FINAL TECHNICAL REPORT

Project no. **X0289** **OPTIMISING UTILISATION OF SEMI-ARID RANGELANDS**

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Executive summary

Purpose

Optimising the utilisation of semi-arid rangelands requires a systematic analysis to identify and evaluate the constraints on production. The purpose of this project was to review existing knowledge of key processes affecting productivity of semi-arid rangeland systems, and to combine this information in a model. This would test whether animal performance and vegetation dynamics could be represented adequately; allow us to assess the components and processes to which the system is most sensitive; identify where knowledge is lacking; and identify management techniques which would repay further development.

Activities

An extensive review of the existing information on semi-arid rangeland dynamics showed that it is, generally, adequate for the purpose of modelling. Critical areas where knowledge is weak were identified. A model was developed that successfully predicts many of the phenomena of semi-arid grazing systems. Field sites were identified where sufficient background data exists for model evaluation, and where experimental work could address key processes about which insufficient is known.

Outputs

The project produced a review of current knowledge (see Appendix), a model of rangeland dynamics (see Appendix), recommendations of research priorities, and an analysis of management options, all in accordance with plans laid out in the logframe.

Contribution to the ODA goal "Optimal strategies adopted for sustainable management of livestock on semi-arid rangeland".

The model provides a way of analysing the constraints on production from semi-arid rangelands. It also provides a scientific and objective basis for optimising the long-term utilisation of vegetation resources. Analysis of the system's performance will help target future research. Annual and seasonal variability in rainfall is an important cause of instability in semi-arid environments, so flexible and opportunistic management practices are needed to increase the sustainable economic yield of rangeland. The model allows such strategies to be evaluated.

Results summary

1 Assessment of the existing information on semi-arid rangeland dynamics showed that it is, generally, adequate for the purpose of modelling.

2 A model was developed that successfully predicts many of the phenomena of semi-arid grazing systems. Predicted animal diets and performance levels, rainfall-stocking rate relations and bush encroachment are all reasonably close to those observed in reality. The current model omits an explicit treatment of soil nutrient status and other (*eg* hydrological) sources of spatial variation, and the does not yet include fire as a determinant of vegetation change.

3 The performance of semi-arid grazing systems was shown to be sensitive to climatic variability, and the separate effects of the mean and variance in annual rainfall were established. With increasing variability in annual rainfall cv from 0.2 to 0.4 (typical of semi-arid regions) and without changing the long-term mean annual rainfall, mean carrying capacity declines by a half. Measures to buffer climatic variability, particularly those designed to limit animal mortality in droughts, could certainly increase system output.

4 Diet quality was predicted to be the first limiting constraint on nutrient intake rates, animal production evidently being limited by the quantity of high-quality forage. Knowledge of the nutritive value of savanna vegetation components is surprisingly poor, and better information is required. Despite the importance of browse in heavily-utilised systems, there is inadequate knowledge of browse production and utilisation (especially of the highly nutritious pods and fruits of savanna trees). Better understanding of the diet selection of free-ranging animals is needed to assess the nutritional constraints on performance and to derive suitable interventions.

5 Bush encroachment is an important process, because it reduces grass yield and predicted diet quality. Bush utilisation by goats was shown to reduce encroachment.

6 The model offers a comprehensive basis on which to evaluate alternative management strategies, but further work needs to be done on the amalgamation of the many objectives of livestock keepers, as expressed in the chosen balance between economic output and the maintenance of high stocking rates.

7 Flexible stocking strategies designed to tackle climatic variation showed only limited scope for improving output over fixed stocking. The main reasons for this are that major losses of stock are associated less with one-year than with two-year droughts, which are difficult to track, and that de-stocking can be really effective only if the productive potential of the herd can be re-established more rapidly than is possible from depleted herds' own growth. If re-introductions of breeding stock are not possible, their numbers will lag behind climatic fluctuations, producing a succession of population crashes and missed opportunities.

8 Further analysis of the feasibility and effectiveness of adaptive management policies is required. Traditional policies of maintaining the maximum number of breeding stock, and of hoping that most of them will survive drought, may be as close as 'opportunistic' management can get to dealing with drought.

9 *Identified constraints.* Variation between years in the supply of sufficiently high-quality forage (caused by seasonal variation in rainfall) is the single most important constraint on production from semi-arid rangeland. The low quality of dry-season forage is the main constraint on nutrient intake by animals, and this directly affects mortality and hence output. Poor ability to predict severe droughts, and to rebuild herds following de-

stocking or mortality, were identified as constraints on the adoption of flexible stocking policies.

Background

Many of the world's poorest countries are in the arid and semi-arid zone, where the connection between land degradation and livestock management is an acknowledged problem. Improvement of livestock management strategies are needed, but land-use planning is impeded by lack of a framework for predicting how rangeland systems respond to livestock stocking policies, management practices and interactions with wildlife. There are currently no scientific and objective methods of optimising the long-term utilisation of vegetation resources, of matching the mix of animal species to vegetation structure, of accounting for the impact of wildlife or of combining wildlife management goals with pastoralism. Annual and seasonal variability in rainfall is an important cause of instability in semi-arid environments, so flexible and opportunistic management practices may be needed to increase the sustainable economic yield of rangeland.

Objectives

(1) To bring together existing knowledge of key processes affecting productivity of semi-arid rangeland systems.

(2) To incorporate existing knowledge, together with improved descriptions of animal foraging strategy and diet selection, in models of rangeland function and test whether animal performance and vegetation dynamics can be represented adequately.

(3) To assess the components and processes to which the system is most sensitive and identify where knowledge is lacking.

(4) To identify management techniques which would repay further development.

(5) To identify field sites where sufficient background data exists for model evaluation, and where experimental work could address key processes about which insufficient is known.

Research activities

The project lasted one year from 1 May 1995. The planned inputs were achieved, and the great majority of the work was completed on time, although the analysis of management options was not finished until mid June, and the paper currently being written is unlikely to be submitted until early autumn. The following description is organised in terms of the objectives (above) and the set of Milestones we set ourselves:

May	1995	Appoint programmer	**(Milestone 1)**
July	1995	Complete basic framework of systems model	**(Milestone 2)**
July	1995	Visit field sites, locate sources of data and review modelling procedures and limitations	**(Milestone 3)**
Oct	1995	Submit report reviewing existing information	**(Milestone 4)**
Dec	1995	Incorporate model of vegetation response to defoliation	**(Milestone 5)**
Jan	1995	Incorporate spatial and temporal variation in primary production	**(Milestone 6)**
Feb	1996	Report on sensitivity analysis and identification of areas where research is required	**(Milestone 7)**
Apr	1996	Report analysis of management options	**(Milestone 8)**
June	1996	Submit paper on optimal species ratios to international scientific journal	**(Milestone 9)**.

The research associate (JF Derry; resource modeller/programmer) was appointed by 1 May, after interviewing six qualified candidates. (**Milestone 1**: Appoint programmer, May 1995)

An initial review of modelling objectives and procedures lead to the establishment of an outline grazing systems model, and this was developed, during May and June, to incorporate the main components of the system (the foraging behaviour and consequent population dynamics of three animal species feeding on three vegetation types with defined seasonalities of production). Programming was carried out both in BASIC and in C++, the latter being an object-oriented implementation which allows considerable flexibility in, eg, inclusion of many herbivore and vegetation classes. C++ programming is, however, commensurably more complex and slow, and the RA had to work long hours to keep up to the prescribed schedule. (work towards Objective 2, above, and **Milestone 2**: Complete basic framework of systems model, July 1995).

In July we (Illius, Gordon & Derry) visited organisations in Zimbabwe and Botswana. Contacts were established with staff and visits made to field sites to discuss the context of modelling and locate sources of data. Zimbabwe: Agricultural Development Authority (Dr L Mhlanga, Gen. Manager and Kelvin Grove Ranch), the Dept of Research and Specialist Services (P Nyathi, Dep. Director and staff at Matopos Research Station), University of Zimbabwe (Prof J Topps, Dr R Sibanda and Dr NR Ndlovu, Dept Animal Science). Botswana: Dept Agricultural Research (Dr Mazhani, Dep Director, Dr B Kiflewahid and G Tacheba, Animal Production and Range Research Unit and Morale field site), Ministry of Agriculture (RM Kwerepe, Sen. Range Ecologist; MJ Powell, Land Evaluation for Livestock Production Specialist; P Curry) and the University of Botswana (Prof R Silitshena and Dr JS Perkins, Dept Environmental Sciences; Dr JM Dangerfield, Dept Biology). We subsequently attended the 1995 World Conference on Natural Resource Modelling (Pitermaritzburg, RSA) and symposium on 'Dimensions of sustainability in herbivore-vegetation interactions in variable environments', and established a wide range of useful contacts.

The visits established the existence of extensive background data on vegetation structure and utilisation and on animal production, particularly at Matopos Research Station (DRSS, Zimbabwe) and at Morale Ranch (APRU, Botswana). The potential for collaboration clearly exists and was welcomed by those responsible. This satisfies Objective 5 (above; also **Milestone 3**: Visit field sites, locate sources of data and review modelling procedures and limitations, July 1995)

From August to October, we carried out an extensive review of the existing knowledge of semi-arid rangeland, and submitted a preliminary report to NRI (*Components, processes and dynamics of semi-arid grazing systems: A review of current knowledge*; Objective 1, above, and **Milestone 4**: Submit report reviewing existing information, Oct 1995).

During the autumn, we worked on a more detailed model relating daily rainfall, infiltration, soil water balance to plant growth and its allocation, in grasses and woody vegetation. By connecting growth to leaf mass as well as to soil water (assuming solar radiation is not limiting in the semi-arid tropics), we were able to describe the principal effect of defoliation on plant growth. (Objective 2 above, and **Milestone 5:** Incorporate model of vegetation response to defoliation**,** Dec 1995**).**

We obtained rainfall data (daily, 1975 to 1995) from four sites in Botswana and 4 sites in Zimbabwe, covering a broad transect (running from SW to NE), from the most arid to the more mesic regions. Our model accepts these data to drive plant growth, and we are thus able to model production across the region. We also have the Zucchini rainfall generator, which generates runs of rainfall data for any site in for South Africa (Objective 2 above, and **Milestone 6** Incorporate spatial and temporal variation in primary production**,** Jan 1995**).**

In mid January, I re-visited Zimbabwe to collect data on plant biomass allocation and digestibility, and to attend a symposium on Savanna Dynamics (Grassland Society of South Africa, Nelspruit, RSA). Both were extremely useful, and strengthened contacts with many of the local researchers we had met on our previous trip to Zimbabwe. In Harare, I visited Messrs Chinembiri and Mupangwa, Livestock and Pastures specialists at AGRITEX, the extension services, to discuss there perception of the most pressing needs in semi-arid grazing systems. The expenses of the visit were largely met out of the overheads component of this grant.

In spring, we completed the animal foraging behaviour/intake component, as well as the prediction of nutrient utilisation by animals, and their growth, reproduction and mortality (Objective 2). We added a range of management routines, to allow animal sales to be controlled and stocking rates to be set, and commenced an analysis of system performance and management options. A final report on the dynamics of rangeland systems, important processes about which knowledge is weak or lacking, and management strategies likely to increase sustainable economic output, was produced in June (Objectives 3 and 4; **Milestone 7,** Report on sensitivity analysis and identification of areas where research is required, Feb 1996; **Milestone 8**, Report analysis of management options, Apr 1996**).**

In May, I visited colleagues and semi-arid savanna sites in Natal and Eastern Cape, South Africa. With Prof TG O'Connor, University of Natal, I commenced writing a paper, partly arising out of our project work, on the dynamics of semi-arid grazing systems. This represents progress towards **Milestone 9** (Submit paper on optimal species ratios to international scientific journal, June 1996), but with a change of subject matter. The trip was funded by the Royal Society (with the primary objective of setting up collaborative links between UK institutions and historically disadvantaged universities in South Africa).

Outputs

The following outputs were achieved, as planned:

(1) *Review of existing information.* This is presented in the Appendix, pp 6-37

(2) *Model of semi-arid rangeland.* Details of this are given in the Appendix, pp 3 and 38 - 53. In brief, the model is based closely on the information reviewed (Illius, Derry & Gordon 1995). It runs on a daily iteration interval, and calculates, from daily rainfall data, vegetation growth (grass and trees) and its allocation to plant parts, the selection and intake of these by animals (cattle and/or goats), the animals' consequent energy and protein balances, body growth, reproduction and mortality. It therefore simulates animal population dynamics by coupling them to vegetation biomass dynamics, allowing the underlying mechanisms to dictate the performance of the system over the chosen time scale - generally 20 years.

(3) *Recommendations of research priorities* Details of these are given in the Appendix, pp 3 and 53. In summary, they are as follows.

Better information is required on browse production in response to rainfall, the allocation to plant parts (especially to fruit) and the utilisation of browse (particularly the extent of utilisation of current season's growth and of fruit). Current knowledge of browse is weak, despite it being a major component of semi-arid, and especially heavily-utilised, systems.

Further work on animal species differences in diet selection (*eg* between cattle and goats) would be justified by the potential benefits of being able to matching vegetation resources with animal types. The main uncertainty relates to the relative utilisation of browse.

Predicting the productive capacity of rangeland is hampered by lack of understanding of browse utilisation by different animal types.

Further analysis of the feasibility and effectiveness of adaptive management policies is required, in the light of our findings that their benefits may be modest.

(4) *Analysis of management options* Details of these are given in the Appendix, pp 3 and 46 - 51. In brief, they are as follows.

Stocking policy The model can be used to define the stocking rate which maximises sales/ha (which might be referred to as economic carrying capacity) or which maximises stock numbers kept (ecological carrying capacity). When compared at equivalent metabolic weights, goats and cattle did not differ markedly in maximum sales of live weight/ha, but a greater metabolic mass of goats than cows can be supported on grass-tree vegetation.

Mixed stocking offers no apparent benefits, in terms of sales of live weight/ha, than stocking with single species. This result is qualified by the conservative assumptions made on the differences in foraging strategies between cattle and goats.

Sales policy and flexible stocking Ways of 'tracking' environmental fluctuations were investigated, as a method of limiting drought-induced mortality. We compared fixed stocking, a policy of pre-emptive sales if drought looked likely, and flexible stocking rates based on rainfall or the severity of mortality. In each case we compared sales policies which either allowed or did not allow sales of female breeding stock.

Stocking rate was the most important influence on output, followed by the sales policy on female breeding stock. Differences between fixed, pre-emptive and tracking policies were significant but not substantial (typically <20%). Higher output was almost always associated with policies which maintained high average stocking rates, even though these also produced higher mortality.

There are two main reasons for the limited improvement in output of flexible stocking strategies over fixed stocking. First, major losses of stock are associated less with one-year than with two-year droughts, which are difficult to track. Second, de-stocking can be really effective only if the productive potential of the herd can be re-established more rapidly than is possible from depleted herd resources. In the absence of an ability to restock after droughts, the traditional policy of maintaining the maximum size of breeding herd is well founded, provided that the total weight of animal sales is not the highest priority.

Dissemination (see also *Follow-up action*, below)

A.W. Illius, J. Derry & I.J. Gordon (1995) *Components, processes and dynamics of semi-arid grazing systems. A review of current knowledge.* University of Edinburgh. pp 46. (This is an earlier version of the Appendix, which may be published by NRI as a Discussion Document.)

Lecture to the Faculty of Agriculture, University of Fort Hare, South Africa, by AW Illius: '*Modelling semi-arid grazing systems*'.

Contribution of Outputs

(1) Optimising the utilisation of semi-arid rangelands requires an understanding of the constraints on production. Land-use planning is impeded by lack of a framework for predicting how rangeland systems respond to livestock stocking policies, management practices and interactions with wildlife. Our assessment of the existing information on semi-arid rangeland dynamics showed that it is, generally, adequate for modelling such systems, and evaluating constraints on production.

(2) The model provides a scientific and objective basis for optimising the long-term utilisation of vegetation resources, and of matching the mix of animal species to vegetation structure. Analysis of the systems performance will help target future research. In particular, the production and utilisation of browse (including the highly nutritious pods and fruits of savanna trees) is highlighted as an area justifying further work.

(3) Annual and seasonal variability in rainfall is an important cause of instability in semi-arid environments, so flexible and opportunistic management practices are needed to increase the sustainable economic yield of rangeland. The model forms the basis for evaluating such strategies. We suggest that further analysis of the feasibility and effectiveness of adaptive management policies is required, in the light of our findings that their benefits may be modest.

Promotion pathways

The project was aimed at benefiting research planners, systems ecologists and extension agencies. Promotion pathways include: submission of the updated review of the dynamics of semi-arid grazing systems, together with the report of the modelling exercise (Appendix) to NRI, and presentation of a seminar there; publication of 3 scientific papers (see below); circulation of research and extension personnel in Zimbabwe and Botswana with the review and modelling results.

Follow-up action

A seminar will be held at NRI to present the results and debate their implications for targeting of future research.

A poster is to be presented to the Grassland Society of Southern Africa Congress 32 in January 1997 at Port Elizabeth: Derry, J., Illius, A.W. & Gordon, I.J., *Modelling semi-arid grazing systems*.

A paper (Illius & O'Connor), on the dynamics of semi-arid grazing systems, is nearly finished and will be submitted to *Journal of Range Management*.

Two papers (Derry, Illius & Gordon) are planned, and the first has been started, describing the model and its results and will be submitted to *Ecological Modelling*.