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More Sustainable Range Use in Semi-Arid Eco-Systems through Adapted Management: A Case Study on Namibian Farms based on Bio-Economic Models

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Abstract

This paper deals with bio-economic modelling of potentially degraded range land in Namibia. It outlines the methodological background, presents a modelling approach in GAMS and offers first results. We show how bush encroachment can be modelled and how various factors, like interest rates and costs of combating bushes, impact on farm behaviour and the environment. In particular the prevalence of bush and range quality decline are a focus of the paper .

1 Introduction

Due to overuse of natural resources, especially over-grazing and the application of non-suitable management practices, such as low recognition of prevalent natural vegetation cycles in grass and thorn bush savannahs, the range quality of many commercial farms has declined. A visually decreased appearance of natural composition of grass and bush cover, bush encroachment, and a decreased biodiversity indicate lower stocking potentials for domestic livestock on large tracks of farm lands. Range degradation has become a threat to the continuation of viable commercial farming strategies in many semi-arid grass lands of Southern Africa. Furthermore, reconsidering long-term degradation processes and seeking of cures for environmental degradation are requests and challenges to professions of range land economists, ecologists and farm extension service.
One the side farms seek to increase size and decrease intensity which leads to a declining number of farmers and labourers who can make a living from acquiring wealth through farming naturally exposed areas. On the other hand political pressure is increasing to encourage intensity of farming and to create job opportunities for a growing population.

2 Methodology

2.1 Background of bio-economic modelling

Bio-economic modelling represents a methodology to integrate ecological approaches into economic analyses and investigate the possible effects of (new) technology choices and policy incentives on farmer welfare as well as the quality natural resources. Mathematical models are designed to represent the main components of both systems, the ecological and the economic, and depict the relationships between them in quantitative terms. The idea behind bio-economic models is to combine the strengths of two approaches for a realistic picture of both, the vegetation dynamics of semi-arid rangelands and interacts of economic behaviour of profit seeking farmers.

2.2 Economic modelling

2.2.1 Objectives and constraints in economic approaches

An important advantage of an economic approach is the explicit formulation of an objective function which measures the system performance and achievements in terms of farmers' goals. In

the objective function preferences of the decision-making unit (e.g. farmer, conservancy, regional government) should find ranked representation. For certain quantitative aspects of the outcome or combination (e.g. cash, cattle numbers, range quality), which are the results from the interaction of farmers and the biotic environment, a qualified objective function can be specified. For instance, meat acquisition can serve as an objective and increased meat availability contributes to increased utility of communal farmers; though commercial farmers normally go for profits.
Also, in a natural environment like range land, sustainability is threatened because of the overuse of limited resources. Furthermore, in a dynamic consideration the time preference is a core element and an economic principle. It should be recognised and should come into the analysis. This means, future yields are less valued than today's yields. Bringing together objectives, discounting and ecological constraints, different strategies in range use over time or technology choices result in various outputs reflecting different degrees of economic viability and sustainability. In particular it is of interest to find out, how an economic unit (the farmer, the household or the village) decides on real life livestock management practices.

2.2.2 Agro-Ecological Representation of Farms

Furthermore, for agro-ecolgical representations we need production functions. Two main underlying processes are fundamental to the formulation of a production function: (i) the traditional relationship between inputs and outputs (for instance, a major consumable input is the fodder of the range), (ii) the relationship between agricultural management practices and environmental variables (range quality as state variable). Low range land quality can thus be viewed as both the cause of output decline and the result of management practices. An increase in production can be achieved either by proportionally increasing input or by changing the technology, i.e. modifying combinations of inputs or combination of accompanying measures like range quality investments.
Production functions are continuous functions, which make it possible to derive optimal points of input allocation where an efficient use of input like labour is indicated.
In economic modelling certain types of production functions are taken as a base model and related coefficients for appearing input variables (e.g. palatable biomass) are estimated. For estimating reliable production functions with different input variables like labour, land etc. an extensive data set is needed. Normally such a broad set of empirical data is hardly available and, in almost every agro-ecological systems, uncertainty remains to what extent (i.e. mathematical formulation) inputs factors like biomass or bush control, chemicals, etc. actually influence the product level. Especially, in those land use studies (Hengsdijk and van Ittersum 2001), which focus on alternative or new technologies, no such data is hardly available. This causes problems to estimate production functions. Therefore other approaches to determine input-output relations for using production relationships in computer models are necessary. For instance, a commonly applied method to deal with this problem is to define discrete input-output combinations.
However, since the fixed points of input-output ratios are introduced, directly, in a mathematical programming framework, there is no need to specify a production function (Kruseman 2000). According to (Kruseman 2000),(Hengsdijk and van Ittersum 2001) Leontief techniques (i.e. technology or activity choices) can be generated with Technical Coefficient Generator (TCG). Then activities are based on basic information on climate and livestock as results of documented models, and they are quantified expert knowledge. These knowledge ist brought into Linear Programming (LP). LP is a core element usually used by farm economist. Such mathematical modelling method is also recommendable for environmental economic studies, since many activities and restrictions can be considered simultaneously. An LP has a structure as in Figure 1.

		ACT2	ACT3	ACT4	
RES1					>=CON1
RES2					>=CON2
RES3					>=CON3
RES4					>=CON4
RES5					>=CON5

Figure 1: Simplified description of a LP- structure

2.2.3 Representing ecological concerns in inter-temporal optimisation

As sustainability is a dynamic concept and involves temporal tradeoffs, bio-economic modelling should become a programming tool for evaluating these temporal tradeoffs (Pandey and Hardaker 1995). Ecologists regard range land degradation as co-evolving by farming practices. For economists, range degradation can also be seen as an income degradation process. Hence, in an inter-temporal frame, range degradation is to be considered a transfer of future income to the present.

As a basis for our modelling, the analysis of the optimal use of renewable resources (Pearce and Turner 1993) serves assuming a temporally profit-maximising land users. Use intensity of natural resources is optimal in dynamic terms if a temporal equilibrium exists. In that equilibrium the own rate of return of the resource (e.g. productivity of a certain state of range land quality) is equal to the time preference (normally determined by the discount rate) of the decision-maker.

2.3 Ecological modelling

Ecological modelling is focused on processes to show differences in approaches on land use and to demonstrate possibilities for integration. Grid based modelling is an approach for a spatial-temporal modelling of vegetation dynamics. A plot of rangeland is divided into certain subplots represented as grid cells in the model. From ecological knowledge, collected through experimental research and expert knowledge, one can derive "rules" which are numerical formulated. According to exogenous variables like stochastically appearing rainfall and mathematical rules the vegetation state in each grid cell and in each time period is determined whereas states and transition between states of primary ecological interest. Furthermore, rainfall events and vegetation states from former time periods are considered as a starting point and work through consecutive periods. Normally these models work with fixed stocking rates or fixed strategies over time to model consequences of different management practices in scenarios which are not derived from explicit modelling of farm behaviour as derived from objectives.

This approach meets the requirements for quantitative applications of a state-and-transition-model like described by Westoby *et al.* (1989), Milton and Hoffman (1994) or Rothauge (2000). For instance, if a particular threshold is exceeded, the whole system would transform itself into another state or frame and then different rules and mathematical equations would apply. In economic terms it means costs of certain measures to sustain ecologically preferred states (for example investment in the habitat) can be measured and be simultaneous calculated as well as the total costs of a certain stage can be displayed. However no explicit objective function appears in ecological models or are formulated by ecologists. Therefore no "best strategy" to achieve certain environments can be derived, and no adoption or flexible reaction of a farmer to changing environmental factors can be considered, and thus no process can be really optimised over time.

2.4 Creating interfaces for ecological and economic information

As a crucial issue in bio-economic modelling, the creation of an interface between the social and biophysical sciences remains a task to be difficult; though to be conducted and not to be excludable. The excellence of a bio-economic model mainly depends on the co-operation of the socio-economic scientists and the biophysical or ecological scientists. Different approaches to incorporate biophysical information have been recently suggested in bio-economic modelling.

2.4.1 Integration of ecological complexity

One way to approach this task lies in the integration of ecological models or ecological modules in an economic model consisting of modules. Conducting this task, several theoretical and technical (like mathematical formulation) requirements have to be met within a logical framework given by computer languages. That causes several problems. So to say, there is no strategy as "copy and paste". A reasonable reduction in complexity has to take place, with a strong focus on the driving forces of the system. It has to be identified by ecological and economic modelling.
The strength of such an approach, once as interlinked model works, is that one can work with continuous functions which provides the possibility to derive exact thresholds of transition states and efficient distributions of habitats. Then the ecological system is described by compiled mathematical functions. Mathematical functions may describe the ecological system sufficiently. But actual interaction of ecological and economic modules must be made explicit, preferably simultaneous, which then determine, for example, transition coefficients in state-and transition models. Dynamics of ecological and economic systems can be considered simultaneously, but how?
Even a reduced representation of the apparent ecological systems remains difficult. Especially, if an optimisation for achieving highest values for an objective function occurs, which identifies "best strategies", is it also ecological correct? For example a GAMS modeller is restricted to limitations in data manipulation imposed by the ability of the software to run dynamic optimisations using a special algorithms. Normally, highly non-linear aspects of ecological dynamics forces modellers to work with c approximations losing important details in parts of the analysis.

2.4.2 Linking models by transition matrices creating transfer vectors

In that context our concept works in such way that, similar to the idea of replacing n-dimensional production functions by input-output relations of separate technology choices, as indicated above, unknown complex ecological functions are replaced by point data as temporal input-output relations. Especially, one approach to deal with complex ecological dynamics is to work with different range land quality states or frames. In that approach ecological thresholds are applied as in ecological state-and transition model for range lands. Activities, which have an ecological impact on the range quality, determine to what extent a plot of land remains in the previous state. Thus one can define different states of range quality. Note, it is a typical Leontief approach. Each Leontief-type of production activity or techniques, which is bounded to a specific state of range quality, has a transfer vector, which determines to what extent land shifts from an initial state to a different quality state. In this regard, complex ecological systems with respect to their corresponding bundles or functions are represented as point data. As a result ecological dynamics can be treated easily within an economic modelling approach using simply coefficients. Each coefficient of a transfer matrix is generated by the corresponding dynamic component in an ecological model. Transfer coefficients act as interface and are complementary to the economic views.
Nevertheless, a close co-operation is needed, for instance, to define stocking rates and it - if necessary- are aligned to system assumptions. Both models remain independent. Especially, it is important to notify that ecological and economic models work with the same time scale. In an example as indicated in figure 3 the assumed activities ACT_state2 (e.g. cattle) and ACT_state4 (e.g. bush control) demand for 25 hectares of land of state 2 or 300 hectares of state

4 respectively. In next period 18 hectares will remain in range quality state 2, meanwhile 5 hectares will appear in state 3 and 2 in state 4 (200 will be in state 2, 80 in state 3 and 20 remain).

	ACT_state1	ACT_state2	ACT_state3	ACT_state4	ACT_state5
RES_state1					
RES_state2		25			
RES_state3					
RES_state4				300	
RES_state5					
TRAN_state1					
TRAN_state2		18		200	
TRAN_state3		5		80	
TRAN_state4		2		20	
TRAN_state5					

Figure 2: Simplified description of a transfer-matrix

3 Actual model structure

3.1 Data base

Our data is obtained from a farm survey which was carried out in the Okahandja district in 2001. It was analysed for information on the economic coefficients for average input-output relationships within a selected farming area. Most parameters such as farm sizes or calving rates are representative for that area. Basic numbers for the sample farm in the Okahandja district, which are mainly derived from the data and act as basis for the modelling of a representative farm, are:

- size: 10.000 hectares, of which are 50 % subject to bush encroachment in different stages
- 600 cattle
- 3 labourer
- vegetation maximum stock densities of natural game animals appear (i.e. 600 oryx)
- 4 camps are each 1200-2800 hectares large

The model structure is extremely simplified and based on further assumptions (e.g. there are only 4 big camps and transfer coefficients are based on estimates done by the author). To implement dynamics a step by step approach is taken. As the model shall be able to describe the dynamics by direction correctly, one can start to replace assumptions by correct coefficients and to extend the model to a more detailed (and realistic) version. Core element is a LP (linear programming) structure with defined activities (e.g. cattle) which assign specific requirements at scarce resource levels (e.g. biomass). Thus new technologies (e.g. natural bush control by hot fires) can be easily considered with the inclusion of additional activities. With the help of mathematical algorithms, optimal solutions are found achieving highest values for the objective function (see above.)

3.2 Programming and results

Simple LP solutions are dominated strongly by limitations in technology and resources as available on farms. Note, the more limiting secondary conditions are, the more the solution of the linear optimisations resembles limitations brought in a priori. This has to be reconsidered. An important issue in this context is the use of internal and temporal delivery functions. Management options are defined partly apart from resource-consuming activities. As scarce resources positively affect activities additional ecological options appear. For instance more labour provides the possibility to expand towards more labour intensive or ecological land use and, assumed more sustainable farm practice should appear, tourism activities like game farming enter the solution.

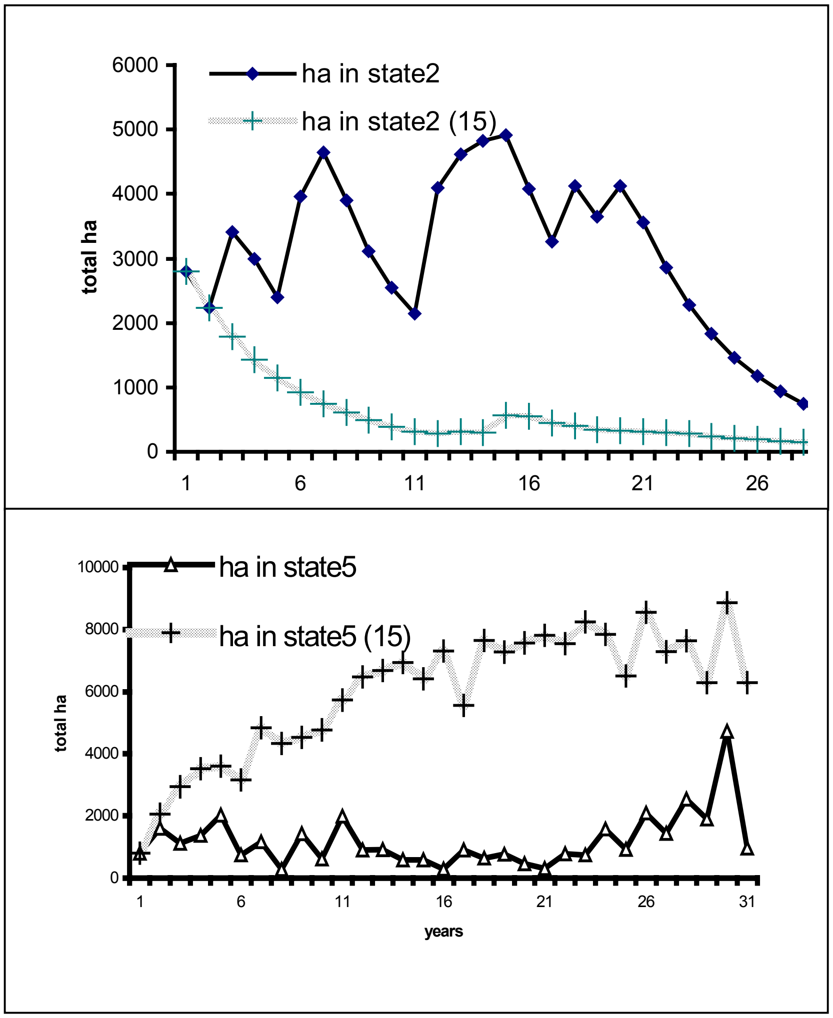

Figure 3: Results from Farm Model: Above land occupation and below states as dependent on interest

Via temporal delivery functions, dynamic linkages are implemented. Whereby, investments in the range quality state like bush control positively affect the biomass availability in the following periods. This is put into operation by a higher herbaceous biomass productivity as associated with a better veld condition. Given the above state-and transition sub-model a results is shown in Figure 3. Note, our state-and-transition sub model is determined by a transfer matrix, in which states are addressed by hectares of land and in which states are subject to land use activities. Note further state 2 is a good state, right after virgin land (state 1). The actual state of the range land is calculated simultaneously, using all 10000 individually addressable hectares in a certain time period. Moreover, to represent the rainfall as one of the most important driving forces of the natural system, several activities are bound to specific rainfall patterns which appear stochastically. Hence, biomass production is a function of both, the actual rainfall and the coefficient for the biomass productivity, again assuming a specified range quality state. For further interpretation note: Next to the stochastically appearing rainfall, the model contains the possibility to transfer biomass surplus from one period to the next period. Initial model runs (as in Figure 3) are set off to show how the economic environment, i.e. time preference implemented by different interest rates, influence the decision-making of the farmer. Thus the impact of different interest rates on land use intensity (Figure 3, below, i.e. exploitation of the natural, slowly renewable, resource) can be examined, whereas state 5 is the worst state. Although the model does not yet illustrate the vegetation dynamics completely, results from various runs indicate already the importance of the time preference. As shown in figure 3 for both interest rates, 5 and 15%, the biomass production tends to decrease over time. However, with an assumed interest rate of 15% the production basis is decimated quickly. The decline in biomass production is caused by a range land degradation process which takes place if no investment in the environment (i.e. veld quality) would be undertaken. Respectively stocking rates remain high.

3.3 Further results and discussion

The development and dependency of range quality is further illustrated in figure 4. As vegetation dynamics are represented by a state-and-transition model, one can follow the total amount of hectares over all simulated camps. Being in sequential quality states in time, land degrades. For instance the amount of hectares in state 2 (i.e. an average good veld condition) decreases with an assumed interest rate of 15% within 11 years from 2800 to less than 300 in 15 years. Correspondingly the number of hectares in state 5 (i.e. a total bush thickened veld condition) increases by 5600. With a theoretical interest rate of 5% the development is marked by a higher fluctuation. Selective measures to keep a specific state of vegetation or to bring it back to a more favourable state are conducted, i.e. bush control. Hereby, some more natural bush control measures like artificial hot bush fires can only take place in exceptional good rainfall years (e.g. year 12), what

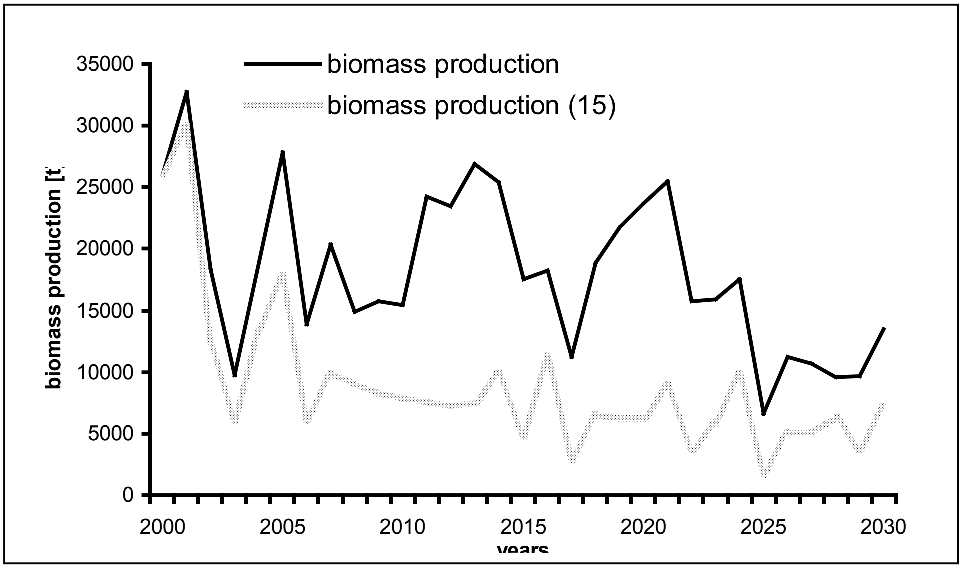

Figure 4: Impact of the interest rate (5 and 15 %) on the total herbaceous biomass production on a sample farm

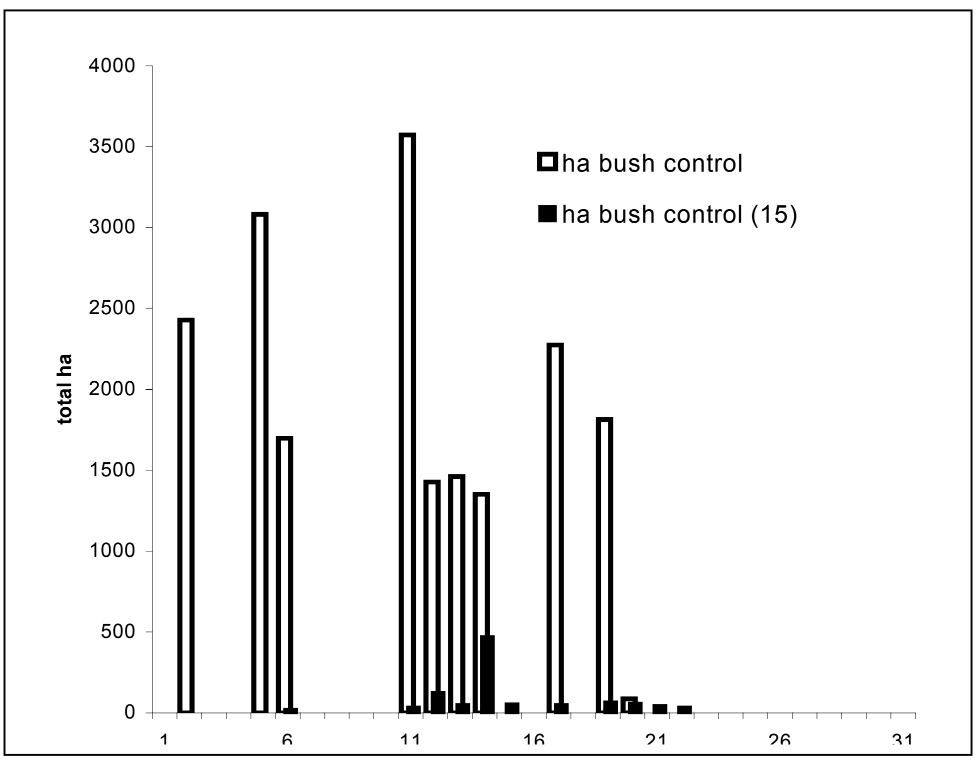

Figure 5: Impact of the interest rate (5 and 15 %) on the total ha subject to bush control measures on a sample farm

explains the event-driven character of the vegetation dynamics for land being in veld class state 2. Note further, discounted value added of different technology choices over time lead to optimal strategies; high time preference becomes a crucial issue for the incentive for a long-term investment in the environment. There is little chance to pay off invested money from a lower stocking rate (an income renunciation this year by an increased biomass in future). As shown in figure 5, little efforts should be made to control bush. For solving the problem, a cure may be low interest. These findings are in line with considerations within the Namibian government to provide cheap loans to farmers (the actual interest rate ranges between 14 and 20% for loans from the agricultural bank), particularly for bush control. Other possibilities with similar effects, which are so far not explicit considered in the model, would be to subsidise labour to stimulate labour intensive bush control measures (e.g. manual bush cutting). As in the actual model small interest rates lead to more capital intensive bush control measure like chemical application, perhaps, a better option; notifying that Namibia faces a serious unemployment problem simultaneously.

4 Qualifications

Several model improvements are still to done. First of all coefficients for the transfer matrix need to be specified, more consistently, for the particularly chosen ecological system. This can be done by the help of local expert, their knowledge and information from ecological models. Such approach should go in a line with a more appropriate representation of the camp system, chosen for management of grazing practices; for instance, as indicated a system of about 35 camps with different soil properties would be good. Furthermore less simplified herd dynamics (i.e. animal related activities) of both, a cattle herd and a game population, has to be develop towards a more comprehensive representation. This will open up discussions for an adoption of more flexible land use strategies, i.e. "speculation farming". Speculation farming particularly implicates that farmers adopt a production system which focuses on fattening of brought-in cattle, noticeable in years of sufficient rainfall. Taking into account that even low stocking rates in dry years are assumed to cause range land degradation and high stocking rates in good rainfall years have nearly no impact on the veld condition, this would facilitate further options for sustainable land use.
Another important improvement of the approach could be seen in the implementation of "transferability conditions" in the final period. In a dynamic optimisation it is necessary to put a value on all assets which remain at the end of the simulated time horizon. This includes, to put (monetary) values on land in future periods. Thereby it can be avoided that the results show a tendency to exploit resources until the last years of the simulated (i.e. finite) time horizon.

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