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Evaluating management options that use climate forecasts: modelling livestock production systems in the semi-arid zone of South Africa

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ABSTRACT: Drought is a frequent occurrence in the Northwest Province of South Africa, and it appears to be strongly influenced by El Niño–Southern Oscillation events. The South African Weather Services produce long-term seasonal climate forecasts for 3 and 6 mo in advance that could allow crop and livestock farmers to plan anticipated wet or dry seasons. We describe a simple economic model linked to an ecosystem model, and we report on the results of simulation runs designed to estimate the economic value of climate forecasts in the study area. For the communal farmers of this region, forecasts may have little direct economic value in terms of modifying management decisions, but they may have value in terms of optimal management for asset accumulation. For commercial farmers, model results suggest that long-term average annual income could increase through utilizing forecasts associated with El Niño–Southern Oscillation events, but at the cost of increased year-to-year variability in farm income. More work is required to investigate other possible management responses to forecast information, identify more clearly the situations where climate forecasts are potentially of value, and implement mechanisms for the delivery and utilisation of this information by livestock keepers in the region.

KEY WORDS: Climate forecast · Republic of South Africa · Savanna ecosystems model · Economic value · Risk

1. INTRODUCTION

Droughts occur from time to time in semi-arid areas of South Africa and neighbouring countries. These often occur during El Niño–Southern Oscillation (ENSO) events (FEWS 1997), although the occurrence of droughts is not always attributable to ENSO. This is in marked distinction to other areas of Africa; in the east, for example, ENSO events are associated with heavy rains and flooding. Droughts typically occur every 3 to 6 yr (Boone et al. 2004), and they can have serious implications for crop yields and livestock and wildlife populations.

Year-to-year climate variability is strongly influenced by interactions between the atmosphere and its underlying ocean and land surfaces in many places, particularly the spatial patterns of surface temperatures of the tropical ocean basins (Hansen 2002). Despite the fact that the ENSO phenomenon occurs within the tropical Pacific Ocean and involves a large-scale warming of the equatorial and central Pacific Ocean, its impacts are felt over large parts of the world, and in some places it can account for a considerable portion of the year-to-year variability in climate. Scientists' ability to predict climate fluctuations months in advance is improving, to the point where there are

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good prospects for using such forecasts to modify the management of crops and livestock so as to ameliorate some of the negative impacts of climate variability in the southern African region (Mason 2001, Hansen 2002, O'Brien & Vogel 2003).

The occurrence of droughts and other extreme weather events in Southern Africa has been shown to be linked to ENSO. Droughts in particular are usually concurrent with Pacific warming events south of about 10° S (e.g. Lindsay et al. 1986, Mason & Jury 1997). The influence of ENSO events on rainfall over South Africa is strongest during the summer peak rainfall months of December–March, when ENSO events typically have reached maturity and when tropical atmospheric circulation is usually dominant (Mason & Jury 1997). Rainfall in the region has been characterized by wet and dry spells that have occurred in the last 2 decades, with widespread wet conditions in the 1970s and drier conditions from the late 1970s, much of the 1980s, and the mid-1990s (Mason 2001).

Being able to harness available science effectively will, however, require more than improved forecasting; it will also have to include better use and uptake of the science through institutional structures that are adapted to manage such processes (Hudson & Vogel 2003, O'Brien & Vogel 2003). In this paper the added value that can be gained from the use of seasonal forecasts for livestock management is traced by assessing the utility of ecological modelling combined with climate forecasts in improving the drought response of commercial livestock farmers in Northwest Province, Republic of South Africa (Boone et al. 2004). This work is part of a larger research effort that had 4 major objectives:

(1) to assess the usefulness of forecasts and determine farmer response to climatic variation;

(2) to demonstrate the usefulness of an ecosystem model linked to climate forecasts;

(3) to model economic decision-making by farmers and assess the value of using forecast information;

(4) to survey potential users to assess the prospects for assembling a real-time forecasting system that would actually be used by farmers.

Hudson (2002) reports on the first of these, Boone et al. (2004) on the second, and work is still underway on the fourth objective. This paper deals with certain aspects of the third objective.

The Northwest Province is well suited to a study of this nature. Droughts are frequent and appear to be quite strongly influenced by ENSO events; farming systems of very different characteristics exist side-by-side in this area of ecological uniformity (commercial and communal); and the South African Weather Service (SAWS) already produces medium-term climate forecasts for 3 and 6 mo ahead. These climate forecasts could allow crop and livestock farmers to plan for anticipated wet or dry seasons. SAWS produces climate forecasts for the entire country, often divided into 2 or 3 regions. For each region, probabilities are assigned representing the likelihood that the coming season will be wetter than normal, normal, and drier than normal (LOGIC 2001).

In this paper, we describe the study area, which is centered on the town of Vryburg, summarise some ecosystem modeling work, outline a simple economic module linked to the ecosystem model, and report on the results of some simulation runs with which we investigate the economic value of climate forecasts with regard to de-stocking decisions. We conclude with a consideration of some pertinent issues concerning the role of information in decision making, and where this work might go next, in terms of addressing some of the constraints to, and opportunities for, using forecast information in livestock-production systems in highly risky environments.

2. ECOLOGICAL MODELLING OF THE STUDY AREA

The study area comprised the western portion of Northwest Province of the Republic of South Africa. Annual rainfall varies from 500 mm in the east of the area to 300 mm in the west, close to the Kalahari Desert. However, rainfall is temporally and spatially highly variable. The land is classified as Kalahari thornveld and shrub bushveld (Acocks 1975). The dominant land use is livestock production, with some irrigated agriculture. Recommended grazing capacities vary from 7 to 30 ha per Large Stock Unit (LSU). The region is a mix of commercial areas, in which Afrikaner land owners produce livestock for market, and communal areas, where livestock are raised on shared land (Department of Agriculture 1999).

The Savanna model was used in this study for simulating ecosystem performance. Savanna (Coughenour 1993) was originally developed for pastoral areas of northern Kenya. It has subsequently been adapted and applied in other areas of East Africa, the USA, and Australasia. Savanna simulates the processes in an ecosystem using a weekly time step. It couples an ecosystem-grazing system simulation with remotely sensed and other spatial databases within a GIS format. At each time step it simulates changes in vegetation quantity, quality and distribution in response to climate and other drivers (such as fire), as well as removal by herbivores. It simulates the spatial redistribution of herbivores in response to changes in vegetation quality and availability, and the production and demographic responses of herbivores to changes in vegetation.

Savanna is a large and complex model, consisting of a number of component submodels (Boone &

Coughenour 2000). It has modules to deal with soils, weather modelling, light modelling, biomass allocation to plant parts, transpiration and net primary production, vegetation population dynamics, plant decomposition and nitrogen mineralization, and animal energy balances and population dynamics. Savanna can model the movement of animals into and out of the study area. It calculates a habitat suitability index for each animal population at each time step, based on information such as elevation, plant cover and forage density. Animal populations are placed in the landscape at each time step based on this index. Animal densities may be constrained using force maps in Savanna, to take account of physical restrictions such as fences or high likelihood of disease, and maps that specify distance to water throughout the landscape (Ellis & Coughenour 1998, Boone & Coughenour 2000).

Boone et al. (2004) explained in detail how Savanna was adapted to the Vryburg study area and how it was calibrated. In brief, the study concentrated on veld and livestock production and condition, and how these may relate to changes in rainfall. Seven plant functional groups were defined: highly, moderately and lowly palatable grasses; annual grasses; acacia shrubs; camphorbush shrubs; and acacia trees. Five animal functional groups were defined: cattle, goats and sheep, representing the livestock, and horses and donkeys, which are the work animals in the region; the numbers of the latter were very small. Commercial farmers do not own goats. Wildlife is a relatively minor component of the herbivore community outside protected areas, and it is not included in the model.

Savanna was parameterized for the entire study area, and then various adjustments were made to represent individual farms, which were the unit of analysis for the simulations described below. Savanna uses geographic layers describing elevation, slope, aspect, vegetation, soils and water sources to model the growth of plants and distributions of animals. All geographic data were generalised to a grid size of 1 km square. Once Savanna was producing results in general agreement with reference data, the model was adapted to 5 commercial farms and 5 communal grazing areas. These were chosen from the 60 detailed data sets collected by Hudson (2002) using stratified random spatial sampling of the study area. The changes necessary to adapt the model to individual farms were rather minor. Commercial farms were extracted from the regional data layers. Communal farms were represented by circular areas stocked at 125% of the recommended levels; these are typical stocking rates for communal areas (Hudson 2002).

3. ECONOMICS OF LIVESTOCK PRODUCTION IN VRYBURG

The most common commercial livestock production system in the study area is weaner production. Herds are essentially 100% breeding stock, with 15% males, and weaner animals are sold at 7 to 10 mo for placement in feedlots. In the Savanna model, animals are removed using a culling routine that calculates the number of livestock to be removed to maintain stocking rates and the number of males required to maintain sex ratios. Older animals are culled first.

Table 1 shows major differences in farm and herd sizes between commercial and communal farms in

Table 1. Key characteristics of commercial and communal livestock operations in Vryburg (Hudson 2002). TLU: Tropical Livestock Units (Jahnke 1982)

	Commercial	Communal
Average farm size (ha)	4100	Not applicable[a]
Reported pasture condition	Generally good	Generally poor
Supplements used	Yes	Yes
Average number of cattle	600	50
Average number of sheep	50	40
Average number of goats	None	40
Average TLU	630	60
Production goals	Raise calves for market (reproductive capacity of the herd is key)	Maintain cattle as a capital asset
	Age–sex composition of the herd is carefully controlled	Maintain as large a herd as possible; sell animals only in extremis
	Want quick turnover in calf production	Goat production is practised as a hedge against drought
	Cull unproductive animals	Do not under-utilise pasture

[a]Despite the problems in estimating the size of communal grazing lands pertaining to households, Hudson derives a figure of 714 ha supporting some 9 people in total, based on number of households, grazing areas, and recommended stocking rates

Vryburg (data from Hudson 2002). The differences in production goals are important. Generally speaking, commercial farmers attempt to manage their herds to maximize profits, maintaining appropriate grazing pressure on their land within the constraints of climatic variability. Communal farmers manage their herds for security, and to meet short-term cash needs. Communal farmers in the Vryburg area basically do not sell large ruminants, but seek to build up as many animals as possible.

3.1. How do farmers react to drought?

The annual mean rainfall in Vryburg district from 1960 to 1995 was 470 mm, with a coefficient of variation of 30%. In dealing with this variability, there are considerable differences between commercial and communal farmers in the actions that they take. The survey of Hudson (2002) indicates that nearly 7 out of 10 commercial farmers either do nothing in the face of drought (23%) or sell animals to reduce stocking rates (44%). Few if any communal farmers will sell animals, and most will do nothing at all; a few will occasionally attempt to buy fodder for their animals. Hudson found only a few respondents who would attempt to rent pasture in droughts or would feed cash crops. There are interesting questions to be asked concerning the relatively high numbers of both commercial and communal farmers who said they never experience drought or have no drought strategy (about 35% for each group). One possible reason for this may be that dry years are simply seen as occurrences in the normal run of events; there are suggestions that commercial ranches are generally somewhat under-stocked, and, as demonstrated below, this is clearly a rational response to periodic drought.

Farmers' perceptions on the impacts of drought on livestock markets (Hudson 2002) are greatly varied. Commercial farmers report, on average, a 15% decrease in livestock prices during droughts, and communal farmers a 30% price decrease, although a third of respondents reported price drops of 50% in drought years. Unfortunately, we were not able to obtain local livestock market prices for Vryburg over the last 30 yr. This merits further investigation, because price responses may be critical in calculating realistic economic benefits of forecasts.

In the analyses that follow, the scenarios investigated revolve around adjustments in stocking rate. For such interventions, the direct economic value of forecasts is essentially zero for communal farmers; the data of Hudson (2002) and discussions at local workshops in Vryburg in 2000 and 2001 (Galvin 2000, 2002) provided little evidence that communal farmers would change stocking-rate decisions on account of forecasts of either wetter-than-normal or drier-than-normal conditions in the coming season. Communal farmers are more likely to buy in fodder. In any case, the survey data of Hudson (2002) indicate clearly that communal farmers are still very keen to receive seasonal forecasts; all those interviewed wanted forecasts at least monthly. This was also borne out by discussions at workshops in Vryburg (Galvin 2000, 2002). In terms of the perceived value of forecasts, Hudson (2002) found that 20% of commercial farmers interviewed thought that seasonal forecasts were valuable. On the other hand, 54% of communal farmers thought that seasonal forecasts were valuable. What communal farmers would actually do with this information, and what purpose it might serve, is far from clear. It is possible that this information could stimulate more communal farmers to buy in fodder as a drought-management practice. Up until very recently, most communal farmers (66%) had not received forecast information (Hudson 2002).

3.2. Incorporating climate forecast information in simulated management decisions

The literature on the economic value of information in decision-making is very large, and it revolves around the (obvious) notion that information derives its value by modifying decisions that would have been made differently in its absence (Raiffa 1968, Anderson et al. 1977). In assessing its value in any situation, therefore, some understanding of farmers' objectives and attitudes, as well as of their biophysical environment, is critical in assessing questions related to the potential value of climate forecasts.

Without detailed information on farmers' objectives and attitudes, we have to make somewhat broad assumptions, where the potential value of climate forecasts is estimated by comparing decisions with and without the forecasts; if decisions never change, then the value is easy to determine if the forecasts are costless. If there is change, then because (as in this case) the analyses are really retrospective (i.e. have all occurred in the past), some method has to be applied to come up with a plausible method of triggering the modified behaviour. For this study we proceeded as follows.

Fig. 1 shows the occurrence of El Niño (warming) and La Niña (cooling) events in the study area from 1920 to 1995, overlaid with the trace of annual rainfall from 1900 to 1995 (see: www.nrel.colostate.edu/projects/wits/index.html). Visual inspection suggests that El Niño events tend to lead to low rainfall (for instance, 1925–1926, 1932–1933, 1969–1970, 1982–1983, and 1991–1992) and La Niña events to high rainfall (1924–1925, 1949–1950, 1973–1974,

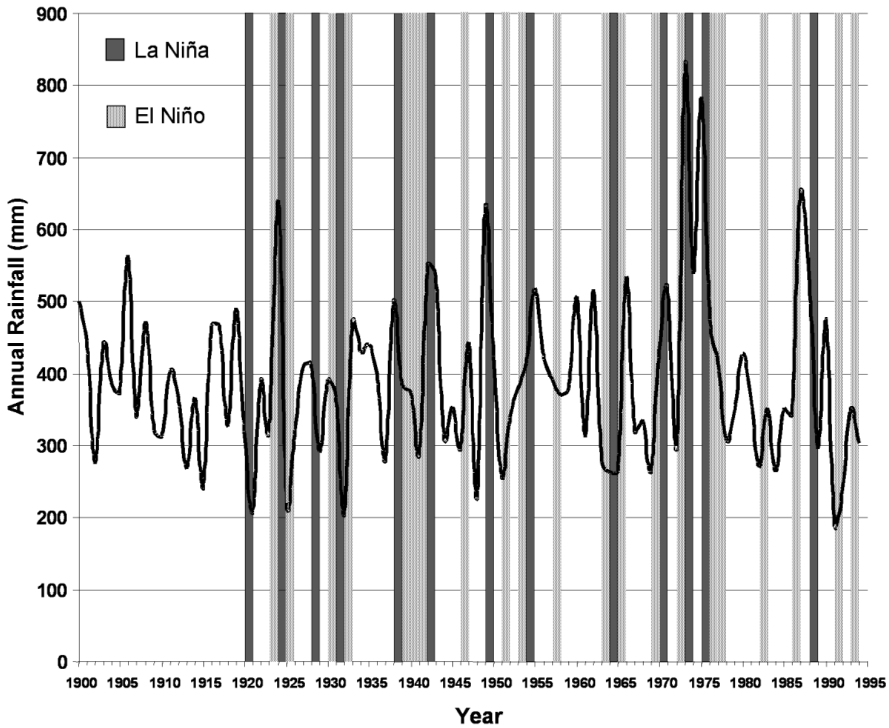

Fig. 1. Annual rainfall and El Niño/La Niña events in the study area around Vryburg, Northwest Province, Republic of South Africa (–26.95° S, +24.72° E; elevation 1190 m above sea level. Mean = 470 mm, CV = 30 %), 1900 to 1995. (Source: R. B. Boone pers. comm.)

1975–1976, for example). In restrospective mode, where we are attempting to simulate what farmers might have done in the past, we cannot simply use retrospective annual rainfall as a trigger. In the absence of historical SAWS 3 mo forecasts for the last 30 yr or so, we decided to use simply the occurrence of an El Niño season as a trigger for alternative livestock management for that season. We could have used retrospective seasonal rainfall (and chosen seasons with rainfall of less than 300 mm, for example), but this would have led to overestimation of the benefits of using forecast information, as this is essentially a perfect predictor. The use of the presence of an El Niño season is probabilistic, in the same way that a prospective forecast is: an El Niño season may have below-average rainfall, but it may not; similarly, a season may have below-average rainfall, without being an El Niño season. In the analyses that follow, scenarios were run for 1970–1995, and so the trigger seasons were therefore 7 in number: 1972–1973, 1976–1977, 1977–1978, 1982–1983, 1986–1987, 1991–1992, and 1993–1994. (Note that for these 7 seasons, the average rainfall was 334 mm, well below the long-term average of 470 mm). It should be borne in mind that, as ENSO events are by no means the only ingredients of SAWS seasonal forecasts, there will be some error associated with valuing the economic benefits of forecasts derived solely on the basis of ENSO events, as in the analyses below.

3.3. Interfacing a simple economics module with Savanna

We constructed a simple mathematical programming (MP) model that could be interfaced with the Savanna ecosystem model. The MP model is based on similar models assembled by Herrero et al. (1999) that integrate detailed biophysical models with a household model that describes the objectives and production goals of the household; describes the activities that the household can undertake; and then defines the constraints faced by the household. The information that can be produced concerns the use of resources by the household in the pursuit of household objectives, with consequences for income, assets, profit, and, in some cases, household nutrition. A diagram of the generic household model is shown in Fig. 2, and the model was programmed in XPRESS-MP (Dash Associates 2001). Links to Savanna were made so that the entire system could be run without intervention, once the input files had been set up. It should be noted that the household model used in the analyses below was extremely simple—essentially, it calculates and keeps track of gross margins in response to different stocking rates. The framework is flexible enough, however, to accommodate a much more complicated household model with multiple objectives, for example.

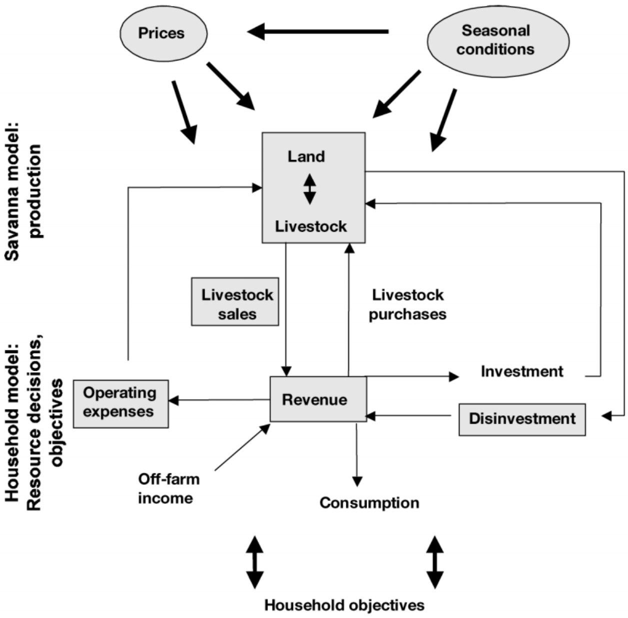

Fig. 2. Flows in the household model and linkages to Savanna. Boxes in grey are currently treated in the model (see Section 3.3 for details)

This amalgamation of the Savanna model with a household optimisation model differs from the socio-economic model linkage reported in Galvin & Thornton (2001) and Thornton et al. (2003). In that example, the socio-economic model is essentially an accounting module that keeps track of cash and dietary energy in the household, coupled with sets of simple rules governing the purchase and sale of livestock. A long-term research goal is to integrate these different types of socio-economic module so that a single linked Savanna system will be able to carry out integrated biophysical and socio-economic assessments for a wide variety of rangeland situations, from subsistence pastoral and agro-pastoral systems through to high-input commercial production systems. An optimisation framework is flexible enough to handle both commercial systems, where profit maximisation and risk reduction are likely to be major objectives of the farmer, and communal systems, where household food security and maintaining animals as a capital asset are likely to be the major production goals.

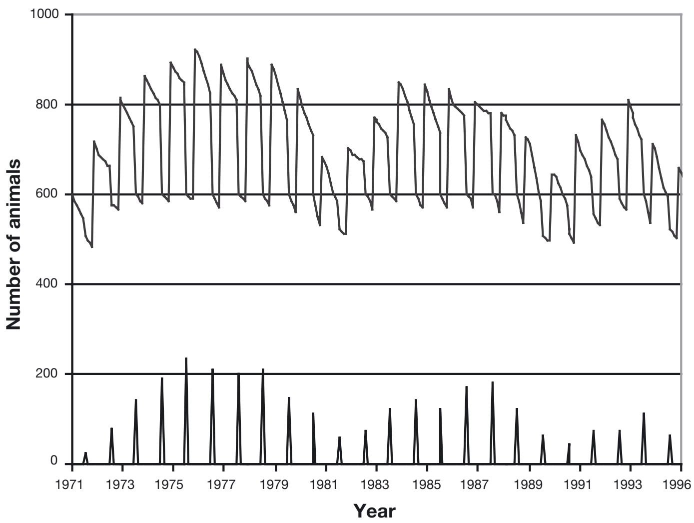

Fig. 3. Simulated cattle numbers for Farm V112, 1971–1995, set stocking with culling to preserve numbers and age–sex ratios. Upper line: total cattle number; bottom line: number culled each season

4. SCENARIO ANALYSIS

We ran 2 sets of scenarios with the model, for the same commercial farm. First, we optimised the stocking rate over 25 yr. This is equivalent to the situation where a farmer makes no special management decisions in the face of drought, but attempts to maintain a set number of animals on the farm in good years and bad. In the second scenario, we introduced alternative management in response to the presence of an El Niño season. This involved heavy culling to reduce livestock numbers, on the basis that an El Niño season was likely to be drier than normal, in which case the feed available to the herd would be severely restricted. A comparison of these 2 scenarios thus gives some indication of the value of adjusting management in El Niño seasons.

4.1. Optimal stocking rates on a commercial farm

To test the performance of the Savanna-XPRESS model, we ran some scenarios for commercial farm V112, the same farm for which results are presented in Boone et al. (2004). This is a farm of 5900 ha with 550 cattle and 50 sheep. Two runs of each scenario were carried out, in which cattle prices were assumed to decrease by 50% in El Niño years, corresponding to the pessimistic impacts reported by both communal and commercial farmers in the survey of Hudson (2002). (Runs were also carried out with 30% cattle price decreases, but the impacts were, qualitatively, little different to those reported below, and so are not included here.) Fig. 3 shows total cattle numbers over the simulation run, and the total number of cullings made each year to maintain a set number of cattle (in this case, 600 animals) and preserve the observed age–sex ratios. The variability in the off-take of weaners is particularly noteworthy, from over 200 in wetter years such as 1974–1975 to less than 50 in drier years such as 1989–1990.

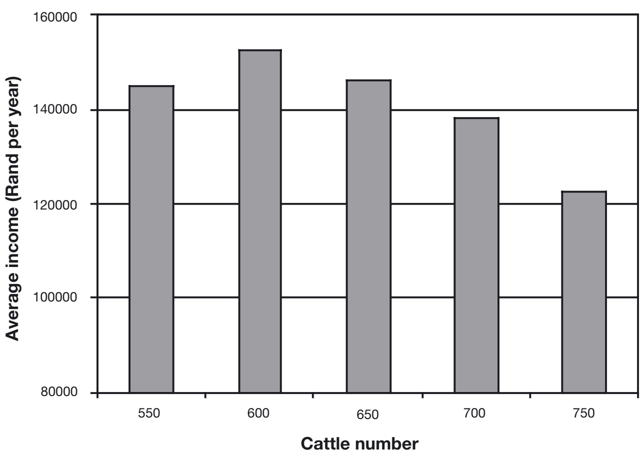

Fig. 4. Simulated stocking density for Farm V112, 1971–1995, showing the optimum at 600 animals (Rand 1 = US$ 0.12 in September 2001)

To assess the optimal stocking rate in terms of maximizing income for this farm over 1971–1995, the model was used to assess various different stocking rates. Fig. 4 shows simulated average farm income as a function of stocking rate. The optimum occurs at 600 head of cattle for these conditions, whereas the farmer actually stocks at 550. However, there is a relatively rapid decline in income at stocking rates in excess of 600 animals. Economically and ecologically, this farm would appear to be somewhat under-stocked, but this may help explain why this particular farmer responded in the survey that he had never experienced serious drought (Hudson 2002).

4.2. Adapting management to forecast information on a commercial farm

In the second scenario, the model was used to investigate the impacts on farm income of culling at different rates, triggered by the presence of an El Niño season. This scenario sought to answer the following question: In El Niño seasons, with an increased probability of low rainfall, what proportion of the herd should be culled to maximize long-term income? This 'heavy culling' was simulated to take place in July at the start of El Niño conditions for that season. In all other years (i.e. normal and La Niña seasons), culling was carried out simply to maintain herd numbers and preserve age–sex ratios, as in the first scenario above. We assumed that there was no direct cost incurred by the farmer in obtaining the forecast itself.

The results are shown in Fig. 5. If heavy culling of the herd was not carried out in El Niño years, then (as shown in Fig. 4) 600 animals maintained over 25 yr was the optimal stocking rate. If 10% heavy culling occurred (i.e. culling to 540 animals in the El Niño years), then long-term returns decreased as shown. Heavy culling to 40% of the 600 animals in the forecast years (to 360 animals) was the strategy that maximized annual income over the long term.

4.3. What is the benefit of using the forecasts?

The 2 scenarios of set stocking and heavy culling are compared in terms of their generation of income over the 25 yr in Fig. 6a. The cumulative benefit of using the forecast by year is shown in Fig. 6b. These results suggest that there are substantial benefits to be gained from using the forecasts. Fig. 6 shows that the farmer is 'cashing in' part of the herd, even when prices are relatively low, but that ecologically, herd numbers can recover adequately in subsequent seasons so as not to decrease long-term profits.

These benefits of using the forecasts come at some cost, however. Fig. 7 shows the various scenarios plotted in mean–variance space. It is immediately obvious that the heavy culling options increase the variance of year-to-year farm income. While over the long term the farmer may be better off pursuing one of those options, there will be an increase in the number of years when annual income may actually be inadequate for requirements of the household.

Would commercial farmers then use a seasonal forecast of El Niño conditions? The results of these simulations suggest that the answer to this is: it depends. Fig. 7 shows, in effect, the classic problem of stochastic dominance in decision analysis, where choices be-

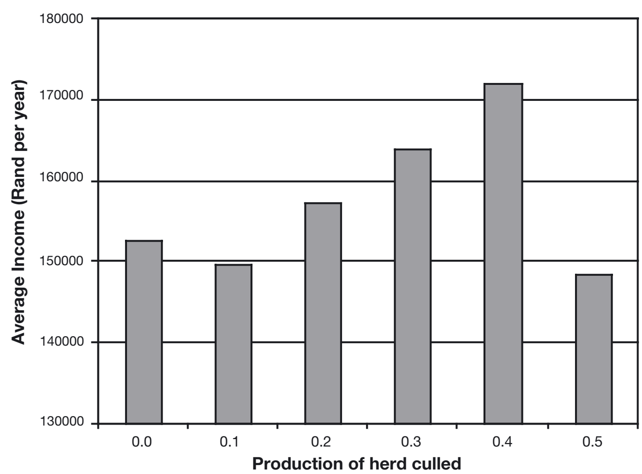

Fig. 5. Simulated culling rates in El Niño years for Farm V112, 1971–1995, showing the profit-maximizing rate of 40% of the herd culled (Rand 1 = US$ 0.12 in September 2001)

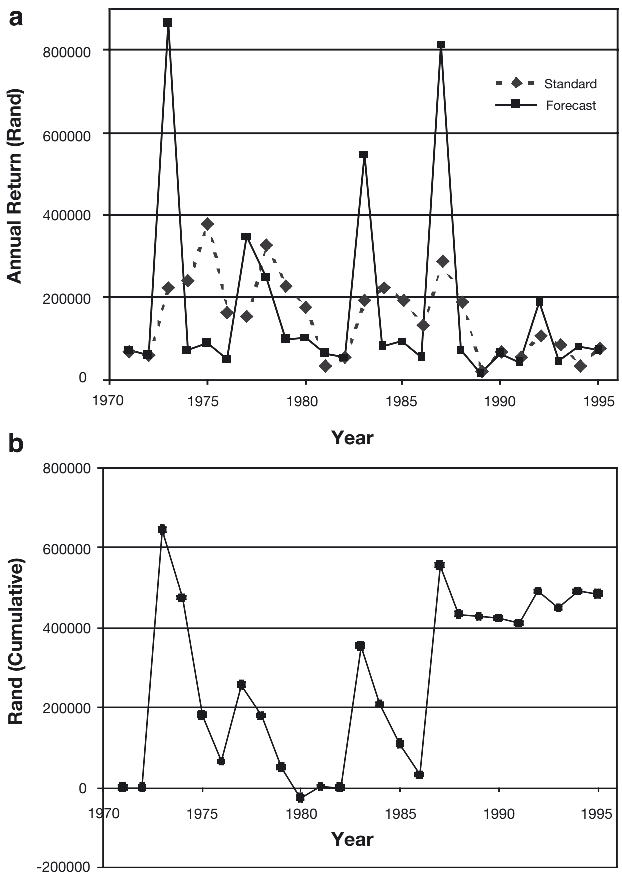

Fig. 6. (a) Income by year on Farm V112 for 2 scenarios, with a 50 % decrease in cattle prices in El Niño years (standard: set stocking; forecast: heavy culling in El Niño years). (b) Cumulative benefit in Rand to using the forecast information to heavy cull compared with set stocking (Rand 1 = US$ 0.12 in September 2001)

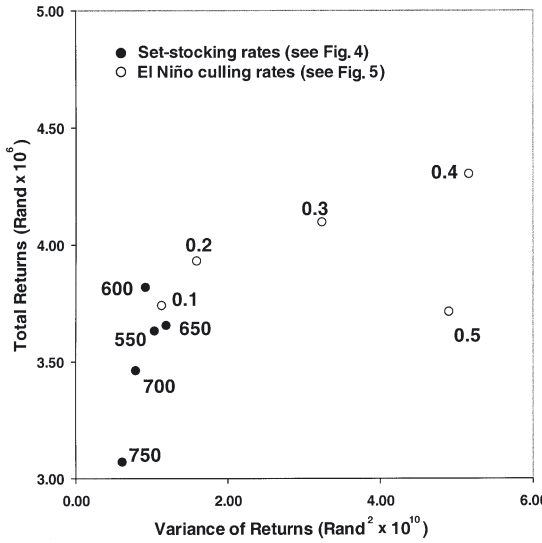

Fig. 7. Set-stocking and culling strategies shown in Figs. 4 & 5 in mean–variance space (Rand 1 = US$ 0.12 in September 2001)

tween different options of differing mean and variance cannot necessarily be inferred for individual decision-makers in the absence of their utility function (Anderson et al. 1977), but depend on the individual's attitude to risk. How much more variance in farm income are farmers willing to put up with for increases in average income? Risk-averse farmers who need as steady an income stream as possible may be unlikely to take on the added risk of using the forecasts. On the other hand, for farmers who are more interested in ranching as an investment and are able and prepared to take on more risk, the rewards may be substantial over the long term, as Fig. 6 shows.

As noted above, the situation for the communal farmers is somewhat different, as it is not clear how forecast information would be used to modify livestock management. In relation to de-stocking decisions, the economic value of forecast information to communal farmers would appear to be close to zero, as very few communal farmers de-stock in response to a drought. However, there may be other benefits to its use. Boone et al. (2004) ran some simulations for communal farmers with smaller herd sizes (see Table 1), and while qualitatively the results were similar to those for commercial farmers (i.e. greater offtake rates are possible using climate forecasts), in our study we have found little evidence to suggest that such management is carried out by communal farmers in the region. Communal farmers may, however, have some options for feed supplementation in times of drought, and while these will generally require some investment, they need to be investigated for their possible economic value over the long term.

5. DISCUSSION AND CONCLUSIONS

Despite living in the information age, we still know rather little about the ways in which information can be synthesized to make better-informed decisions. In many cases we have a very incomplete understanding of why farmers make the decisions they do, and this has been identified as a major reason for poor adoption of agricultural technology, particularly in Africa (see Thomas & Sumberg 1995, for example). Without involving farmers from the outset and understanding the true nature of the constraints that they face, designing and even trying to implement particular policy and technological interventions are essentially random processes. Such hit-and-miss approaches are increasingly inefficient in times of scarce resources, but understanding of decision-making processes has to improve if agricultural research is to have real impact at the farm level.

The situation when dealing with information such as climate forecasts is complicated by the fact that, being probabilistic in nature, they will sometimes be wrong. It is important to highlight to users of this information the fact that forecasts are essentially probability statements. When forecasts are wrong, as they inevitably will be from time to time, the issue becomes one of trying to win back and maintain their credibility, and this may not be easy to do (Hansen 2002).

Our field survey (taken in 1999 and following the 1997–1998 El-Niño-related drought) showed that few of the commercial farmers interviewed were then using climate forecasts (Hudson 2002). This was because this El Niño event was forecast to be the worst in recent history, but it failed to materialize. However, when we held a workshop in 2001, some commercial farmers were again warming to the idea that forecasts might be useful.

The study above has highlighted various other problems. There is the perennial problem of assembling farm budgets in African farming systems (for instance, what is the most appropriate way to value family labour in communal systems?). In addition, if forecast information does not appear to modify the decision making of communal farmers, does this information have other, perhaps cultural or social, value (optimal management for asset accumulation, perhaps?). Or does it modify household behaviour in other more subtle ways that have hitherto been overlooked? It may well be that economic value is only one facet of information value. It is unclear what the other facets may be, but they may well be important.

For commercial farmers, model results suggest that individual low-income years cannot be avoided directly through de-stocking decisions, as culling impacts will usually be felt well after the event. Even if bad years cannot be avoided entirely, analysis of the scenarios outlined above indicate that long-term average annual income could increase through utilizing climate forecasts, but at the cost of increased year-to-year variability in farm income. This may be acceptable to some farmers, in terms of their attitudes and objectives, but for many, the increased risks may not be worth it.

There is much work still to do to refine these analyses. One area of work relates to the model itself. Calibration and validation of Savanna is generally a difficult and data-intensive process. Boone et al. (2004) noted that the model still needs a significant amount of assessment work before the results could be used at the farm level with a great deal of confidence. We also plan to develop the household model further to incorporate multiple objectives, including a livestock asset accumulation objective, which may make the results more pertinent to communal farmers. There are also other options that may be available to some farmers, such as purchasing fodder when required. These need to be investigated also.

Another remaining area of work relates to the more refined identification of situations where climate forecasts are of value, so that the results of such model runs as those outlined above can be generalized. Allied to this is the need for attention to be given to designing appropriate institutional structures and mechanisms, so that the best 'fit' between forecasts and their use and uptake is ensured.

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LITERATURE CITED

Acocks JPH (1975) Veld types of South Africa. Mem Bot Surv S Afr 40:1–128

Anderson JR, Dillon JL, Hardaker JB (1977) Agricultural decision analysis. Iowa State University Press, Ames, IA

Boone RB, Coughenour MB (2000) Integrated management and assessment system: balancing food security, conservation and ecosystem integrity. Using Savanna and SavView in ecosystem modelling. NREL, CSU, Fort Collins, CO

Boone RB, Galvin KA, Coughenour MB, Hudson JW, Weisburg PJ, Vogel CH, Ellis JE (2004) Ecosystem modelling adds value to South African forecasts. Clim Change (in press)

Coughenour MB (1993) Savanna—a spatial ecosystem model. Model description and user guide. NREL, Colorado State University, Fort Collins, CO

Dash Associates (2001) XPRESS-MP user manual. Dash Optimization Ltd, Leamington Spa. Also available at: www.dashoptimization.com/

Department of Agriculture (1999) Atlas products of the North West Province. Technical Supportive Services GIS Section, Department of Agriculture, North West Province, Potchefstroom

Ellis JE, Coughenour MB (1998). The Savanna integrated modelling system: an integrated remote sensing, GIS and spatial simulation modelling approach. In: Squire VR, Sidahmed AE (eds) Drylands: sustainable use of range lands into the twenty-first century. IFAD Series: Technical Report, IFAD, Rome, p 97–106

FEWS (Famine Early Warning System) (1997) El Niño's effects on rainfall in eastern and southern Africa. FEWS Bulletin AFR/97–10. US Agency for International Development, Washington, DC

Galvin KA (ed) (2000) Users of seasonal forecasts workshop, Armoedsvlakte, Vryburg, Republic of South Africa, 5–6 October 1999. Workshop proceedings. Natural Resource Ecology Laboratory, Colorado State University, Fort

Collins, CO. Also available at: www.nrel.colostate.edu/projects/wits/index.html
Galvin KA (ed) (2002) Integrated assessment of drought responses, climate forecasting and modeling for the livestock sector. NOAA Project Workshop, Armoedsvlakte, Vryburg, Republic of South Africa, 30–31 May 2001. Workshop proceedings. Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO. Also available at: www.nrel.colostate.edu/projects/wits/index.html
Galvin KA, Thornton PK (2001) Human ecology, economics and pastoral household modeling. In: Boone RB, Coughenour MB (eds) A system for integrated management and assessment of East African pastoral lands: balancing food security, wildlife conservation, and ecosystem integrity. Final Report to the Global Livestock Collaborative Research Support Program. Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO, p 105–123. Also available at: www.nrel.colostate.edu/projects/imas/prods/finals/GLCRSP_IMAS_2001.pdf
Hansen JW (2002) Realising the potential benefits of climate prediction to agriculture: issues, approaches, challenges. Agricult Syst 74:309–330
Herrero M, Fawcett RH, Dent JB (1999) Bio-economic evaluation of dairy farm management scenarios using integrated simulation and multiple-criteria models. Agricult Syst 62: 169–188
Hudson JW (2002) Response to climate variability in the livestock sector in the North-West Province, South Africa. MA thesis, Colorado State University, Fort Collins, CO
Hudson JW, Vogel C (2003) The use of seasonal forecasts by livestock farmers in South Africa. In: O'Brien K, Vogel C (eds) Coping with climate variability: the use of seasonal climate forecasts in Southern Africa. Ashgate Press, Aldershot, p 75–96
Jahnke HE (1982) Livestock production systems and livestock development in tropical Africa. Kieler Wissenschaftsverlag Vauk, Kiel
Lindsay JA, Harrison M, Haffner M (1986) The southern oscillation and South African rainfall. S Afr J Sci 82:196–189
LOGIC (Long-term Operational Group Information Centre) (2001) Seasonal outlook for southern Africa, August 2001. South African Weather Bureau, Pretoria. Also available at: www.weathersa.co.za/Forecasts/forecast.htm
Mason S (2001) El Niño, climate change, and Southern African climate. Environmetrics 12:327–345
Mason S, Jury MR (1997) Climatic variability and change over southern Africa: a reflection on underlying processes. Progr Phys Geogr 21:23–50
O'Brien K, Vogel C (2003) A future for forecasts? In: O'Brien K, Vogel C (eds) Coping with climate variability: the use of seasonal climate forecasts in Southern Africa. Ashgate Press, Aldershot, p 197–211
Raiffa H (1968) Decision analysis: introductory lectures on choices under uncertainty. Addison-Wesley, Reading, MA
Thomas D, Sumberg J (1995). A review of the evaluation and use of tropical forage legumes in sub-Saharan Africa. Agricult Ecosyst Environ 54:151–163
Thornton PK, Galvin KA, Boone RB (2003). An agro-pastoral household model for the rangelands of East Africa. Agricult Syst 76:601–622

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