothetical 1000 households (15,000 people) in 2000.
7 DISLOWSE	This is the DisLow scenario in Boone and Coughenour (2000), where the rate of loss in female cattle from disease is reduced by 50%. Other inputs are as for the control run (2000-2014, 0 % population growth rate, agriculture allowed).
8 PRODINCR	This is the BirthHi scenario in Boone and Coughenour (2000), where through vet care, cattle birth rates are increased by 5%. All else is as for the control run.
9 DROUGHTS	This is the Drought scenario in Boone and Coughenour (2000) -- a 2-year drought in 1983/84 with rainfall decreased by 50%. All else is as for the control run.
10 MOREAG	What happens if the area cultivated by households is doubled? Other parameters as for the control run, except double the areas of agriculture shown for the control run.

Table 12. Summary output for scenarios with 3% and 6% population increase per year over 15 years for the three household types

	Poor	**Medium**	**Rich**
3% Population Increase			
Total gifts/relief (% in diet)	15.7 (+17)	9.9 (+18)	0.1 ( )
Own food available %	38.8 (-6)	41.5 (-7)	56.4 (-2)
Average TLUs per Adult Equivalent	0.86 (-20)	1.33 (-19)	3.55 (-19)
6% Population Increase			
Total gifts/relief (% in diet)	17.7 (+32)	11.7 (+39)	0.1 ( )
Own food available %	36.7 (-11)	38.6 (-13)	54.3 (-6)
Average TLUs per Adult Equivalent	0.68 (-36)	1.05 (-37)	2.8 (-36)

Figures in parentheses show the percentage change from the control run (Table 10)

Figure 6. Evolution of herd numbers for poor households with 3% annual human population growth

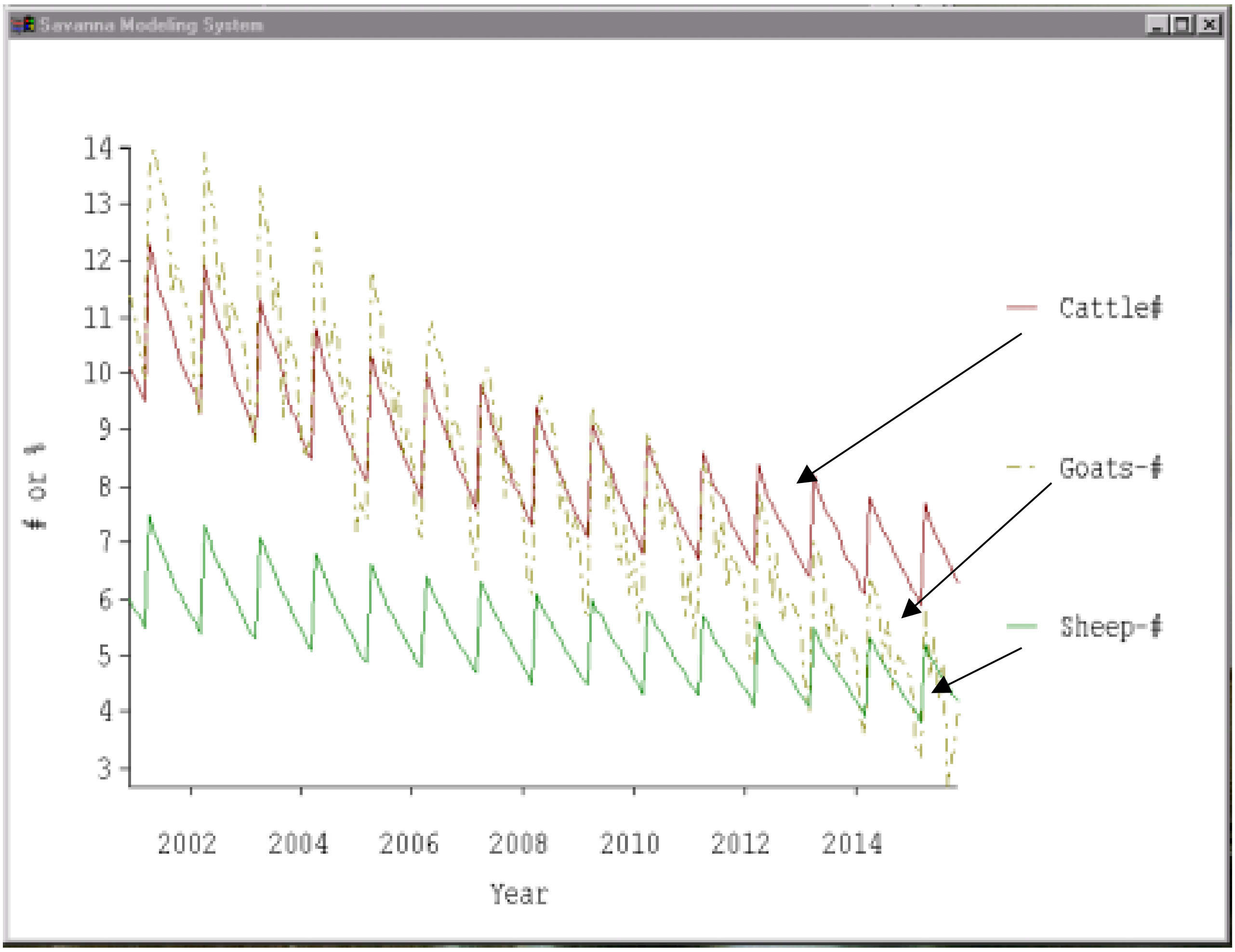


Figure 7. Annual percentage of relief food in diets of poor households with 3% and 6% annual human population growth rates

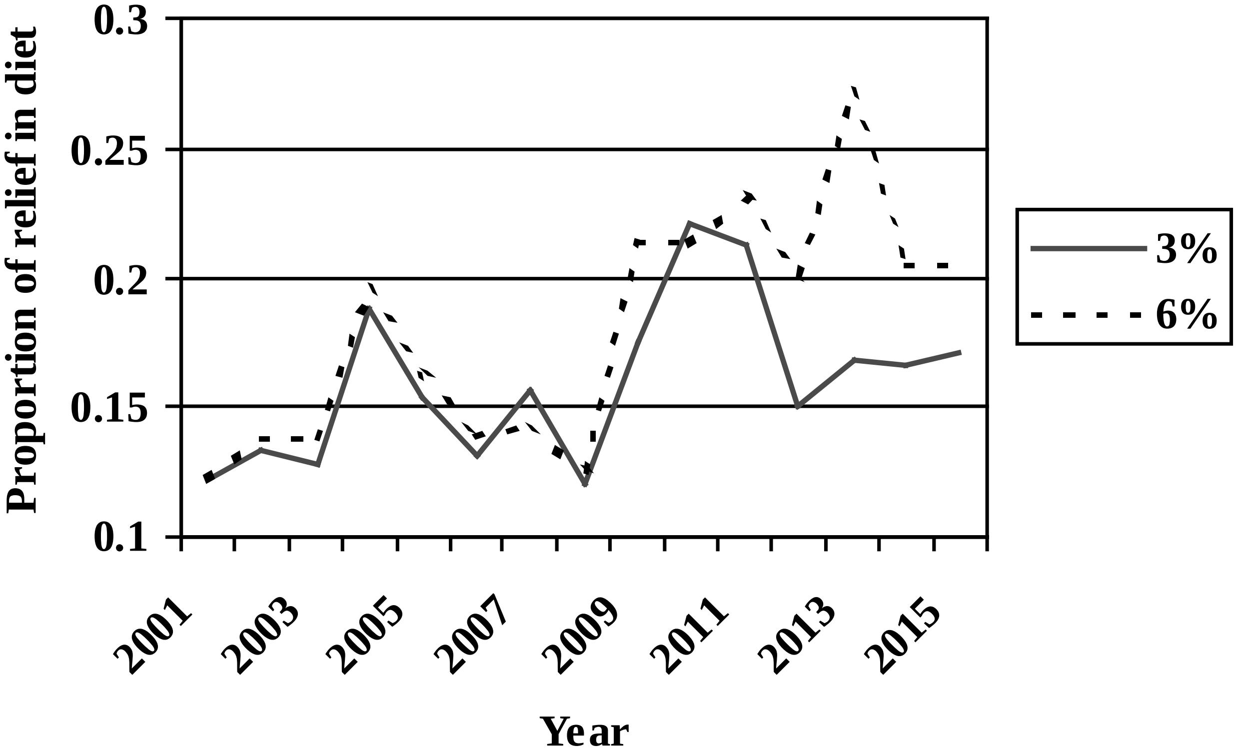


Figure 8. Evolution of the TLU ratio and the cash ratio in medium households with a 6%annual human population growth rate

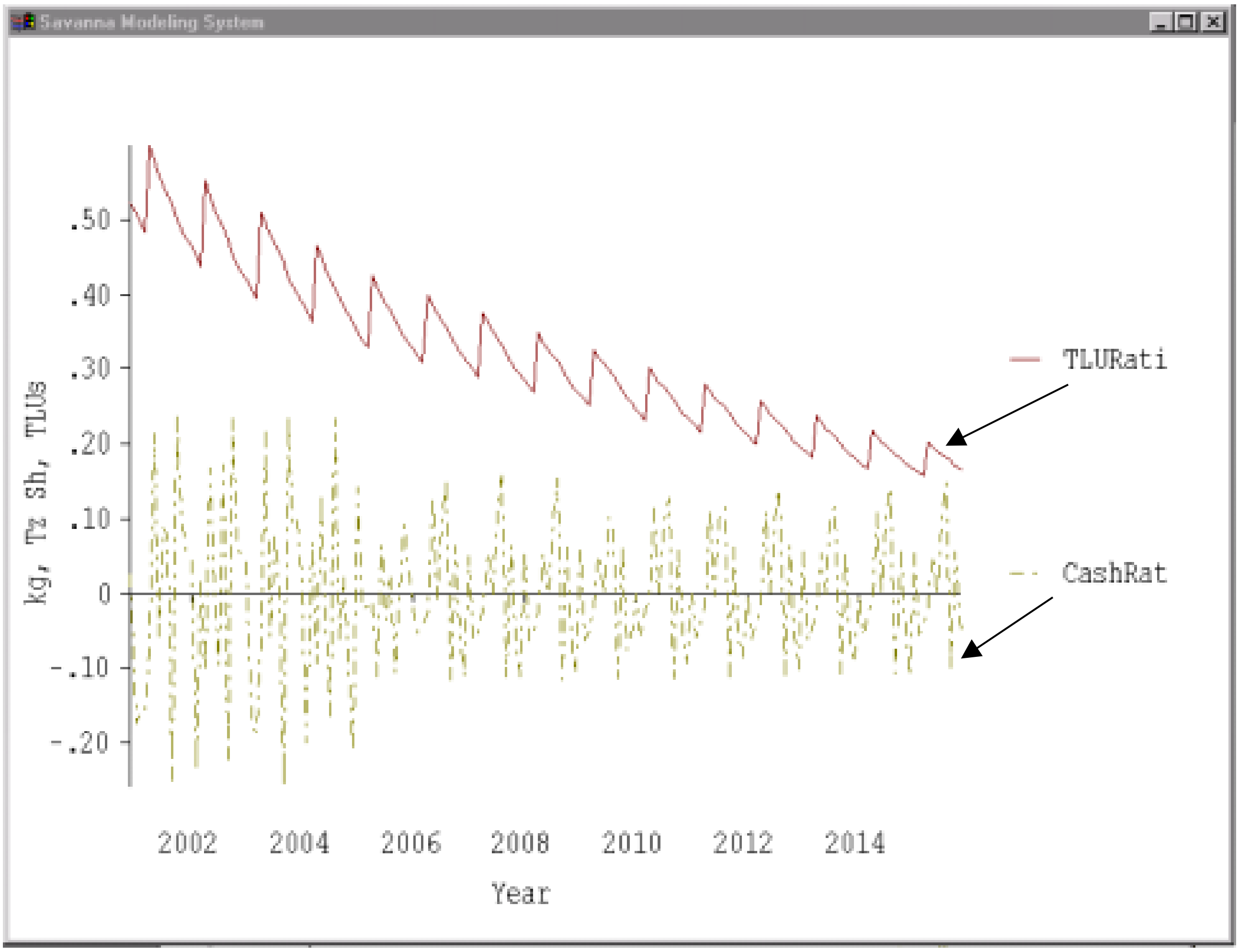


Figure 9 shows the increase in human population density in NCA from the first four months of the run to the last four months. Even with increasing areas of agriculture, as a result of increasing numbers of households, the total area even with a 6% increase per year is relatively small, and the impacts of a change from about 2,800 ha (the current situation) to 6,800 ha (after 15 years of 6% growth) of agriculture on wildlife numbers was shown to be very limited (Boone and Coughenour, 2000). It appears inevitable that any population growth from current numbers would adversely affect all households, but particularly the less well-off, whose food insecurity would do nothing but increase.

Scenarios 4a and 4b: The introduction of agriculture in 1991

These two scenarios were designed to look at NCA from a historical perspective. For the first, the run went as from 1980 to 1990, but with no agriculture allowed. The human population was set at 14,600 in 1980 (NCAA, 1999), with a growth rate of 6% per year to arrive at 27,800 in 1990 (as observed). The second run went as from 1991 to 1999, with a population growth of 6% per year, to finish in 1999 with the observed population of about 47,000 people. Agriculture was allowed for this second period, again using the areas per household as for the control run. The object of these runs was to compare and contrast changes in welfare with respect to population increase and the introduction of agriculture in 1991. Wildlife numbers are as assumed in the control run.

Figure 10 summarises the change in diet relief for poor and medium households. Even with a 6% population growth, the model suggests that the introduction of agriculture made a large and immediate difference in household food security in 1991 and 1992. It appears also that the rate of increase in diet relief was slowed markedly for both household types. For the period with no agriculture, the rate of increase in diet relief was about 1.9% per year for poor households and 1.3% for medium. After 1991, this decreased to about 0.6% increase per year for both household types, although model results suggest that things were deteriorating seriously in the late 1990s. By the end of 1990, poor, medium and rich households were providing 37%, 41% and 42% of their own food requirements themselves, with 2.7, 4.2 and 11.1 TLUs per Adult Equivalent, respectively. By the end of 1999, they were providing 44%, 47% and 58% of their own food, while their animal holdings had decreased to 1.4, 2.2 and 5.9 TLUs per AE, respectively.

Figure 9. Human population density in NCA for the first (top) and last (bottom) four months of the 6% annual human population growth rate scenario

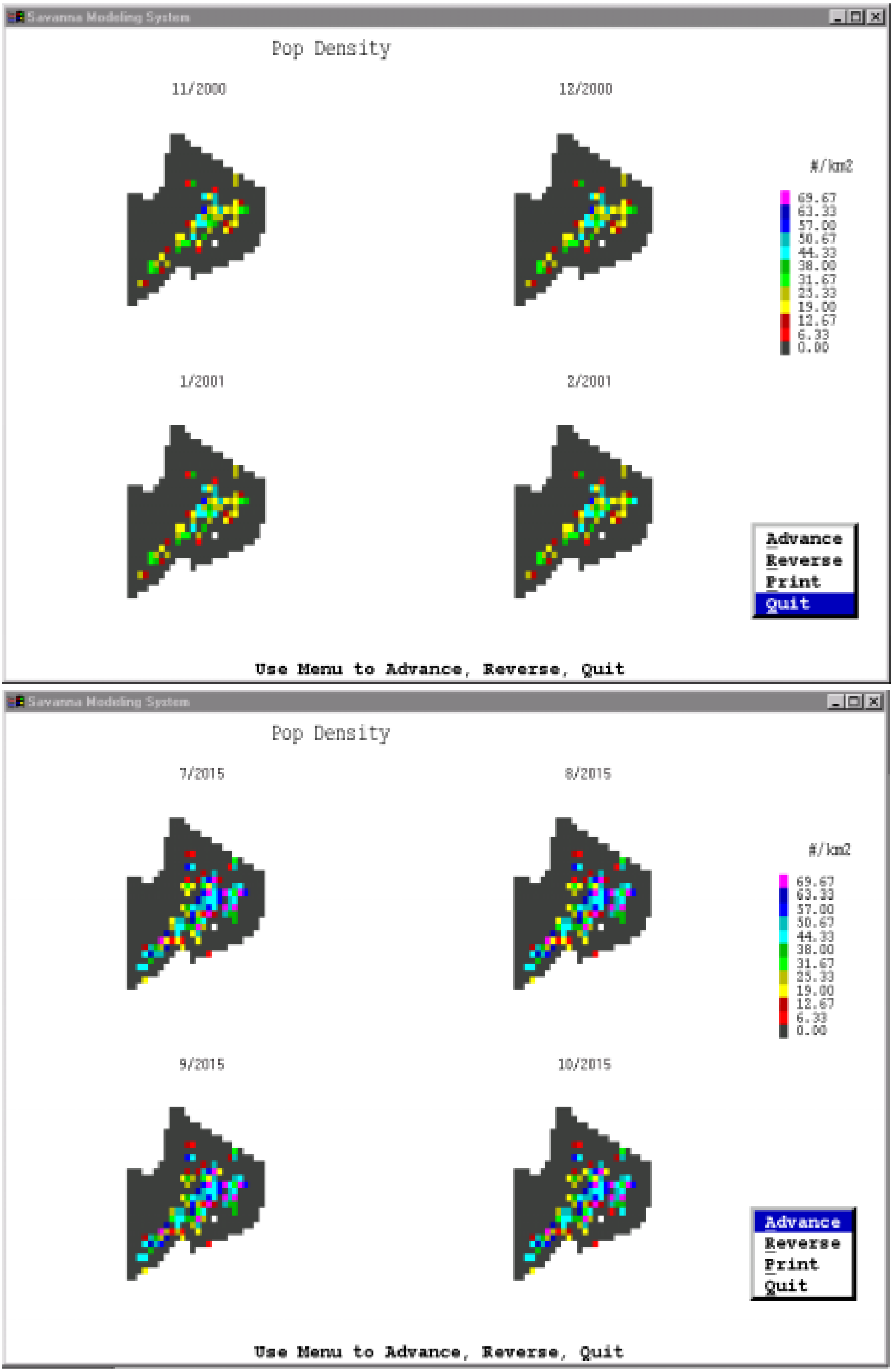
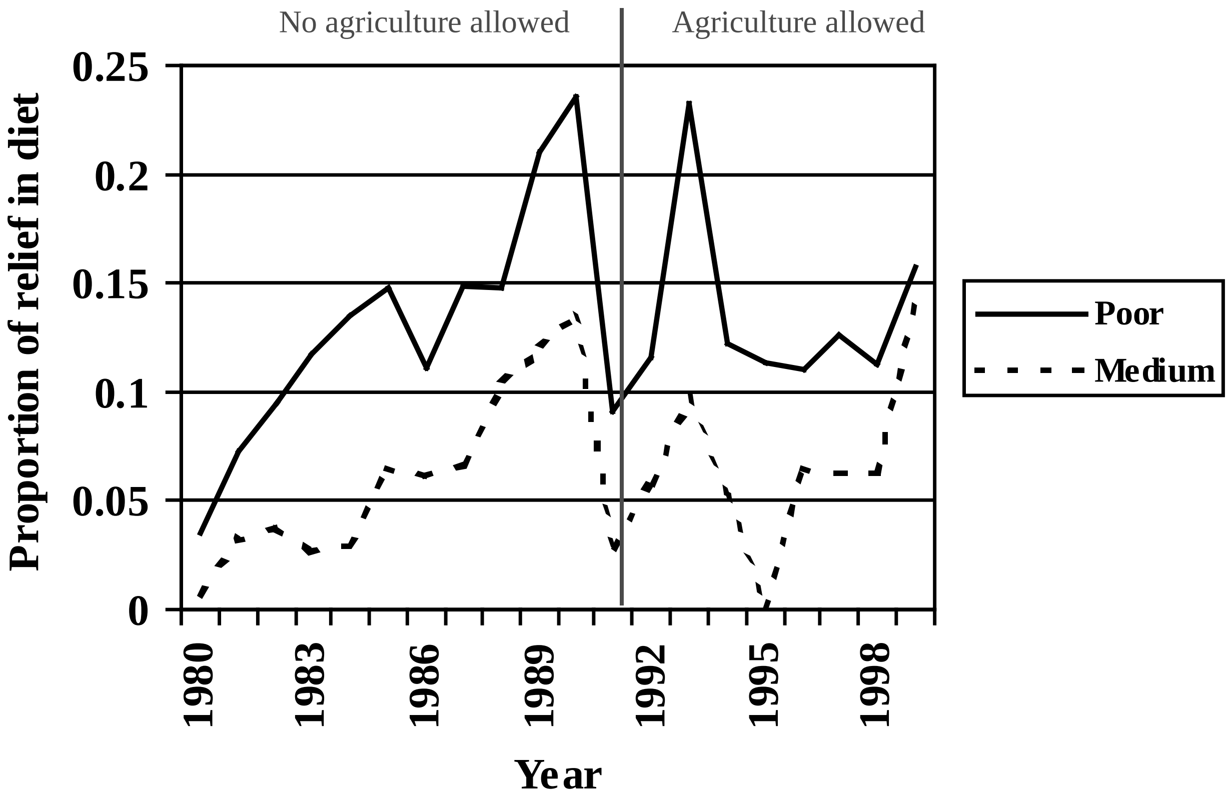


Figure 10. Evolution of the proportion of diet relief in poor and medium households for the period 1980-1999, including a 6% population increase per year and the introduction of agriculture in 1991



Given the lack of real market integration of the pastoralists, even under conditions of relatively low population density, poorer households would still not have had enough animals to minimise food insecurity. The dependence on grain, prior to 1991, could only have been met through cash transfers, and model results shown that, certainly in the years immediately after agriculture was allowed, food insecurity for the less well-off decreased substantially, even though cash flow in theses households (results not shown) was not much affected. These welfare "gains", if they can be so termed, appear to have been quickly overtaken by the late 1990s, as human population growth rates of 6% per year put increasing pressure on the NCA livestock populations; there were simply too few cattle to go round the burgeoning number of "new" households being established in NCA.

Scenario 5: The banning of agriculture in 2001

This scenario was set up as for the control run, but a 3% population growth rate was imposed, and no agriculture was allowed, for the period 2001-2015. The question being asked here is, given the current state of the system, and if agriculture was suddenly banned, how bad would things get for the pastoralists?

Summary results are shown in Table 13. Basically, if agriculture is banned in 2001, then cash almost disappears from the system by 2015, as households are forced to purchase grain. Livestock numbers decrease as all household types are forced to sell more animals for cash and as population growth continues apace. Poor households are dependent for nearly one quarter of their calories from gifts and relief, on average.

Scenario 6: Sustainable human population numbers with no agriculture

The various scenarios considered thus far are decidedly grim, from a pastoralist view point. Household welfare can only decrease under most of the conditions considered, which involve continued population growth at some level and/or detrimental changes in access to food calories. In this scenario, we look at the following: with no agriculture allowed, what are sustainable human population numbers to give "reasonable" welfare indicators -- how many people can NCA support with no agriculture and given no change in the economic base, from a sustainable human welfare perspective? The scenario was run as for the control, but with no agriculture allowed. A 1.5% population growth rate was imposed, since zero population

Table 13. Summary output for the "agriculture banned in 2001" scenario over 15 years for the three household types

	Poor	Medium	Rich
Total milk consumed (% in diet)	10.8 (-12)	17.1 (-15)	29.0 (0)
Total own grain consumed (% in diet)	0 ( )	0 ( )	0 ( )
Total meat consumed (% in diet)	12.0 (+2)	11.9 (0)	11.9 (-3)
Total other (incl sugar)(% in diet)	2.9 (0)	3.0 (0)	3.0 (0)
Total bought grain consumed (% in diet)	51.5 (+21)	54.1 (+23)	54.8 (+38)
Total gifts/relief (% in diet)	22.8 (+70)	14.0 (+67)	1.2 ( )
Total income from selling (Tz Sh, 000)	475 (-5)	301 (-56)	2,354 (-17)
Cash used to buy food (Tz Sh, 000)	1,236 (+13)	2,231 (+14)	2,549 (+21)
Average cashbox per month (Tz Sh)	7,397 (-22)	7,344 (-34)	68,891 (-48)
Cashbox sd per month (Tz Sh)	6,688 ( )	8,060 ( )	28,791 ( )
Own food available %	22.8 (-45)	29.0 (-35)	40.9 (-29)
Average TLUs per Adult Equivalent	0.87 (-19)	1.33 (-19)	3.56 (-19)

Figures in parentheses show the percentage change from the control run (Table 10)

growth is not realistic. As has happened in the past, it is assumed that there are no large in-migrations of people occurring. The run starts with a purely hypothetical 1000 households (15,000 people) in 2001.

Results in Table 14 support the notion that agriculture for the households in NCA is extremely important. Without it, even with a human population of about one third of what it is currently, food insecurity is increased compared with the control run. The impacts on cash flow in the poorer households is apparent also – more spent on grain, even though TLUs per Adult Equivalent are much higher than for the control run (Table 10). The question of what human population can be sustained in NCA is thus somewhat beside the point. This scenario would tend to suggest that if there are to be pastoralists in NCA, then even if there are rather few of them, the practice of agriculture is of critical importance to them and to their household food security. If not agriculture, then some other forms of household economic diversity would need to be available to pastoralists.

Table 14. Selected summary outputs for the scenario of an NCA without agriculture, 15,000 people, and a 1.5 % population increase per year over 15 years, for the three household types

	Poor	**Medium**	**Rich**
Total gifts/relief (% in diet)	14.5 (+8)	5.9 (-30)	0.0 ( )
Average cashbox per month (Tz Sh)	4,146 (-56)	6,021 (-46)	110,100 (-17)
Cashbox standard deviation per month (Tz Sh)	6,523 ( )	8,126 ( )	54,950 ( )
Own food available (%)	36.5 (-11)	41.2 (-7)	42.2 (-27)
Average TLUs per Adult Equivalent	2.58 (+141)	3.97 (+141)	10.61 (+141)

Figures in parentheses show the percentage change from the control run (Table 10)

Scenarios 7 and 8: Productivity increasing scenarios, through reducing the effects of cattle disease and increasing birth rates

Cattle populations in NCA are generally thought to be below the carrying capacity, largely because of diseases such as East Coast fever. One of the scenarios in Boone and Coughenour (2000) was utilised, where the rate of loss in female cattle from disease was reduced by 50%. This reduction might emulate the case where improved veterinary care is practiced in NCA, for example. Other inputs were as for the control run (2000-2015, 0 % population growth rate, agriculture allowed).

Another scenario in Boone and Coughenour (2000) was run, where through veterinary care, cattle birth rates were increased by 5%. Again, all else was set as for the control run. Results for these two scenarios are considered together, under the general heading of productivity increasing scenarios.

Table 15 presents selected summary outputs from these two scenarios. As might be expected, increasing household livestock numbers, either through fewer losses to disease or through increased birth rates, works its way through to reduce the proportion of relief in the diet. The average cash box size is greatly increased compared with the control run, as offtake rates, even from small herds, can be greatly increased to increase the flow of cash in and out of the system. – although the variability of the cash box is substantial. For poor and medium households, the proportion of own food available increases, as does the overall TLUs per AE. Both scenarios have similar impacts on household food security and cash flow. It should be noted that there may be increased costs of production associated with (for example) better veterinary care. These costs are not included, but the results show clear impacts on improved food security.

It is clear that with such scenarios, there are two things the household can do – either build up herd numbers to desired levels of TLUs per AE, or sell animals to increase cash flow in the household. Of course, households will probably do both these things. Currently, the productivity scenarios in PHEWS result in both herd sizes being built up and off-takes being increased as well. Figure 11 shows the increase over time in the ratio of actual to desired TLUs per Adult Equivalent for poor and medium households, as livestock numbers are built up (the values for rich households are similar and are not shown for clarity). Whether this is

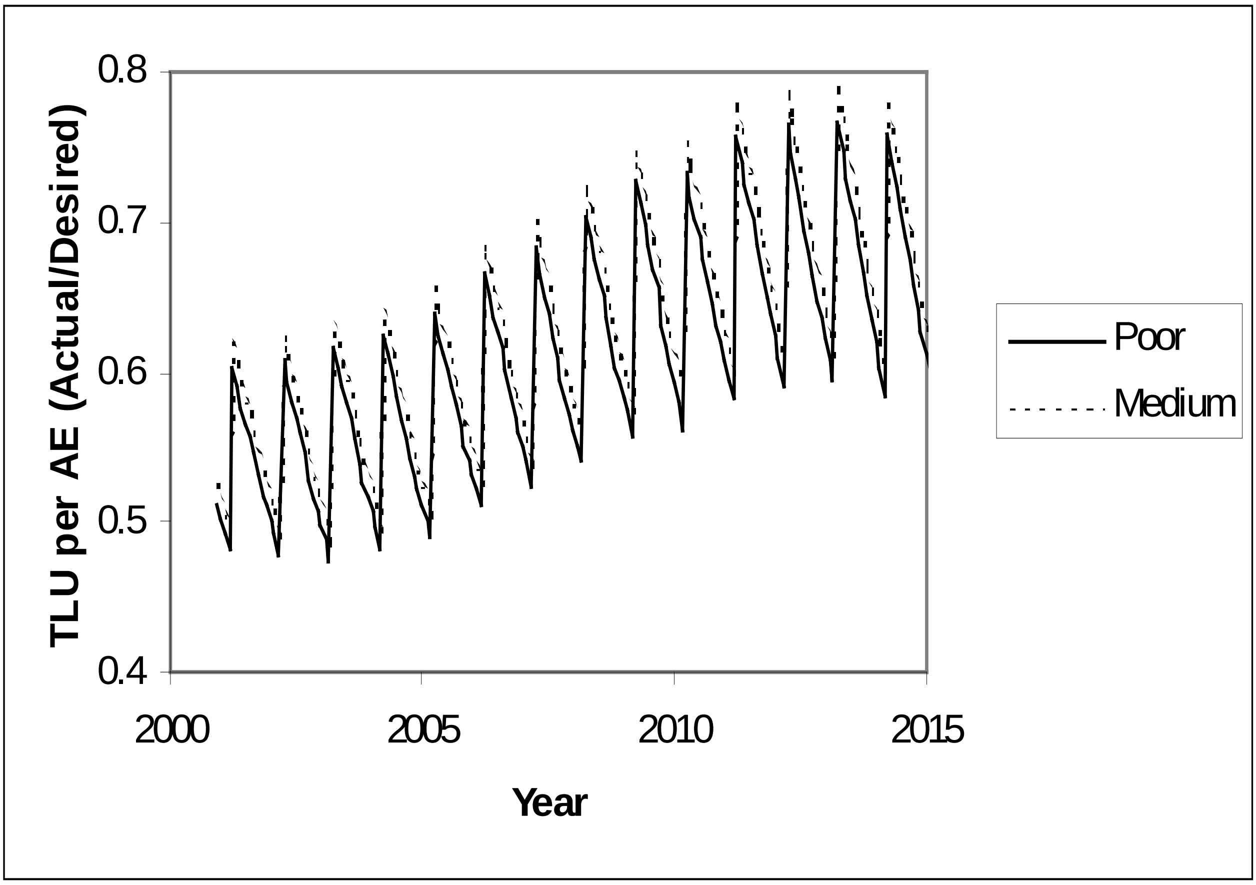
Table 15. Selected summary outputs for productivity increase scenarios in NCA (with agriculture)

	Poor	**Medium**	**Rich**
Lower disease scenario			
Total gifts/relief (% in diet)	7.3 (-46)	6.4 (-24)	0.0 ( )
Total income from selling (Tz Sh * 1000)	924 (+86)	1,096 (+60)	3,047 (+8)
Average cashbox per month (Tz Sh)	47,660 (+401)	12,982 (+17)	249,718 (+89)
Cashbox sd per month (Tz Sh)	51,844 ( )	12,336 ( )	124,959 ( )
Own food available %	43.0 (+5)	46.3 (+4)	57.5 (0)
Average TLUs per Adult Equivalent	1.35 (+26)	2.08 (+26)	5.53 (+25)
Increased birth rate scenario			
Total gifts/relief (% in diet)	7.4 (-45)	7.1 (-15)	0.0 ( )
Total income from selling (Tz Sh * 1000)	923 (+85)	1,032 (+50)	2,996 (+6)
Average cashbox per month (Tz Sh)	46,194 (+386)	13,019 (+17)	237,815 (+80)
Cashbox sd per month (Tz Sh)	49,757 ( )	12,198 ( )	113,025 ( )
Own food available %	42.7 (+4)	45.9 (+3)	57.5 (0)
Average TLUs per Adult Equivalent	1.34 (+25)	2.06 (+25)	5.50 (+25)

Figures in parentheses show the percentage change from the control run (Table 10)

realistic or not is as yet not really known. In general, we need more information on how households respond in such situations, because details at the household level on the trade-off between increasing herd sizes and increasing cash flow are essentially absent. We do know, however, that after agriculture was allowed in 1991 herd sizes increased (McCabe et al.

Figure 11. Evolution of the actual-to-desired livestock welfare ratio (TLUs per Adult Equivalent) for poor and medium households for the "reduced livestock disease" scenario



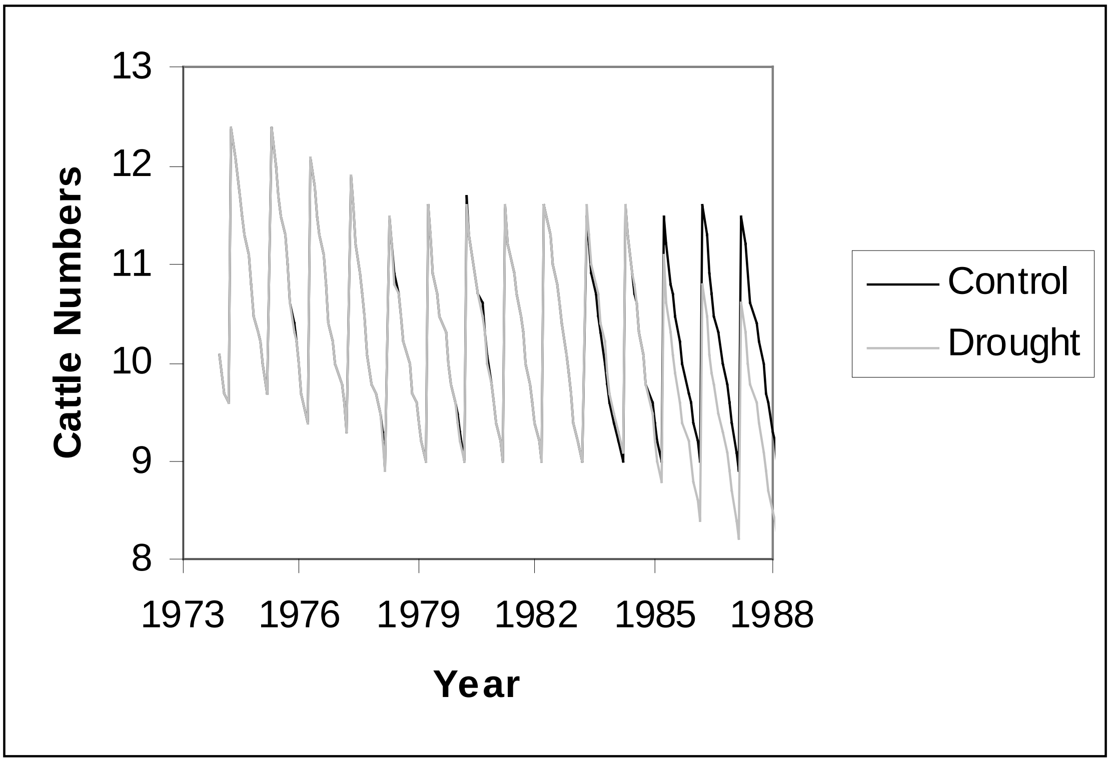
1997a). So, through analogy, we might surmise that household herd size will increase first when conditions are good. Livestock will only be sold for emergencies and only after agricultural produce has been sold.

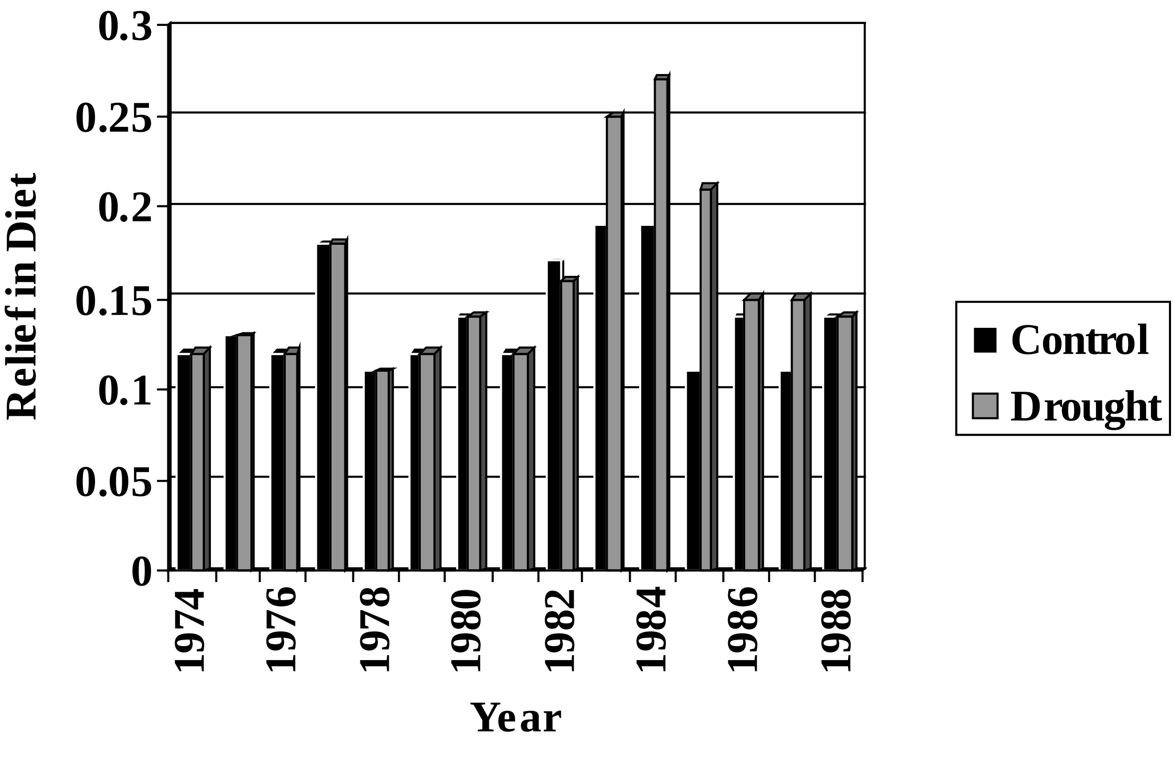
Scenario 9: The effects of drought

This is the drought scenario in Boone and Coughenour (2000) . A 2-year drought was imposed for the period 1983 to 1984 with rainfall decreased by 50% from observed values. All other inputs were kept the same as for the control run.

Impacts on cattle herd size for poor households are shown in the top of Figure 12. There is a lag of some 2 years before the major effects are felt at the household level in terms of livestock numbers. In terms of dietary energy intake, the effects are immediate; the bottom of Figure 12 shows the proportion of relief in the diet for poor households, and this increases substantially from 1983 onwards, compared with the control run. These figures are reflected in the summary variables, where the proportion of gifts/relief increased to more than 15% of the entire dietary energy intake for poor households and to 9% for medium households, compared with the control run. Own food available decreased to 39%, 42% and 55% for poor, medium and rich households, and TLUs per AE decreased somewhat also, compared with the control run (Table 10). Drought clearly has important impacts: in the immediate term, household food security is severely compromised, but there is also the longer-term impact on livestock numbers, where pastoralists have to build up livestock numbers again.

Figure 12. Comparison of the control run and the 1983-1984 drought run:
(top) Cattle herd size for poor households
(bottom) Proportion of relief in the diet for poor households





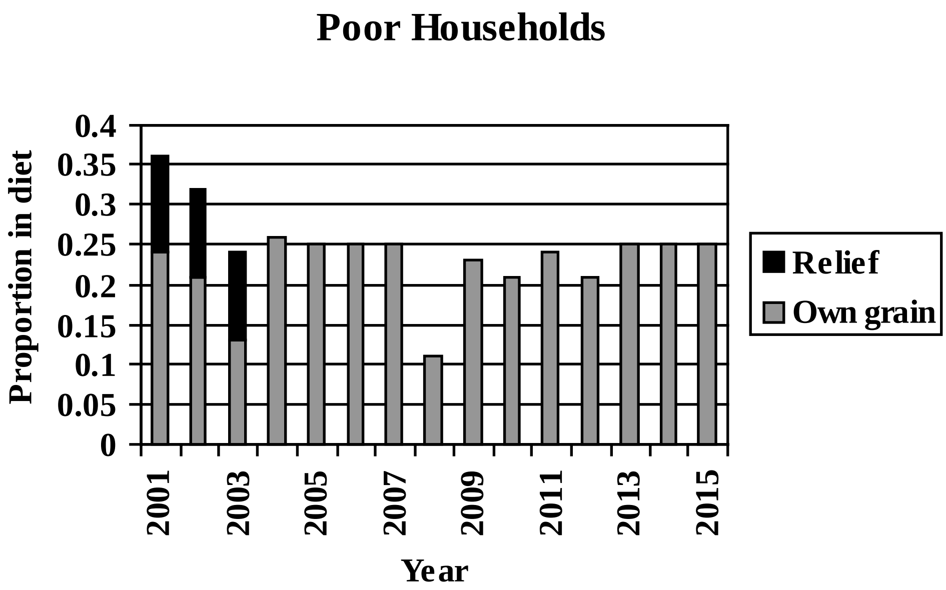
Scenario 10: Doubling the area of agriculture per household

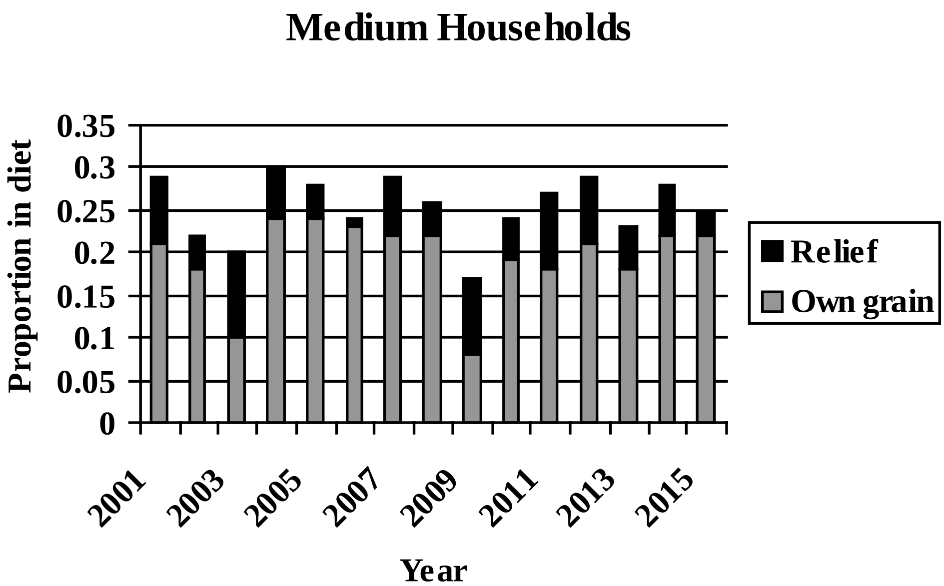
This scenario explores what happens if the area cultivated by households is doubled, from the standard values of 0.67, 0.89, and 1.42 ha per poor, medium and rich household, respectively. The impacts of this scenario are summarised in Figure 13, in terms of annual percentages of the diet coming from own grain consumed and gifts/relief for poor and medium households. Overall, relief decreased to 2% only for poor households and to 5% for medium households. The amount of cash spent on food (purchased grain) decreased for all three household types by up to 25%, compared with the control run. As might be expected, the average cash box per month increased for all household types. These impacts were reflected in the percentage of own food available: 52%, 54% and 65% for poor, medium and rich households, showing substantial increases over the control run values (Table 10). The doubling of agricultural area per household has a highly beneficial impact on poor households and on medium households, although somewhat less impact in terms of food security on the latter, because medium household have 40% more occupants but only 33% more agricultural land than poor households.

The simulated impacts of increased agriculture on household food security are thus substantial. Compared with the control run, this scenario entails an increase in agricultural area in NCA from some 2830 ha to 5660 ha. The higher figure is still only about 0.6% of the land area of NCA, and Boone and Coughenour (2000) showed only modest impacts on wildlife of levels of agriculture up to 5% of the land area. PHEWS takes no account, however, of labour and cash constraints in terms of establishing and maintaining crops on this increased land area. Similarly, nothing is said about the aesthetic impacts of increased areas of agriculture on the landscape from the tourist's point of view. Even so, if pastoralists are to continue as part of the landscape of NCA, then allocating increased (but still small) amounts of agricultural land seems an effective mechanism for improving household food security for the less well-off.

A summary of the scenario analysis carried out for NCA, and some comments on the suitability of PHEWS as currently formulated, may be found in section 5 below.

Figure 13. Annual proportion of diet relief in poor and medium households for the period 2001-2015 with double the area of agriculture per household of the control run





4 The Kajiado Case Study

4.1 Background

The situation in the second case study site, Kajiado in Kenya, is very different from the case of NCA. Kajiado District forms part of Kenya's rangelands, and contains the Amboseli National Park. Amboseli was made a reserve in 1948, and in 1974, the central 488 square kilometers (188 square miles) were designated as the Amboseli National Park. Local Maasai and Park managers have worked together to resolve ongoing issues of joint resource use, conservation impacts on wildlife and Maasai, and compensation to Maasai for their forfeiture of Park grazing and water.

The land tenure reform programme implemented in Kajiado District from 1966, in which group and commercial ranches were established, set the stage for the development of conflict between wildlife and pastoral livestock. Pastoralists were able to move about to avoid concentration of wildlife in their grazing areas at certain seasons in order to minimize transmission of diseases from the wildlife. However, the assignment of property rights to discrete land rights has circumscribed such movement and reduced the flexibility with which pastoralists can use nomadic movement to minimize wildlife-induced losses.

Kajiado District was the experimental district for the implementation of the government-instigated group ranch programme: 52 group ranches were established in the district, covering 1,526,812 hectares which constitute about 76% of the previous trust land. The remaining 24% of the trust land was adjudicated into 378 commercial ranches. This excludes land owned by the government or land meant for public utilities. The group ranch programme, therefore, covers the largest part of the land area in Kajiado District.

The group ranch programme had the objective of increasing the off-take of pastoral livestock for commercial sale and thereby meeting the objective of satisfying the beef demand of urban markets and also commercializing livestock production for the benefit of the pastoralists. But probably more important was the objective of making the group ranch a vehicle for bringing development assistance to pastoralists in terms of communal facilities, such as boreholes, dams, and dips, which when shared by many pastoralists in a group ranch, reduce the unit cost to the individual due to economies of scale. Group ranches, in addition, allowed for communal grazing, just like traditional pastoralism, for the purposes of enabling pastoralists to make a smooth transition to commercial private ranching and to maintain mutually viable ranches.

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

Without the sharing of acquired inputs, the group ranch implies merely joint ownership. The focus of individuals in group ranching then becomes land ownership. Conflicts have arisen and proliferated over membership of a group ranch and, therefore, over entitlement to a share of the group ranch, as well as over the actual use of group ranch resources, such as grazing and water. The group ranches that have not been subdivided are generally those that have pending court cases concerning disputes over land ownership. There are also a few group ranches that have not been subdivided either because they are too dry (those in Magadi division, for example) or because there are some wildlife tourism benefits anticipated. Otherwise, the unmistakable trend for group ranches in the district is a movement towards privatisation through subdivision. Table 16 shows the status of the subdivision of group ranches by September 1999. Twenty-nine group ranches have been completely subdivided such that the owners have obtained individual title deeds. In total, these group ranches account for 51% of all group ranches and 35% of the group ranch area. However, when these are added to another eleven group ranches in the process of subdivision, the extent of group ranch privatisation becomes clear. There are thus 40 subdivided group ranches, constituting some 70% of all group ranches and 59% of group ranches moving into private ownership and

Table 16. Status of group ranch subdivisions in Kajiado District, 1999

Group Ranches	Completely Subdivided	Partially Subdivided	Not yet Subdivided	Total
Number	29	11	17	57
Percentage	50.9	19.3	29.8	100.0
Total area	552,734 Ha (34.7%)	384,517 Ha (24.2%)	653,409 Ha (41.2%)	1,590,660 (100.0%)
Average Size (Ha)	19,060 Ha	34,956 Ha	38,436 Ha	

Source: Mbogoh and Munei (1999)

control. Only 17 group ranches remain intact, constituting 30% of all group ranches and covering 41% of the group ranching area.

In the 1980s, Maasai group ranches began to initiate wildlife and tourism projects. At the same time, Maasai were rapidly changing from subsistence pastoralism to an economy of farming, salaried employment, and commercial livestock ranching. Changing land use is currently transforming the entire economy of Amboseli from a mixed wildlife-livestock system to a primarily agriculture-based system. The proximity of wildlife, farm fields, and ranching is a cause of constant conflict. The Maasai production systems are thus very much in a state of flux. As in NCA, food security is still an issue of great concern, but the market orientation of these systems is generally widespread.

In addition to trying to provide useful information concerning some of these conflicts, Savanna is being used to investigate another aspect of Amboseli: critical swamps outside the Park that wildlife and livestock use for dry-season grazing and watering. Some swamps are accessible mostly to wildlife in the protected areas, while others are being converted to agriculture to meet the demand of urban consumers in Nairobi and Mombasa. Savanna, coupled with PHEWS, will be used to look at different options for management of these swamps so that pastoralism, agriculture, and wildlife can continue to co-exist.

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

4.2 Data collection

The first University of Nairobi survey

As part of the socio-economic sub-component of the IMAS project, two surveys were carried out in Kajiado to generate data for the socio-economic modeling effort. In addition, a 15 month PhD socioeconomic research project is underway. Data from this research will also contribute to the modeling effort. The first survey was carried out in mid-1999 and a draft report written up (Mbogoh and Munei, 1999). This study of the wildlife, livestock and human interaction in Kajiado District of Kenya focused on the case of the Amboseli National Park wildlife dispersal areas encompassing Kimana Group Ranch and Mbirikani Group Ranch. The main objective of the study was to examine the economics of livestock keeping within the game reserves wildlife dispersal areas, including a documentation of the following:

- Other economic activities that compete with livestock keeping in these areas;
- The magnitude of income and/or losses due to wildlife, eco-tourism and other non-livestock keeping activities in the said wildlife dispersal areas.

As noted above, pastoral livestock and other human economic activities have coexisted with wildlife in the East African rangelands for a long time. This interaction has come under stress in the last few decades, and is now resulting in conflicts over the use of resources. The change of property rights to pastoral rangelands from communal ownership to group ownership and, most recently, to private ownership, has brought the conflicts to a new level where the prospects for sustained coexistence are diminishing. One of key activities of the Kajiado socio-economic case study was to attempt to evaluate the prospects for continued coexistence of pastoral livestock and other human economic activities by analysing the nature of these conflicts as well as identifying possibilities for resolving some of them, by using the Savanna and PHEWS models to search for possible avenues of mitigating the costs imposed by wildlife on pastoralists and their economic activities.

The activities involved in the study included the following:

- A literature search and review of secondary data sources;
- Design and testing of a simple survey instrument to elicit information from ranchers and pastoralists on the economics of group and commercial ranches in Kajiado;
- Data collection using the survey instrument and through informal interviews, and data analysis and interpretation.

Apart from informal discussions with relevant government officials and other stakeholders in the Kimana and Mbirikani wildlife dispersal areas of the Amboseli National Park, a sample of 34 members of the Kimana Group Ranch and 27 members of the Mbirikani Group Ranch was randomly selected and interviewed to establish the status of individual livestock ownership within the group ranches and the associated costs and returns from the various economic activities undertaken by these members. The two group ranches are representative of others in terms of the mix of human economic activities carried on as well as ecological conditions. Kimana Group Ranch, the smallest of the six group ranches, was chosen to reflect and represent the growing importance of agro-pastoralism. Kimana Group Ranch has the highest proportion of high potential land and consequently a high proportion of cultivated area. Mbirikani Group Ranch, on the other hand, represents the other extreme ecologically. Although containing some pockets of high potential land along the rivers, Mbirikani Group Ranch basically consists of arid grassland. It was anticipated that these two group ranches would give a sufficient representation of the nature of interaction between wildlife and livestock in the dispersal area of the Amboseli National Park (Table 17). The six group ranches in this dispersal area are the largest in size in the whole district, averaging 84,388 hectares. They account for 32% of the total group ranching area of the district. Of the six group ranches, only one group ranch is currently undergoing subdivision, Ololarrashi / Olgulului Group Ranch.

Table 17. The status of the dispersal area group ranches in Kajiado District, 1999

Group Ranch	Size (Ha)	Number of Members	Per capita size (Ha)
1. Eselaki	74,794	1,280	58.4
2. Kuku	96,000	4,401	21.8
3. Rombo	38,365	3,565	10.9
4. Mbirikani	125,000	4,650	26.9
5. Kimana	25,120	843	29.8
6. Ololarrashi	147,050	4,000	36.8
TOTAL	506,329	18,739	
Average	84,388	3,123	27

Source: Mbogoh and Munei (1999)

The survey carried out in 1999 collected information on a wide range of aspects, including the following: resources, household composition and food consumption, livestock herd composition, details on the costs of livestock production (including veterinary care, acaricide use, watering charges, herding labour usage), wildlife and ecotourism income, off-farm income, milk production and utilisation, livestock off-take rates, farm-gate prices for livestock, costs and returns of crop production, producer prices, and average crop yields and gross margins per ha.

Survey results are presented in Mbogoh and Munei (1999). In summary, the survey found no evidence of severe competition for available resources between livestock and crop production in both Mbirikani and Kimana group ranches. On the contrary, there appears to be some degree of complementarity . Manure from cattle and livestock keeping finds use in crop production. Livestock and cropping enterprises give relatively high rates of return to capital, and most of the pastoralists and agro-pastoralists are able to derive their livelihood from the two enterprises.

The second University of Nairobi survey

The second survey was carried out in July 2000, in an attempt to concentrate on the more highly commercial ranching operations found in Kajiado District. The survey questionnaire sought more detailed information on herd structure, herd dynamics, labour and other inputs, and livestock output, compared with the first survey. Data were collected from 47 ranches in Kajiado District.

In summary, all respondents were married male adult ranchers (in Maasai culture, ranching is a male activity). While ranching was the main economic activity, 57% engaged in other economic activity in addition to ranching. Some 23% of the sample attempt to produce crops within their land holdings, whenever rainfall permits. Most ranchers keep cattle (mostly local breeds), sheep and goats. Over 70% of the herding, milking and other livestock-related labour is hired, the rest being provided by family members. All respondents control ticks and give veterinary drugs (commonly antibiotics) to their cattle. Respondents had invested quite widely in a range of facilities such as water boreholes, cattle crushes and dips, fencing and water tanks. Most had also invested in residential and workers' housing. Only 12% of ranchers had taken credit over the last 5 years. Most was for steer purchasing and fattening. Respondents cited high risk, high interest rates and the logistical difficulties of getting credit as the major reasons for not taking more credit for ranch development.

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

Socioeconomic field research

The field research here has focused on the issue of how pastoral welfare, livestock production and human-wildlife interactions are impacted by larger-scale political economic changes in pastoral land use patterns. The research efforts revolve around the following three core questions:

1. What are current Maasai land use patterns across a gradient of ecological and human induced infrastructural heterogeneity?
2. How is the traditional strategy of pastoral mobility modified within the constraints imposed by current land tenure arrangements and household level choices of economic strategies?
3. What is the relationship between levels of pastoral welfare and the quantity/quality of human-wildlife interactions and Maasai land use patterns as reflected in economic strategies/spatial land use?

Data gathering and data synthesis activities included the following:

- Intensive multiple-entry interviews with a core group of sampled households.
- Documentation of grazing orbits for intensively interviewed core households.
- Large-scale survey of households across the study areas.
- Large-scale settlement survey of households for identification of economic strategies and information on the spatial scale of resource use.
- Development of a land-use typology and landscape heterogeneity index.
- Anthropometric survey and diet composition questionnaire.

Description of Study Areas and Land Use Types within Zones

Six study areas have been chosen as focus areas for the study. As well as falling along a climatic/vegetation gradient, these study areas represent a range of land tenure types, levels of market access and available combinations of resource/economic infrastructure, all variables that interact to affect the land-use strategies pursued by pastoralists within the wider Amboseli study area. General characteristics of pastoral land use strategies in each area are described in Table 18.

Table 18. Socio-economic field data study areas in Kajiado District

Study Area	Characteristics	Chosen # of Households
Northern Mbirikani	• Pastoralism with 1-7 day grazing/watering regime • Some irrigated agriculture for sale/consumption (illegal) along the pipeline • Many households maintain 2 bomas-i.e.; economically diversified in space (1 agricultural shamba in swamp area/1 livestock boma in North)	7
Southern Mbirikani	• Agropastoralism with livestock watered daily in swamps • Households involved in irrigated agriculture for consumption and sale • Movements of livestock occur on a significantly smaller spatial scale	7
Meshanani Ridge	• Pastoralism with 1-3 day grazing/watering regime • Many households maintain 2 bomas -i.e.; economically diversified in space (1 agricultural in swamp area/1 livestock on ridge) • Movements of livestock are extensive	7
Lengisim	• Pastoralism with 1-3 day grazing/watering regime • Area is too dry for rain fed agriculture w/ no access to pipeline water • High percentage of households with outside employment of family members • Movements of livestock are extensive	6
Selengei	• Agropastoralism with 1-3 day grazing/watering regime • Rain fed and irrigated agriculture (for consumption) are common • Livestock movements are extensive	6
Oscillate	• Agropastoralism in sub-divided group ranch • Agriculture is rain fed primarily for consumption • Livestock movements occur within a limited area	5

Intensive Interviews with Households

Survey data on Maasai economic and production strategies are being gathered at two scales. A core group of 38 Maasai households was randomly selected across the six study areas. These households are being interviewed at three separate time periods. The goal of the first interview is to establish the range of economic and productive activities with which each household member is involved, to identify the range of interactions households have with wildlife (both economically and productively), as well as to begin a process of documenting the timing of household interactions with the market and grazing movements of a household's livestock. This information is linked directly to the larger research questions, i.e., to both identify spatially what processes of diversification and/or intensification of pastoral strategies are taking place, as well as to highlight the combinations of resources (infrastructural, natural, or household specific (i.e. labour/wealth)) which push households down one economic path versus another.

Grazing Orbits

An additional core research question asks if there are gains and losses in scale of resource use associated with choices of economic strategies (agropastoralism) and/or land tenure arrangements (i.e., subdivision). In order to address this question, the daily grazing movements of the core 38 households are being documented at three different time periods (long dry, short rainy and short-dry seasons). Initially we documented the 1999-2000 grazing movements of household animals verbally in interviews. As well, we have followed the herds of these households from sun-up to sun-down during the previous long dry season using a handheld GPS unit. Additional data being gathered concurrently includes vegetation type and herd behaviour observations (Table 19).

For analysis purposes the data are being put into a GIS format. Combined with oral accounts of grazing movements, analysis of grazing orbits will allow us to quantify both seasonal livestock movements and "scale" of resource use for a variety of household types across different land use areas within the larger Amboseli study zone.

Table 19. Grazing orbit data collection

Grazing Day Type	Watering versus Grazing Day
Herd Owner/ Herding Labour	Herder age/relationship to herd owner
Herd Composition	#'s by age/sex group
Grass	% cover, dominant species, height
Trees	% cover, dominant species, height
Bush	% cover, dominant species
Herd Behaviour	Walking/resting/grazing/being pushed
Other	Water points, wildlife observed, etc

Survey Development- Generalized Land Use/Economic Survey

A large-scale land use/economic survey is scheduled to be carried out across the six Amboseli study sites. Approximately 120 households across the six study areas will be interviewed by six enumerators employed and trained in the field. The function of this survey is twofold: to contextualize the data gained through the intensive interviews with households across multiple seasons, and to contribute additional data to the formation of a "land-use typology" across the study area.

The methodology is based on the use of cluster analysis for identifying categories of pastoral land use. The importance of the cluster analysis is to arrive at homogeneous households that are engaged in similar economic activities. In the Amboseli study area, we will use data from the large scale surveys of households (n=120) to identify clusters of homogeneous pastoral households across the study areas (i.e., households that are similar to each other based on a cluster of specific land-use and economic variables).

Large Scale Settlement Survey of Households

Detailed information on settlement locations, spatial patterning of land use types (agriculture and livestock settlement locations) and economic strategies of individuals within households (i.e., type of diversification activities) has been gathered for each settlement within the six study areas. These data will provide contextual information on overall economic patterns and land-use types in each study zone. Combined with data from the generalized economic/land use survey, the settlement data will provide the basis for development of "a land-use typology" for the study area, as well as contribute to the formulation of the landscape heterogeneity index (described below).

Development of a Land-Use Typology and Landscape Heterogeneity Index:

One of the central questions motivating this study is to identify what are "current Maasai land-use patterns across a gradient of ecological and human-induced infrastructural heterogeneity". Four types of data gathered so far are contributing to the resolution of this question:

1. Basic GPS data documenting human infrastructure types.
2. Large- Scale Settlement Survey of Households.
3. Generalized Land Use/Economic Survey.
4. NDVI imagery.

There are two goals for the development of a "typology of land use strategies" for the Amboseli study area: to describe the resource landscape available for pastoralists, and to categorize the land-use choices (economic and spatial, i.e., diversification and intensification) being made by pastoralists within the various constellations of available resources across the system. The second goal will be accomplished using survey data and cluster analysis from the general land-use/economic survey to define land-use categories. The first, description of the resource landscape, will be based on the development of a heterogeneity/complexity index. This index will be a combined function of both ecological and human-induced infrastructural heterogeneity of particular areas. NDVI values will be used as a basis for quantifying the ecological heterogeneity of the system, while a distance function developed in an ArcView GIS database will represent human-induced complexity in the system. The index will be used to answer the following questions:

1. What ecological and human infrastructural heterogeneity currently exists for pastoralists within and across the study areas?

2. Given the existing complexity in the system, and using spatial data from grazing orbits and cluster analysis, are pastoralists organizing their production strategies and/or economic strategies in order to increase their access to ecological and human infrastructural heterogeneity within the Amboseli system?

Anthropometry and Diet Intake

Anthropometric measures of nutritional status were taken on almost 1000 Maasai during May and June 2000 and within each of the six study areas. In addition, a number of diet intake surveys were conducted in June and July 2000 for Maasai women and their children.

The nutritional status information and the household diet data provide information on human economic status and human welfare under current circumstances. This information will be used in the PHEWS modeling system to project the effect of changes in policy, management, economic or ecological conditions. For example, if policy or management decisions are contemplated that suggest an increase or decrease in the flow of income or food energy, we can, based on the current notional status indicators, suggest what the impact of these decisions may be on human welfare and food security. In addition, data on current nutritional status provide a baseline measure for monitoring of human welfare changes. Monitoring provides a means of measuring the impact of policy or human agent changes, resulting either from IMAS recommendations or other considerations.

4.3 Model development for Kajiado

In terms of the changes to PHEWS that are envisaged for the Kajiado version of the model, the same basic structure will be used. However, various changes will be needed. First, the cash flow sections of the model will need to be augmented, to take account of much more detail on the costs of livestock and crop production. Full enterprise budgets will need to be included in PHEWS, given the degree of market integration in many of the production systems. Second, decision rules on livestock trading may need to be modified. Third, PHEWS may need to be made more spatially explicit, to take account of the fact that a proportion of households in Kajiado have access to land resources in different places and in different parts of the landscape. This is also related to the question of a small set of characteristic households and how these may be defined.

As for the NCA case study, there are various sources of data for the model modification and calibration processes:

- Previous studies and surveys in Kajiado, including Nestel (1985), Munei (1990), ASAL (1990), Bekure et al. (1991) and Rutten (1992).

- Studies and surveys carried out in Kajiado as part of the GL-CRSP. These included Mbogoh and Munei (1999), Mbogoh (2000), and Burnsilver (in preparation).

Data collection and analysis will be complete by early 2001, and at that stage the modification of PHEWS and its calibration for Kajiado could be undertaken. At that time, integration of PHEWS within the new SavView modeling shell (Boone and Coughenour, 2000) could also be carried out.

Once this has been done, then a wide range of scenario analyses can be carried out. Ellis (1999) articulated a set of objectives for the application of IMAS in Kenya, including the following:

- Estimation of the impacts, both positive and negative, of human land-use on wildlife populations, biodiversity and ecosystem integrity in the areas surrounding the Amboseli National Park (ANP), and on the ANP itself.

- Determination of strategies to improve human welfare and food security among pastoralists in areas where there are important livestock-wildlife interactions.

- Exploration of ways to improve livestock-based systems in the areas surrounding ANP and at the same time improve conditions for management within ANP.

Two sets of scenarios were proposed: one set to compare the utility of various policies and management actions aimed at reducing the major obstacles to wildlife conservation, and another set to simulate the effects of imposing a sequence of buffer zones around ANP. To these sets of scenarios various others might be added: for example,

- Comparisons of household welfare between NCA and Kajiado; what are the impacts of small-scale commercialisation on household food security?

- Scenarios built around the issue of land tenure:
    - Are group ranches viable, economically, ecologically and socially, in situations where there is sharing of group resources?
    - What are the impacts of subdivision on household welfare and food security?
    - What are the likely impacts of privatisation in the longer term?
    - How are such impacts exacerbated by drought, for example on the levels of off-farm employment that would be needed to provide reasonable levels of food security?

5 Conclusions

The major objectives for the NCA case study site have been met. A fully functioning socioeconomic household-level model was constructed and calibrated, and a range of scenarios were simulated. Some of the scenario results proved quite interesting:

1. In the NCA at current levels of population, food security and household welfare are of real concern. The poorer households depend for at least 10% of their calories on gifts and relief. They have little cash reserves in the household to tie them over periods of need. All households depend on outside sources of calories; even rich households obtain 40% of their diets from outside the household. Pastoralist welfare in NCA, even with small amounts of agriculture allowed, is not internally sustainable at current human population levels.

2. If realistic population growth rates are imposed, then the situation deteriorates markedly. The need for gifts and relief in all household types increases, and the classic squeeze

occurs: fewer animals with which to feed the household, and fewer to sell for cash for grain, and no realistic opportunities for increasing livestock numbers.

3. Model results suggest that the introduction of agriculture in 1991 in NCA occurred at a time to make a substantial improvement in householders' welfare, by reducing the dependence on "outside" grain at a time of rapid population growth. By the late 1990s, these welfare gains would have been quickly overtaken by human population growth rates in excess of 6% per year.

4. From a household welfare perspective, banning agriculture again is simply not an option. Model results show that cash would largely disappear from all households by 2015, and poor households would be dependent for nearly one quarter of their calories from gifts and relief. Without agriculture for the households in NCA, even with a human population of about one third of what it is currently, food insecurity would be substantially increased.

5. Doubling the area of agriculture per household was shown to have a highly beneficial impact on the food security of poor and medium households. This doubling would still amount to only 0.6% of the land area of NCA, and the impacts on wildlife would be negligible. Perhaps the aesthetic impacts would not, but model results clearly show that if pastoralists are to continue as part of the landscape of NCA, then allocating increased (but still small) amounts of agricultural land seems an effective mechanism for improving household food security for the less well-off.

6. Model results highlight the fact that drought has important and differential impacts: in the immediate term, household food security is severely compromised, but there is also the longer-term impact on livestock numbers, where pastoralists have to build up livestock numbers in the aftermath of drought.

7. Model results also highlight the potential beneficial impacts on household cash flow and food security that can arise from productivity-increasing interventions, such as improved veterinary care or increased cattle birth rates.

PHEWS seems to operate in a sensible fashion, on the whole. The types of impacts expected from the scenarios run appeared to be largely logical. There are two areas where some modification might usefully be made. The livestock trading matrices are an efficient device for assembling appropriate rules in the model, but the performance of this aspect of the model is very sensitive to the thresholds used. More work is required to make this aspect of PHEWS somewhat more robust. The second area could involve some more field work to determine household behaviour in situations where herd productivity is slowly increasing over time. We know relatively little about the trade-offs that household engage in, between increasing herd sizes and increasing animal off-take to improve cash flow.

The major objectives for the Kenya case study in Kajiado have not yet been achieved. By the end of Phase 1, primary data collection was close to complete for the socio-economic modeling work. Pending a fully-calibrated version of Savanna for this study area, work on PHEWS for Kajiado can be completed. A set of scenarios to be simulated has been defined, although the actual work has yet to be completed.

The work in both NCA and Kajiado is but a first step in addressing broader issues on two fronts. First is the general objective to continue developing the socio-economic module to lead to an integrated model that can simulate production systems across the whole spectrum from subsistence to commercial systems. The NCA case study can be seen as being at the subsistence end of the spectrum; the Kajiado case study is somewhere in the middle. Other collaborative work being undertaken in southern Africa is dealing with production systems much closer to the commercial end of the spectrum, and a long-term objective is to amalgamate these various modules. In this way, what is essentially one socio-economics module would have great flexibility and applicability. When operating alongside Savanna, such a system would allow a very wide range of scenarios to be assessed in terms of ecological impacts, household welfare, food security, and financial performance.

There are also good prospects for linking the Savanna and PHEWS models with other models that consider land-use change in a more explicit fashion. Such an assemblage of models could be used to address questions such as, how is the traditional strategy of pastoral mobility (mobility in grazing patterns, and mobility of livestock through stock-sharing arrangements) modified within the constraints imposed by current land tenure arrangements (pre-subdivision group ranches, sub-divided group ranches), and how do changes in pastoral land use patterns (subdivision, sedentarization) affect human welfare, livestock production and the quantity and quality of human-wildlife interactions?

The second broader issue relates to regional assessment. Household-level analysis is very important, for it is at the household level that the impacts on people of policy making and technological interventions are most immediately felt. But the broader picture at the regional level is also of crucial importance. Understanding the drivers of regional land-use change, and assessing the regional economic impacts of proposed changes in the policy environment, will require a great deal more work.

We are currently some way from being able to develop a regional economic model, particularly in terms of being able to assess the economic value of wildlife to the tourism industry and the economic costs and benefits of wildlife to pastoralists and agro-pastoralists. Clearly, however, such a model could address some central issues. For example, East Africa is still undergoing rapid human population growth. This will affect land use and interactions with wildlife. What effect are human demographic changes likely to have on human welfare? The area is also one of substantial climatic variability. Preliminary analysis suggests that there will be highly differential impacts of climate change in East Africa to the middle of the twenty-first century. Parts of East Africa will become drier, with substantial reductions in the length of the growing period. Other areas, including southern Kenya and northern Tanzania, may become wetter, with increases in the length of the growing period (Jones and Thornton, 2000). Such changes may have radical effects on human land-use and human welfare, as well as on the ecology of these systems.

Such questions address the trade-offs between the need to conserve wildlife and preserve or enhance the food security of a growing number of humans. Complementary interactions do exist under some conditions. The pressures on these systems are such that defining what these conditions are, and identifying how people and wildlife may be affected, have become extremely important questions that need to be answered sooner rather than later. The IMAS offers enormous potential for addressing these vital issues and for helping to inform the debate as to what is feasible and desirable for stakeholders with very different objectives.

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