**AFRICAN JOURNAL OF
RANGE & FORAGE SCIENCE**
ISSN 1022–0119

Climate variability and impacts on east African livestock herders: the Maasai of Ngorongoro Conservation Area, Tanzania

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East African pastoral adaptation and vulnerability to climate variability and climate change is assessed, using data from decision-making processes and ecological data of the Maasai of Ngorongoro Conservation Area as an example. The paper uses integrated modeling, linking PHEWS, a household model, to SAVANNA, an ecosystem model to look at the effects of drought and a series of wet years on the well-being of Maasai pastoralists. Model results suggest that the ecosystem is quite resilient and suggests that the Maasai of the NCA are not very vulnerable to climate variability. However the economic situation in the NCA is precarious and food insecurity is prevalent without drought. The result is that drought has a very negative effect on people.

Keywords: adaptation and vulnerability, modeling

Introduction

Human-environment interactions are iterative processes. Many people in the world structure their lives in concert with their environmental contexts. For various reasons associated with climate people can become vulnerable, that is, they are at a high risk of negative outcomes as a result of climatic events that overwhelm the adaptations they have in place. Vulnerability to environmental changes occurs due to variation in frequency or duration of those changes or because people are constrained economically, socially or politically from responding adequately to those changes. Economic and policy factors, in and of themselves, can also result in increased vulnerability.

East Africa is home to thousands of pastoralists who herd their livestock in the semi-arid to arid areas of the region. Rainfall seasonality affects forage availability, livestock production and ultimately the livelihoods of these people. East African rainfall is bimodal, but is characterised by uncertainty both spatially and temporally. The 1998 El Niño produced an estimated five-fold increase in rainfall, for example (Galvin *et al.* 2001). On the other hand, 1997 was a drought year and the 1999 drought was estimated to be one of the worst on record (WFP 2000). Other climate analyses suggest 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 considerable reduction in the length of the growing season. Other

areas, including southern Kenya and northern Tanzania, may become wetter, with increases in the length of the growing season (Thornton *et al.* 2002). Such changes surely will make fundamental changes to ecosystem structure and function. These in turn will affect human land-use and livelihoods and have the potential to make these populations more vulnerable.

East African rangelands are generally heterogeneous, due to spatial gradients of climate, soils, landscape and disturbance (Coughenour and Ellis 1993). Temporal and spatial variability in rainfall, in particular, increases heterogeneity of the system. Rainfall is more patchily distributed in arid than in mesic systems, and adequate rainfall from year to year cannot be assumed for a given location (Ellis 1994). There is a more subtle distinction between mesic and arid sites. Productivity varies in any ecosystem, but mesic systems may include a productive landscape matrix containing some very productive patches. In contrast, semi-arid and arid sites are relatively unproductive landscape matrices that may contain productive patches. In semi-arid and arid systems the landscape matrix cannot support livestock on its own, and access to productive patches, that is, key resources, is required (Scoones 1995). Pastoralists exploit spatially distinct areas of vegetation type and productivity by moving species-specific livestock across the landscape. Thus, livestock and the people who depend on them require access to

a complex set of vegetation communities to maintain animal condition, productivity, and population stability, especially under conditions of high climatic variability and other sources of perturbation (Ellis *et al*. 1987, Ellis and Swift 1988, Coughenour 1991, Ellis and Galvin 1994, Ash and Stafford Smith 1996, Hobbs 1999).

In this paper we address issues of human adaptation and vulnerability to climate variability and climate change for pastoral populations. We then discuss these issues for Maasai pastoralists of the Ngorongoro Conservation Area, northern Tanzania. Making use of studies of Maasai pastoralist household decision-making processes and ecological data, we describe some integrated modeling, linking PHEWS (Pastoral Household and Economic Welfare Simulator) (Galvin *et al*. 2000, Thornton *et al*. 2003) to SAVANNA, an existing spatial-dynamic ecosystem model. We then discuss scenario analysis using the linked models to look at the effects of drought and a series of wet years on the well-being of Maasai pastoralists who live in the Ngorongoro Conservation Area. We end by addressing the implications of climate variability for pastoral vulnerability and the ecological and human systems upon which they depend.

Pastoral adaptation to climate

Adaptation is defined as adjustments in social or economic systems made in response to actual or expected climate effects (Smit and Pilifosova 2001, Smith 1996). These adjustments are intended to reduce the vulnerability of society to changes in the climate system (Kates 2000). Adaptive capacity is the ability to cope with impacts of climate variability and change (Smit and Pilifosova 2001). Capacity varies among regions and socioeconomic groups, in that those with the least capacity to adapt are generally the most vulnerable to climate variability and change impacts. Issues of policy, growing populations and low agricultural production, including livestock production, contribute to adaptive capacity and ultimately, vulnerability (Finan and Nelson 2001, Lamb 1995, Little *et al*. 2001). Developing countries are dependent on climatic resources and because of growing populations and lower technological capabilities, they generally have lower adaptive capacity (Downing *et al*. 1997, Magistro and Roncoli 2001). This is especially true for pastoral people, who inhabit the arid and semi-arid regions with high climate variability. Most pastoral adaptations to climate variability are socio-cultural (that is, changes in management), usually a series of reactive responses to a climate event such as drought (Galvin *et al*. 2001, Little *et al*. 2001).

East African pastoralists have a diversity of strategies to sustain production which is important for their own livelihoods and for their national economies, as pastoralists are responsible for providing a large share of livestock to markets in the region. Pastoral strategies for maintaining production include moving livestock according to vegetation needs and water availability, keeping species-specific herds to take advantage of the heterogeneous nature of the environment, and diversifying economic strategies to include agriculture and wage labour, among others. In some cases temporary or permanent emigration out of the pastoral system can happen and even allocating seasonal and drought-induced nutritional stress among community members occurs (Galvin 1992, Galvin *et al*. 1994).

However, there are currently constraints on some of these strategies that have made people more vulnerable to natural and human-derived perturbations. Rising human populations along with many land tenure and land-use changes have squeezed pastoral livestock onto land areas that are too small to be sustainable for pastoral production. This has led to an untenable situation where pastoralists can no longer depend on their livestock for the sole basis of their livelihood while opportunities for livelihood diversification are few. Furthermore, livestock populations have tended to be stable rather than expanding because of disease epidemics and livestock starvation associated with recurring drought. The result is a rising human population dependent on a stable or declining livestock population.

So while east African pastoralists have been able to track climate variability very well in the past, their strategies, based on centuries of exposure to intra- and inter-annual droughts, as well as floods, are not working now due, in part, to an inability to implement them. Furthermore, it is likely that the nature of the climate variability that pastoralists are used to dealing with, will itself change, adding new variability to the system (IPCC 2001). Here, as is the case for many developing regions of the world, government organised adaptations are still poorly developed (Kates 2000). Where public adaptations have been tried, they have been largely unsuccessful. Theu *et al*. (1996) describe how climate policy in Malawi encourages farmers to grow drought resistant crops, keep smaller livestock herds, and maintain food reserves. These adaptation policies have led to conflicts because maize is the preferred staple food, livestock represent prestige and wealth, and households require cash for basic needs that they obtain by selling their food reserves. Malawi farmers' adaptive strategies consist of seeking alternative sources of income rather than altering their traditional food staples and livestock management.

Vulnerability

Vulnerability is defined as the likelihood that an individual or group will be exposed to and adversely affected by circumstances (Cutter 2001). It can also be defined as the characteristics of individuals or groups in terms of their capacity to anticipate, cope with, resist and recover from the impacts of environmental change (Vogel 1998). Human populations can become vulnerable for various reasons such as changes in the environment (floods or droughts), changes in human and wildlife populations, climate change, diseases, changes in environmental and social policy, etc. Impacts of these changes are felt unequally throughout a community or region (Galvin *et al*. 2001). The severity of impacts experienced will depend on which resources are available to a given group or individual. Although various communities may face similar risks, they may not be equally vulnerable.

Vulnerable people generally have a variety of alternatives to increase their adaptability and decrease their risk in times of stress and shock (Kasperson 2001). However, new and persistent environmental, political and social pressures can limit choices that have traditionally been available.

Human groups may already be vulnerable, placing them at even greater risk should a natural disaster, such as a flood or long-term drought, occur. A better understanding of vulnerability could help to mitigate effects of these events for both human populations and the environment.

There are a number of proposed methods to measure a group's vulnerability. Adger *et al*. (2001) suggest that vulnerability can be measured by combining poverty indicators with a measurement of the diversity of resources. It has also been proposed that vulnerability can be measured by a series of indicators for sensitivity to socio-economic variability. The sensitivity indicators include food sensitivity, ecosystems sensitivity, settlements/infrastructure sensitivity, and human population health sensitivity (Moss *et al*. 2000). There is a close interaction between the social and economic vulnerability of populations and the degree of resilience of the ecosystem. Thus, measuring both ecosystem vulnerability and some indicator of human vulnerability seems especially relevant, particularly in pastoral systems. In addition to understanding human-ecosystem vulnerability, it is also important to understand how decisions the vulnerable human population makes today will affect the environment and options available in the future. However it is measured, it is clear that measuring vulnerability is a complex endeavor that requires the ability to analyse the relationships between diverse indicators. A powerful tool for this type of analysis is integrated modeling, which we discuss later.

Maasai of the Ngorongoro Conservation Area

The Ngorongoro Conservation Area (NCA) is one of the leading wildlife areas of east Africa, and the gateway into Serengeti National Park. It is known for its spectacular megafauna and diversity, rising up from the Rift Valley to high mountain (2 500m) forests and grasslands to the west. From the highlands it slopes down into the Serengeti plains with its different set of vegetation and wildlife. The Maasai have shared this region with wildlife for hundreds of years but have lived with conservation policy since 1959 when the NCA was designated as a multiple use area for wildlife, people and their livestock (Perkin 1997, Kijazi 1997).

Much has changed over the last 40 years, including a large increase in the human population that is dependent on a relatively stable livestock population. The population since 1990 has risen dramatically from about 23 000 people to approximately 50 000 a decade later (a population growth rate of about six percent per annum, which includes immigration). Disease, among other factors, has impacted the livestock population so that the total biomass of livestock was approximately the same in the year 2000 as it was 40 years ago. This put serious food security stress on households so that by 1991, people were selling their female livestock to purchase food, depleting their core reproductive herds. As a result, the government of Tanzania allowed limited agricultural production to alleviate food insecurity.

Diversity and intensification of livelihood strategies (beyond limited cultivation), a process common among other east African pastoral populations, have been options generally not available to the Maasai of the NCA due to conserva-tion policy. They were not permitted to benefit from tourism until the mid-1990s, and only then in a limited way. Cultural *bomas* or tours of traditional homes are now permitted along with the sale of handicrafts, ceremonial viewing and walking tours. Interaction with the Conservation Area Authority, the policy-making and enforcement body of the NCA, has been generally adversarial. And agriculture is limited, each woman in a household being allowed to cultivate one acre. However, the re-introduction of agriculture in 1991 had an immediate and positive effect on household food security. Through simulation runs of PHEW we have estimated that harvests from agriculture decreased the food shortfalls substantially and allowed the Maasai to keep their reproductive herds more or less intact (Galvin *et al*. 2000).

Integrated assessment of climate variability

We have developed a pastoralist socio-economic model that is linked to the SAVANNA ecosystem model (version 4E) to investigate options and scenarios of changes that may impact pastoralists and their ecosystems. Some of these include changes in human populations, agricultural production and climate. The socio-economic model PHEWS (Pastoral Household and Economic Welfare Simulator) tracks the flow of cash and dietary energy in pastoralist households using a simple set of rules (Galvin *et al*. 2000, Thornton *et al*. 2003). The integrated PHEWS and SAVANNA models first attempted to model Ngorongoro as it is now (Boone *et al*. 2002, Thornton *et al*. 2003). The control model simulated changes for a 15-year period. The results from the control run for the household model show reasonable stability over a 15-year period, but poor households are less well off. No households are self-sufficient. We then defined several scenarios that included human population growth, drought, and increased agriculture, among others.

Here we have defined some drought scenarios that go beyond those in the NCA study. To pick out some low rainfall records that were at least possible in NCA, we took the monthly rainfall records for 55 sites assembled by Boone *et al*. (2002) and rejected all records with one or more months of missing data. The remainder we sorted in ascending order, then took the first percentile of this distribution. The annual total rainfall for this record was about 250 millimetres, which is equivalent to the mean rainfall in NCA minus about two standard deviations. This record we applied over the entire NCA for one year (1978) for one scenario, then for two years in succession (1978 and 1979) for the second scenario.

Table 1 shows some key output variables of the experimental simulation, compared with the control run. Over 15 years, it is clear that the model predicts rather modest differences in terms of the overall average supplementation needed by all households compared with the control run, but this hides a great deal of within-year variability and problems.
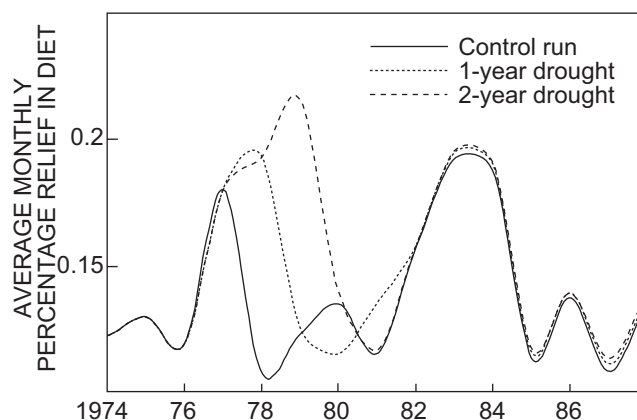
The impacts on households for the drought years can be seen more clearly in Figures 1 and 2. Figure 1 shows the condition indices of cattle, sheep and goats for the one- and two-year droughts. The impacts of these declines on the household are as expected; livestock numbers per house-

Table 1: Summary output over 15 years for the three household types for the control run and the two drought scenarios

Scenario	Poor	Medium	Rich
Control Run			
Total own grain consumed (% in diet)	16.20	12.50	17.10
Total gifts/supplements (% in diet)	13.40	8.40	0.00
Own food available %	41.10	44.50	57.60
Average TLUs per adult equivalent	1.07	1.65	4.40
One-year drought			
Total own grain consumed (% in diet)	14.70	11.30	15.50
Total gifts/supplements (% in diet)	14.20	9.00	0.00
Own food available %	39.50	43.20	56.20
Average TLUs per adult equivalent	1.06	1.63	4.36
Two-year drought			
Total own grain consumed (% in diet)	13.30	10.30	14.10
Total gifts/supplements (% in diet)	14.90	9.50	0.10
Own food available %	37.90	41.80	54.90
Average TLUs per adult equivalent	1.05	1.62	4.32
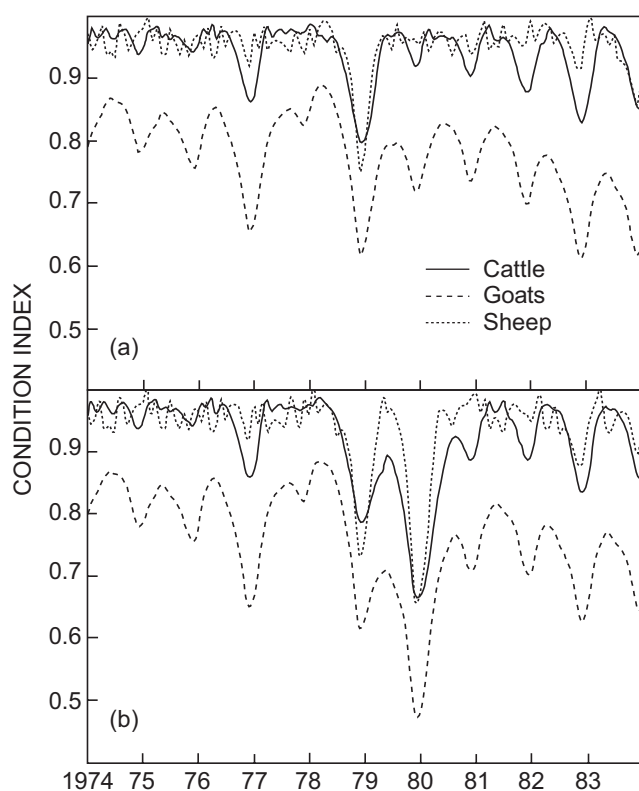
Figure 1: Condition indices for cattle, sheep and goats for the first 11 years of the run: one-year drought (a), two-year drought (b)

Figure 2: The average monthly percentage of dietary calories from supplements in poor households over 15 years for three scenarios. The monthly values are actually average values per year

hold decrease slightly; milk yields suffer and in the drought years there is no home-produced maize, so more money has to be spent on maize from outside the system. In the months when insufficient money is available in the household, the need for supplements increases. This is illustrated in Figure 2, showing the average monthly percentage of the diet coming from supplements in poor households for the two scenarios, compared with the control scenario. This increases substantially for 1978 and 1979, but interestingly,

the long-term differences between the control run and the drought scenarios in later years of the simulations are small.

The model results suggest that the overall system is remarkably resilient. Even after two years of severe drought, there are no great differences in terms of source of calories for different household types, suggesting that drought of this nature can be dealt with without there being marked long-term effects. We suspect that this may well be the case in reality. Livestock populations are thought to be below some long-term capacity of the system, because of disease, and this was included in the ecosystem model. In the model there is typically forage that remains unused. A mild dry year may use up that extra forage without affecting ungulates. Only a severe drought would follow through to livestock losses.

On the other hand, SAVANNA has not yet been calibrated for NCA for extreme events such as a two-year drought scenario. It is possible that part of this resilience effect is an artefact of the SAVANNA model, and might arise from overly vigorous simulated regrowth of perennial forages after severe drought, for example. In that case, livestock per-

formance may suffer more markedly during and after drought than has been shown in these model runs, and one could then expect that impacts on cash flow and dietary energy flow would be substantially greater than these results suggest. This scenario warrants further investigation, although the fact that the household model is related very closely to the performance of livestock in the system is clearly not a bad thing — the pastoralists of NCA definitely do survive periodic severe drought, but householders' well-being is inextricably intertwined with the well-being of their livestock.

To look at the other side of the coin, we then defined a scenario with an extreme El Niño event, which manifests in parts of east Africa as a greatly increased probability of a particularly wet year. In the same way as for the drought scenarios, we took the 99th percentile of the complete annual rainfall distribution for the area and applied this record over the study area for the period July 1978 to June 1979. Total rainfall in that year was 1 650mm, or the long-term mean plus three standard deviations. For completeness, we defined a second 'wet' scenario for a very unlikely event, two El Niño years in succession, 1978/1979 and 1979/1980, using the same high-rainfall record.

The 15-year impacts on households were very small (not shown). There may be various reasons for this. First, because households in NCA are not well connected with the market, households are not really taking advantage of the increased productivity that results from particularly wet years. But productivity is limited, in any case, as particularly wet years increase tick-borne disease losses. Second, it is likely that household herds in the model are not greatly constrained by feed even in normal years. What this suggests is that under current conditions in NCA, households exhibit some sort of 'plateau' response to system changes (trajectory B in Figure 3. A less resilient system, and one with more options for responding to good years, is shown as trajectory
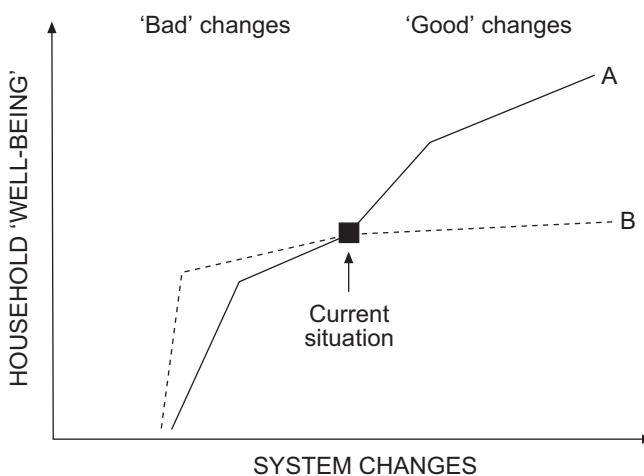
A in Figure 3). The lack of options open to households means that 'good' years may have little real impact (even over the short-term, increases in household cash and energy flows are rather modest, results not shown). In bad years, on the other hand, household impacts are certainly greater, but even here these are somewhat muted because of the resilience of the system. Obviously, however, at some point the system will crash — the last few years of six percent population growth for NCA, for example, is clearly moving towards this point.

It is tempting to read too much into the outputs of what after all is perhaps an excessively simple household model. One might have expected PHEWS to pick up rather more cash flow impacts in successive El Niño years, given possible reductions in food purchases and in food needs because of relatively good maize yields and animal growth rates. While these impacts can be observed, they are not very large. As for the drought scenarios, this warrants further investigation; it may be that SAVANNA is calibrated too tightly at present. On the other hand, if these impacts are indicative (and again, they appear to be eminently plausible), it would suggest that the range of interventions that may have beneficial impacts on households in NCA are somewhat limited: one can increase the resources available to households, such as the size of maize plots, with direct impacts on household food security; or one can increase household herd sizes directly or indirectly through productivity impacts on disease and/or calf mortality rates, for example. The broader impacts of these interventions on the ecosystem are described elsewhere (Galvin *et al*. 2000), but in the long term they may not be beneficial for wildlife populations.

Implications

The NCA is a fairly wet system relative to most other pastoral systems in east Africa. It is known that intra- and inter-annual rainfall has had, and continues to have, profound impacts on pastoral systems in the region (Galvin 1992, Galvin *et al*. 1994, Grandin *et al*. 1989, Little *et al*. 2001, Oba and Lusigi 1987). The NCA system seems to be resilient to drought and high rainfall as depicted in the model runs, in that livestock production and economic activities are not overly impacted. The scenarios described here suggest that the Maasai of the NCA are not very vulnerable to climate variability. And this may be the case. But a perturbation to a system, first, rarely acts alone to produce vulnerability, and second, the impact of any perturbation is based on initial conditions. The results in Table 1 and Figure 2 are somewhat misleading. What the long-term averages do not show is that for the one and two year droughts, there is no home-produced maize for two seasons, and the percentage of needed food in some months in poor households goes up from 70–80% of all calories. How are these households to deal with the situation that sees a doubling in the amount of supplemental calories needed just to survive in certain key months?

The fact is, the Maasai economic situation in the NCA is precarious and food insecurity is prevalent even without drought (Galvin *et al*. 2002, Lynn 2000, Smith 1999). We also know that during the El Niño event of 1998, the Maasai

Figure 3: Some possible responses of households to system changes. (A) Systems with low resilience with options available to take advantage of beneficial changes. (B) Systems with high resilience with limited options available to take advantage of beneficial changes

of the NCA were affected by the floods (Galvin *et al*. 2001), and these are generally factors that are not yet incorporated in our models at this point. The long duration of the rainfall and high levels of rainfall damaged the region's infrastructure, destroyed agricultural plots and caused health problems for livestock and people (Horn of Africa Review 1997, World Meteorological Organization 1998). Furthermore, during the 1997 drought the NCA acted as a sink, that is, people and their livestock poured into the NCA for its relatively better vegetation and permanent water sources. This puts pressure on the existing system. While the current NCA human-ecological system appears to be resilient, this is the case only up to a point. Biophysically, the system does seem to be resilient over the long term, but the human food security issues over the short-term in response to one- or two-season droughts in NCA are truly terrible.

Under continuous population changes and probable policy changes, resiliency is likely to decline. Thus, to really assess vulnerability we need a comprehensive understanding of complex interactions among climate, ecological, demographic, political and economic systems.

This model application may be unique to the particular situation of the Maasai in the Ngorongoro Conservation Area due to, for example, its high rainfall, policy restrictions on cultivation and disease impact on livestock numbers. However, the model can and should be applied to other pastoral areas. Our research includes currently applying the models to Kajiado Kenya in the vicinity of Amboseli National Park, but further work should be conducted in other regions.

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