On Management of Natural Rangelands :
A case study of commercial farms in Southern Namibia

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Abstract

In Namibia range degradation is a permanent concern among scientists, national land planers and local land users. Information identifying elements of sustainable land use or influencing sustainable management of natural rangelands is sought, especially in the actual context of land redistribution. This paper makes a first contribution to this issue in which it seeks to investigate land users' strategies and practices in their ecological context. At first a qualitative analysis was carried on to deliver information on the variety of management practices existing. Second we use the paradigm of high-reliability as a rational underlying farmers' strategies. Accordingly we develop an optimization model with two objectives: income maximization and range condition optimization. It enables us to make a link between various practices and range degradation and value the trade-offs occurring between both objectives. The method is used for a case study analysis in southern Namibia where farmers ranch on entirely natural rangeland under conditions of erratic rainfall and thus extremely variable biomass resource availability. In the small area, farmers strategies vary greatly in the nature of farmers reactions to opportunities such as high rainfall events and threats such as droughts. The modelling exercise reveals that strategies change as the nature of trade-offs between income and range condition decreases. In addition the value of the trade-off delivers information on the value the farmer is ready to 'invest' in order to maintain his range in good condition. This is the result of an economic strategy and might also be influenced by a series of additional social factors which we discuss briefly.

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1. Introduction

Namibia's economy relies totally on natural resources: mining and fish industry, green tourism and agriculture are a source of occupation for an important part of its small population. Namibia is a mercantile economy and depends heavily on exports: two thirds concern mineral and the reminder is livestock and fish related products. Although the livestock sector contributes only 8% GDP and 8% of total working population, 68 % of the population derives their livelihood directly or indirectly from agriculture (Wardell-Johnson G., 2006). Two thirds of the country is covered with natural rangelands where cattle and small stock are being kept in large ranches. In 1990 about 4200 commercial farmers owned more than half of the agricultural land in the country. The situation has not changed drastically today so that a large part of the country's natural resources belong to and are managed by a little part of the population.

Parallel to this situation authorities and the scientific community are concerned with the loss of biodiversity and of productivity of rangeland due to desertification/degradation (Strohbach B.J., 2000). Desertification designs the process of degradation of semi-arid and arid ecosystems that leads to desert formation (Natural Resource Conservation Service, Ministry of agriculture, USA, 1999). Despite new theories of rangeland ecology and the importance that abiotic factors play in range degradation it has been demonstrated that stocking rate has a great impact on rangeland condition (Batabyal A.A., 2004). Correspondingly Stephan & al. (1996) find that the level of biomass yearly left in situ after grazing influence range condition in the long term. Thus the management of natural rangelands is a big issue for farmers as well

as for research: an example is the development of a guide for management of arid rangeland of The Karoo in South Africa (Milton S.J. et al., 1998). However rangelands of southern Namibia are very diverse, knowledge about their ecological dynamic is incomplete and above all, farmer practices are not only the result of their ecological knowledge but rather form under the influence of several other factors: social, historical, ecological and also economic (Leeuwis 2004). Finally pastoralists' strategies have been the object of an important discussion and are usually described as risk-aversive. However Roe & al. (1997) suggests that in such labile environment farmers may behave under another paradigm that is high-reliability.
In order to increase our understanding about farmers practices and strategies it is worthwhile to first assess existing strategies, evaluate their impact on range condition and develop theories on what influences such strategies. In the present paper we chose to describe the ecological-economic system of the farm viewing farmers as high-reliability seekers. Our objective is to explore the possibility for farmers of optimizing both their income and the condition of rangeland at the level of the farm. By using a multi-objective approach (MOP), trade-offs between maintaining rangeland in a "good" condition and income generation are investigated and conditions necessary to achieve high maintenance of healthy rangeland are explored. Results are compared to management options available to farmers in a small region of south Namibia thanks to a case study analysis. Our conceptual framework is explained in the next chapter. Following are results of an empirical research concerning management practices in the area of Keetmanshoop. Then we describe our bio-economic model which is our tool to depict and understand the dynamic of a farm viewed as an ecological-economic system. Finally results from the model are presented, discussed and related to results of the empirical research.

2. Challenges in the management of natural rangeland and following conceptual framework

The conceptual framework adopted in this paper is the result of a selection of existing theories guided by the results of an explorative research phase among Namibian farmers. With this hermeneutic approach (Flick U., 1991), the first field work was done very early in the research process. As our primary goal was to gather elements allowing the modeling of pastoralists decisions, we used the explorative research to guide the development of our conceptual framework and thus of our mode. This is particularly important when the researcher has had no previous contact (little knowledge) with the object of the study. Two results of the explorative process in particular guided the development of the conceptual framework. First farmers of the considered area perceive rangeland degradation to be caused by rainfall patterns primarily, whereas they consider that management is rendered difficult by insufficient knowledge and financial pressures (Table 2.1). This suggests that most farmers perceive rainfall as a major driver of the ecology and therefore as a major potential threat; still they do not consider it the reason of the failure of their own management. Rather they accept the risks and adapt. Second a farmer explicitly indicated a key-stone of his management, showing that the emphasis lied on the management of the natural range in priority.

> "*I am not farming with animals, I am farming with* veld *[range]. With my new system it is a pleasure to see the veld improve year after year[…]*."

Table 2.1 Motors of rangeland degradation and factors affecting good rangeland management as perceived by farmers (Interviews 2005). Frequency of citations.

Issues raised by farmers in response to open formulated questions	Motor of rangeland degradation (N=15)	Factor affecting good range-land management (N=13)
Relationship farmer-environment	2	4
Relationship animal – environment	2	2
Investments, finances	3	5
Rainfall or climate change	7	3
Farm size and natural resource characteristics	1	0
Speculation activities	0	1

2.1. Rangeland ecological dynamics

Until the 1990's the so-called succession model was used to depict the ecological behavior of rangeland in arid and semi-arid climates. The succession model is based on the idea that changes in the state of the system are reversible and linear. In particular in the case of grassland, the domination of the herbaceous layer is the result of an interaction between grazers and the vegetation and constitutes a climax. However, rangeland scientists consider now the non-equilibrium theory more adequate to explain phenomena observed in the field. The non-equilibrium theory relies on evidences that grassland ecology and productivity are more correlated with external abiotic factors -interaction between soil, vegetation, rainfall, temperature, and other abiotic factors- than with biotic factors -grazing pressure (Ellis & Swift 1988, Illius & O'Connor 1999, Sullivan & Rhode 2002, Vetter 2004). An application of this theory is the State-and-Transition model, in which ecosystems tend to behave towards stables attractors, but flips can occur, making the ecosystem switch from one stable state to the other. Reversibility of such shifts in ecological state is not self-evident (Westoby & al. 1989, Bestelmeyer & al. 2003, Stringham & al. 2003, Janssen 2004). Implications for the management of rangeland are considerable and were explicated by Westoby & al (1989): in order to avoid undesired flips of the system from one desirable state to another less desirable, pastoralists must consider both abiotic and biotic interactions. This means that management of the controlled biotic interactions (domestic grazing) must take into account both threats (e.g. droughts) or opportunities (e.g. high rainfall events) created by the interaction of abiotic system factors. Successful management is a challenge since mistakes would have dramatic consequences and requires very good knowledge over the interaction of both interaction types.

2.2. High-reliability pastoralism

Roe (1997) links the non-equilibrium theory of rangeland ecology to the concept of high-reliability strategy and its application to pastoralists. According to him, pastoralists express the characteristics of high-reliability institutions[1] and have the goal of maintaining a reliable production in a context of highly varying rainfall. Further he states that high reliability is achieved through the good management of performance fluctuations rather than when trying to achieve constant production. This implies the management of the bandwidth fluctuation is

[1] The nine features of high reliability institutions are (Roe & al. 1997)

1. high technical competences
2. High performance and oversight (knowledge exchange with high reliable informants is part of it)
3. constant search for improvement (thanks to feed back with natural resources)
4. highly complex activities (it is)
5. High pressures, incentives, and shared expectations for reliability
6. Hazard-driven flexibility to ensure safety (with redundancy in the system as a key to success, that is redundancy in livestock in our case)
7. Culture of reliability
8. Reliability is not fungible (not replaceable by other capital or traits)
9. limitations on trial and error learning (although there is little space for experiment, no replications and mistakes have tremendous implications)

important and not the management of the output itself. In the present case bandwidth management requires creative reactive capacities (Roe & al. 2005). Farmers are well-aware of this fact and it is actually the reason why small stock (versus cattle) is predominant in the area: sheep and goats can be marketed easily and they are prolific: ewes get their first lamb short after one year. Their second asset is the rangeland itself and how it reacts to the highly variable rainfall. Perennial grasses and shrubs are able to buffer for variability of rainfall in which it produces fodder even in case of (small) droughts. Annual species produce much biomass in cases of rainfall but none in case of drought. Therefore rangeland is of the best quality when both seed types are present in the soil and develop according to the conditions in a vegetation cover. If annual species disappear the system becomes more vulnerable and thus less reliable. Then the less the vegetation cover, the less reliable the grazing system becomes. Batabyal (2004) also suggests that farmers will tend to minimize the time that their rangeland veld is in a middle condition with the risk of shifting to a worse one.
Finally, guided by the concept of "veld farmer" versus "animal farmer" explained above, we propose that maintaining specific rangeland condition can become a goal as such for the farmer, parallel to the commonly accepted one of utility, approximated by income maximization[2]. These two objective functions will be used in a Multi-Objective Programming approach.
Responses and reactions of farmers to variations in input are varied as we will see in the following chapter.

3. Farmers and farming practices of the case study area

3.1. Case study

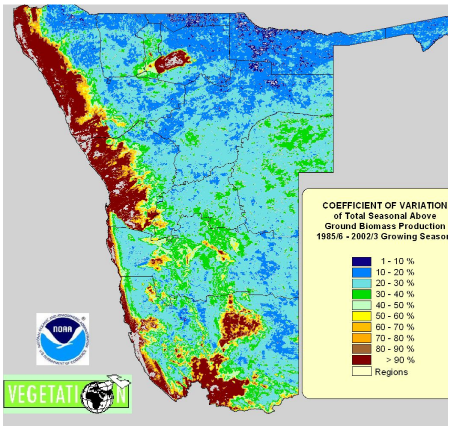
An essential prerequisite for modeling farmer reactions to variations in resource availability is the identification of management dimensions and management options as well as their impact on arid rangelands of southern Namibia (average rainfall in the area from 120 to 140 mm per annum). The analysis was performed for a small particular region of the Karas region around of the town of Keetmanshoop, where farmers face particularly important variations in rainfall causing variations in biomass production reaching 95% (map 1). Most other areas of Namibia confronted with such variations are used as natural parks. There is a small park in the study area as well although most of the area is farmed commercially. The risks for farming are thus particularly high (map 2).
In the 6 districts of southern Namibia one counts 1703 properties predominantly farming with sheep on 164 650 ha (Barnes J.I. and de Jager J.L.V., 1995)

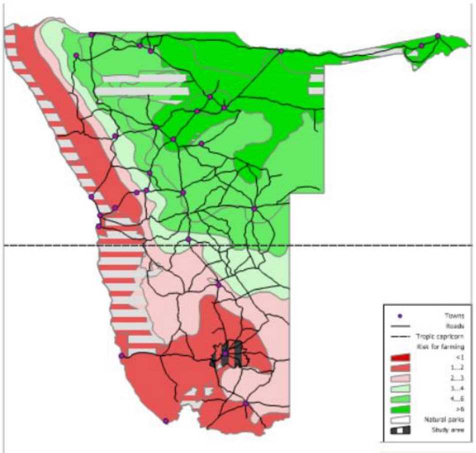
The area is located in the dwarf-shrub savanna biome where grasses, dwarf bushes and high bushes constitute most of the vegetation. Perennial grasses are mostly *Stipagrostis* species, and are typical of rangelands perceived as being in "good" condition. Characteristic shrubs are Driedorn (*Rhigozum trichotomum),* Gabbabos *(Catophractes alexandri),* Soetdorring *(Accacia Nebrownii),* Khoibos *(Tetragonia shenkii),* Perdebos (*Monechma genistisifolium*), Luzernebos (*Petalidium linifolium*) and Skilpadbos (spp. *Zygophyllum*). All shrubs are of value as fodder, some being more palatable than others. Important for most farmer is to have a variety of shrubs and grasses to ensure the fulfillment of nutrient requirements and the availability of fodder in the winter time (dry season) thanks to the presence of shrubs. Veld degradation implies a change in the vegetation composition of the veld, eventually a change in the soil properties as well. Vegetation changes are the replacement of perennial grasses by annual ones, eventually on some soils, simply disappearance of perennial grasses leading to

[2] Studies using income as a proxy for utility in the modeling of farm systems are numerous. Examples are Buss, 2006, Unterschultz, 2003, Farm resource allocation model, anonymous.

increase of the bare area. Degraded areas can be subject to bush encroachment by less desirable shrubs such as Skilpadbos (Spp. *Zygophyllum*) on calc soils or by Driedorn *Rhigozum trichotomum* (own observations and reported farmer observations). Degradation reduces in the short and middle term the productivity of the farm and increases it vulnerability to rainfall variations.

Map 1. Variability in biomass production in Namibia – Source:(MAWF Namibia, 2004).
Map2: Gradient of risk for farming activities and location of natural parks and study area – adapted from MAWF.





The study area is relatively small counting 700 000 ha around the town of Keetmanshoop, of which 535 000 ha are privately owned and farmed. About 50% of that area was covered thanks to interviews done with 20 farmers between March and June 2005. Pretests were done on 4 farms with highly differing activities (goat, sheep and game) to cover all agricultural domains.

Inspired by ranch model of Buss (2006) we proceeded with structured interviews with mostly open-ended questions, with the following goals: the explorative description of the farming system, the identification of farmers' management options and stocking behaviors, the identification of productivity parameters. Biomass production and impact of grazing on rangeland quality was investigated by Popp (being drafted). In this paper we want to present only results concerning management.

Due to the suburban location of the study area only 10 farms out of 20 relied solely on farming to match their household needs. Farmers farm with Dorper sheep for the production of mutton which has often replaced the Karakul sheep and the production of skins due to a drop in karakul skin prices. Goats are kept on all farms as well. Most important costs are infrastructures: fences and water provision, the latter being perceived as an important limiting factor to production (N=8).

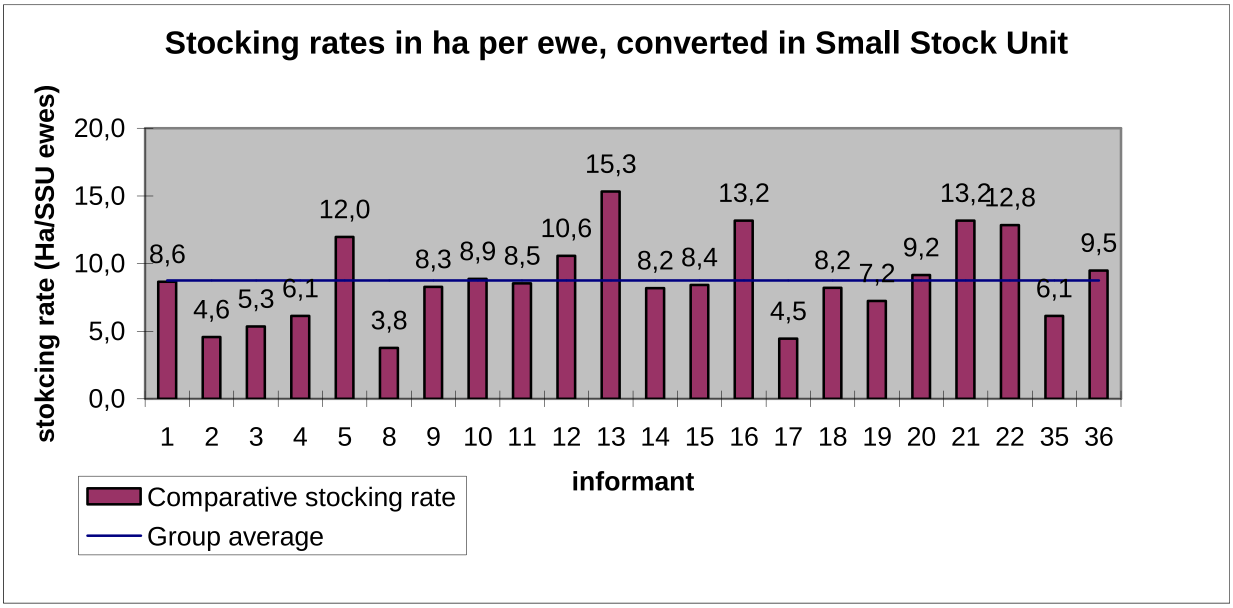


Fig 3.1. Number of ewes kept per ha on 20 commercial farms of the area as well as 2 commercial farms in the Karas mountains. Data of 2004

The area is considered to have a Carrying Capacity of 1/5, that is 1 Small Stock Unit (SSU) for 5 ha. Farms are 10 000 ha big on average (Carrying Capacity proposed map of October 2000, MAWF). Transformed in terms of the number of ewes, a herd of about 1200 Dorper ewes should be sustainable on a 10 000 ha farm, which corresponds to a stocking rate of 1 ewe / 8ha. On average farmers of the area keep to this rule (fig 3.1). In the detail however there is a huge variation in the stocking rates practiced which is not to be related to reliance on income: the average stocking rates for both full time farmers and farmer with external income sources are very comparable (8,1 N=9 - 8,3 N=11). Note that not only Dorper are being kept but also smaller sheep breeds such as karakul or Damaras[3].

Data was gathered for one year only, 2004, time at which herds were recovering from the drought of 2002-2003. Due the constant variability of herd sizes in time, these results are only descriptive and cannot be used for the analysis of strategy.

3.2. Management issues and options for farmers

There are 3 dimensions of the grazing management.

Spatial elements of herd-veld management. Due to particular heterogeneity in plant diversity and habitat at such a small scale as the farm, farmers tend to allocate parts of the farm to the one or the other production type. There might also be a pattern of use in time, some areas being more productive relatively speaking than other in the rainy / dry season.

Temporal elements of herd-veld management. Farms are divided in camps and farmers rotate the animals around the farm to manage both the herd and the range. Rotation timing is important to avoid overgrazing a camp: The challenge for farmers is to be able to move their animals out of a camp before overgrazing occurs.

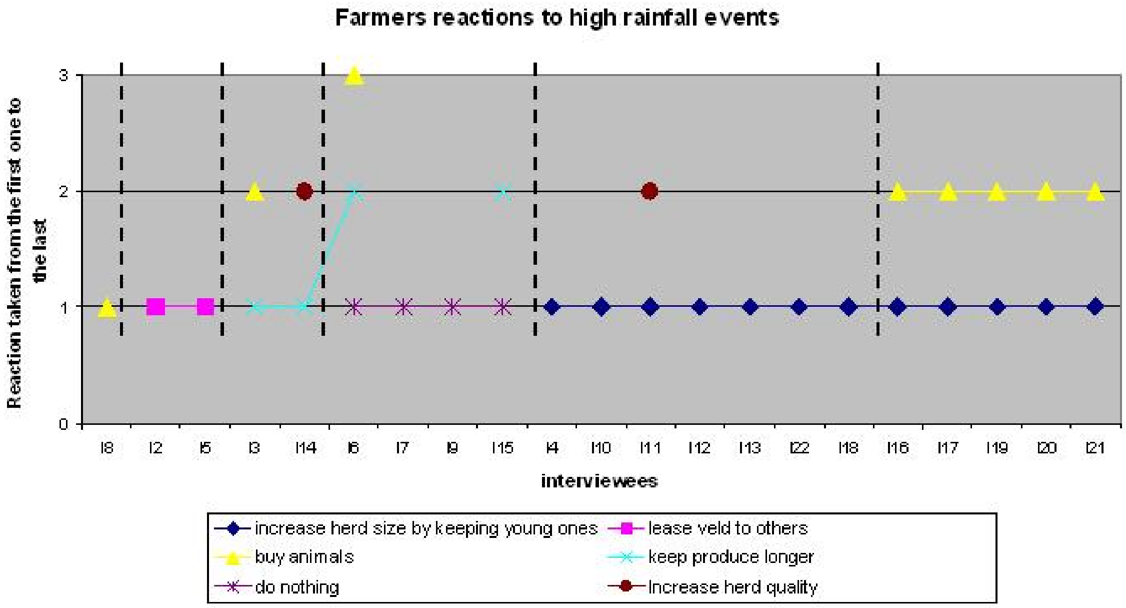
Yearly dynamic of herd-veld management. This is the dimension we focus on in this paper**.** Herd size must be decided upon and has a major consequence on range condition (Unterschultz J.R. et al., 2003;Batabyal A.A., 2004). The decision making occurs at two levels: in the one year the farmer decides on the number of ewe lambs to be kept for replacement or increase of the herd. In next year the farmer has to adjust his herd size to the

[3] Karakul are sheep kept for skin production: the lamb is slaughtered at 1 day and the skins are exported to Copenhagen. Damaras are indigenous meat sheep which develop slower than dorper. Dorper is a type of improved meat sheep, as dwarf stem wheat during the green revolution and has higher needs in fodder.

actual availability of resources of that year. Adjustment costs may occur. Depending on the farmer's objectives these might be justified or not. Costs of having too many ewes are their impact of the range -that is overgrazing and possible degradation- and costs of having too few animals if the rains are favorable are the income foregone of production.

We asked farmers how the react to the threats and opportunities that droughts and high rainfall events represent. Farmers choices concerning the sequence of actions to be taken in both situations were coded and allowed the definition of behavioral patterns or groups.

High rainfall years. Basing the classification on 1st reactions three important groups appear. In the first less reactive group farmers chose not to take special action or are content with keeping lambs longer on the farm to increase the value-added. The second group is more reactive and will increase the amount of ewe lambs kept for the productive herd, which we name 'replacement lambs'. The 3rd group involves in purchasing extra stock in addition, willing to profit from a maximum from the available resources (fig. 3.2). Replacement and purchase are key regulatory variables that are available to the model farmer to react to changes in the natural resources environment.



<u>Fig 3.2. Actions undertaken by farmers as a reaction to abnormally high rainfall after years of "normal", average rainfalls.</u>

Drought years. Options are de-stocking (selling the whole herd), rent your herd to a farmer outside the area, reduce herd size, buy extra fodder, reduce costs, no reaction (Fig. 3.3).

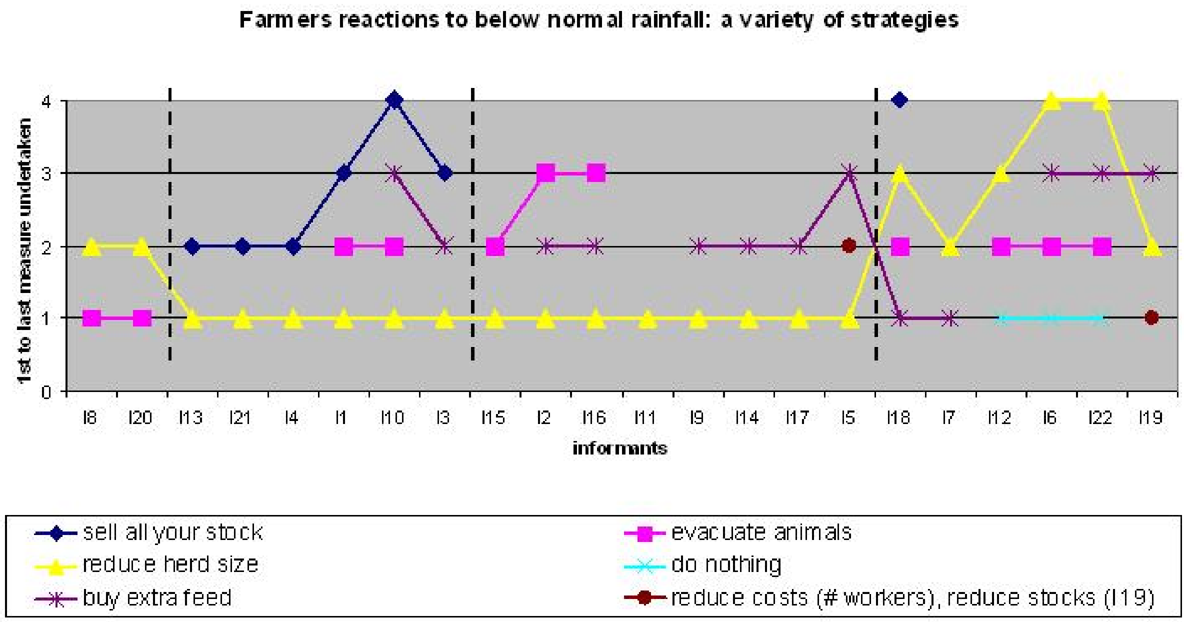


Fig.3.3: Actions undertaken by farmers as a reaction to drought years following "normal rainfall years".

In drought years as well three main behavioral patterns appear. The first group is highly reactive and reduces its herd immediately, eventually fully de-stocks the farm in extreme cases. The second group reacts also quickly by reducing the herd but in persistent unfavorable conditions will then revert to feed purchase to sustain the heart of the productive herd. Finally the third group is less reactive and will first purchase fodder or has the means to sustain the herd and undertakes no adjustments at first; only in persistent unfavorable conditions will it seek to dispose of the herd or reduce herd size.

Tables of correspondence suggest that the relationship between the behavior towards the recommended carrying capacity and reactions to above rainfall years is strong: farmers farming today below the recommended carrying capacity tend to adopt the rather static or responsive but constrained strategy, showing a conservationist behavior towards the rangeland. On the other side, farmers farming at recommended carrying capacity tend to be more responsive at higher rainfalls, allowing on the long run more frequently a high number of animals on their farm than the previous group. Behavior in drought situations seems to be more related to the dependency of farmers' households on farm income: when the dependence is full, farmers will tend to be less reactive to drought than farmers that don't depend only on farm income for their livelihood. A more detailed analysis of possible causes in differences is not attempted in this paper.

The combination of choices in both types of events leads to 10 different behavioral patterns observed but the most important (in frequency of observation) for the area of Keetmanshoop are the 5 described in table 3.1.

Table 3.1: Classification of behaviors according to farmers choices of actions in case of drought and above rainfall event (own data)

Behavioral category	Behavior description	Key word	Informants	Total
Category 1	Very reactive to drought, measured reaction to high rainfall events.	Threat avoider	I1, I10; I13, I4	4
Category 2	Middle reactive to drought and highly reactive to high rainfall events	Opportunity seizer	I16, I17, I2, I5	4
Category 3	Static response to drought and measured reaction to high rainfall events	Less flexible strategy	I18, I12, I22	
Category 4	Middle reactive to drought and un-reactive to high rainfall events.	Less flexible strategy with emphasis on drought reaction	I15, I9, I14	3
Category 5	Very reactive to both high and low rainfall. Respondants don't rely on farm income or speculate.	Highly reactive farmer	I21, I20, I8	3
Extra Category	Static response. Full time farmers farming at low stocking rates outside research area, where rainfall are less variable and slightly higher.	Conservative stocking farmer	I6, I7	

The extra category is constituted of the 2 farmers that do not belong to the small study area but to the closely situated Small Karas Mountains, which is not situated in a "high risk" area in map 2. Both show a behavior that is not found among the sample farmers of the study area. The dimension of reactivity to indicators in farmers strategies was addressed by Janssen & al. (2004).

4. Bio-economic modeling exercise

4.1. Model framework

We used the GAMS mathematical programming software to program a dynamic linear optimization model of a typical farm for the study area. Many studies using bio-economic approaches use mathematical programming in an optimal control approach (Costanza and Neumann 1997, Batabyal 1999, Bach 1999, Duraippah and Perkins 1999, Wossink & al 2001, van Wenum et al 2004, Okumu & al 2004, Börner 2005). Optimization programs describe the evolution of a system over a time horizon and determine optimal levels of decision variables over time and under constraints. Decisions concern the amount of inputs in a system in order to invest in future gains versus the withdrawing from the resource system exchanged for future gains. The optimal solution defines the sequence of inputs and outputs in time, taking into account short and long term gains.

Our multi-objective model's general purpose is to depict strategies of managers in time and to evaluate trade-offs occurring between the two objectives of the farmer: utility and range condition. MOP models have been used lately to include both social goals such as resource conservation or damage reduction and private goals, usually income or utility in the search of an optimal land use practice (Giasson E. et al., 2002;Thankappan S. et al., 2006). Traditionally, they serve to find a solution when the decision makers pursue two conflicting goals (Romero C. and Rehman T., 1989) One challenge of the management of non-equilibrium systems is the manager's knowledge on the interactions between both economic and ecological systems. As theoretically demonstrated by Finnoff & al. (2005), feedback from the ecological system to the economic system is crucial in case of imperfect knowledge of the decision maker. In the case of complex and ever changing systems such as arid rangelands it is recommended to invest in the explicit modeling of this feedback. Therefore we included the impact of grazing on range condition in the model which allows a dynamic feedback to the farmer on the changing state of the resource. Our approach uses a constant damage function as done in most bio-economic models encountered in the literature (Abel N., 1997;Bach C.F., 1999),(Kreuter U.P. and Workman J.P., 1994;Costanza V. and Neuman C.E., 1997;Wossink G.A.A. et al., 2001;Bulte E.H. et al., 2003;Boerner J., 2004;van Wenum J.H. et al., 2004) and is not influenced internally by the system, contrary to recent work done by Finnoff and Tschirhart (2003). However, because the model is dynamic changes in the resource affect farmer practices which in turn affect the system. We model a complete interaction of the two systems. This coupling inspired by the work of Buss (2006) is described in detail in Popp (being drafted).

The model has first been parameterized to allow simulation of farmer practices under actual knowledge and conditions. All parameters describing input-output relationships are the mean for the farmers of the study area. These include parameters determining herd dynamic, variable and fixed costs and product prices. All data gathered was used in the descriptive statistics (Available Case Analysis) and for income and costs calculations missing information on prices was approximated using the average of the group (Toutenburg & al. 2004). Parameters have been confronted to the opinion of at least one local expert in a cross-checking process. Triangulation thanks to literature (Barnes J.I. and de Jager J.L.V., 1995), group and individual interviews with farmers of the study area was done to evaluate the adequacy of the most important production-related parameters – yearly fixed costs and numbers of marketable lambs produced per ewe per year. Calibration of the model was done with the help of expert interviews: 2 individual and 2 group interviews with local experts have guided the elaboration of the model by evaluating the plausibility of the outcome[4]. These discussions guided the definition of levels for unknown parameters, such as the economic value of self consumed lambs or the economic cost of buying stock in from outside the farming system [1][5]. This is conforme to parameterizing and calibrating practices seen elsewhere for farm modeling (Buss 2006, Unterschultz, pers. communication 2006).

We have chosen to model activities at the level of the farm for a time period of 30 years because farmers most often plan to give the farm over to their children (Buss 2006). Pastoral activities include goats and meat sheep (Dorper) breeding, the two most popular productions.
The optimization problem involves finding a suitable way of using stocking rates *st* and animal types *P* by using the land and labor available, under varying rainfall conditions while meeting requirements in terms of overhead costs (*FIXCOSTS* and *NEEDS*) and at the same time the two objectives U_1 and U_2 (table 4.1).

In modeling, one distinguishes between several types of variables and parameters:
• S*tate variables* describe state of system at any time: in our system most importantly the number of animals.
• *Control variables* are time dependent and determined by decision-maker: here we consider the number of animals sold, bought and the number of lambs kept to enter the herd after 10 to 14 months after birth.
• The system may also be affected by uncontrollable "*random" variables or parameters:* in our case rainfall.

[4] As group and individual interviews are considered complementary for qualitative and quantitative data collection (Flick 1991, Kaplowitz 2001, Frey and Fontana 1993), we attempted to gather farmers in small groups and complemented with individual interviews with farmers which did not attend group meetings.
[5] The calibration of such parameters was done according to qualitative and quantitative statements made by experts concerning the behavior of control variables (numbers of replacement ewes and bought ewes) and optimizing income only.

Table 5.1: Main activities in the linear programming model and requirements of resource for each activity

Resource	dorper	goats	rest	Borehole construction	limits
Labor (hours per year per SSU)	5	10	0	0	**=< 7680 (3 Working Units)**
Land (ha)	3, 5, 7 SSU/ha, depending on stocking rate	3, 5, 7 ha per ha, depending on stocking rate	400 ha (size of an average camp)	1250 ha (area that 1 borehole can supply water to)	**=<10 000**
Biomass (Kg dry matter per year)	712	854	0	0	**=< Depends on rainfall (linear relationship)**
Income (N$)	350 (lamb)	400 (lamb)	0	- 35 000	**>= 0**
Income (N$)	350 (lamb)	400 (lamb)	0	- 35 000	**Maximization**
Range condition					**Maximization**

The model includes 4 sub-systems: (1) farm resources and biomass production, (2) rangeland dynamics, (3) herd dynamics, and (4) farm economics.

Model sets:

St set for the different possible stocking rate or intensities of grazing per ha st3 (1 small stock on 3 ha), st5 (1 small stock on 5 ha), st7 (1 small stock on 7 ha).
S set of the different ecological states of the rangeland: s1,s2,s3, s4,s5,s6
Sfin Alias (s,sfin)
P activities that deal with pastoralism: goats, dorper
Re veld regeneration activities, here only resting
T time /2005 * 2035/
LY set designating the 2 vegetation layers: grass and shrubs

Farm resources and biomass production

Rainfall is the most important variable in the considered agro-ecological system because it influences the impact of stocking rate on rangeland condition and it determines the yearly available biomass. According to Du Pisani from the Ministry of Agriculture, Water Resources and Forestry (Pers. Comm. 28.03.05) the rainfall distribution for the south of Namibia follows an incomplete gamma distribution: there are more below average rainfall years than above average rainfall years. Here we approximate the gamma distribution using a logarithmic transformation of rainfall data in combination with a normal distribution.

$$Raintr = \ln(Rain)$$

where

Raintr is the transformed rainfall and
Rain the rainfall data of the Keetmanshoop station.

Moments of the normal distribution were calculated for the transformed rainfall data.

$$Raintr = F\ \{\ \sigma(Raintr), m(Raintr)\ \}$$

where

$\sigma(Raintr)$ is the standard deviation of the transformed rainfall data
$m(Raintr)$ is the mean of the transformed rainfall data.

The opposite transformation provides us with simulated rainfalls approximating the gamma distribution, which are used as a stochastic parameter in the model. In practice, moments of the transformed data for a normal distribution are (m,σ) = (4,7588; 0,63768). We incorporate the "incompleteness" of the gamma distribution of the real rainfalls by adding 20 to the computed rainfall values.

Biomass calculations are done using a linear distribution depending on rainfall. Coefficients were calculated by A.Popp thanks to a detailed spatially explicit and dynamic vegetation model for the area (Popp & al., being drafted).

$$Biomass_{t,ly} = restbiom_{t-1,ly} * BIOMLOSS + \sum_{s} (RAIN_t * biomassCoef_{s,ly} * HAstate_{s,t}) \quad (1)$$

With

$biomass_{t,ly}$ the amount of biomass available as fodder in year t given in tons

$restbiom_{t,ly}$ the amount of biomass left on the veld after grazing at the end of the year t-1 and potentially available for the next year t.

BIOMLOSS coefficient of biomass lost from one year to the other.

$Hastates_{s,t}$ the amount of land on the farm in each ecological state given in ha and for year t.

$RAIN_t$ the rainfall in year t in mm

$biomassCoef_{s,ly}$ coefficient of biomass growth for an assumed linear relationship between biomass growth and rainfall. Source: Vegetation model from A. Popp.

The number of water supplying boreholes on the farm depends on the boreholes stock, the number built that year and the "BrakeDown Borehole Coefficient" : one borehole infrastructure has a life expectancy of 10 years.

$boreholes_t = boreholes_{t-1} + boreholbau_t - Dryborehol$

with

$boreholes_t$ the total number of boreholes on the farm

$boreholbau_t$ number of borehole bored in year t

Dryborehol scalar for the number of boreholes that fall out of order each year

The number of boreholes constrains the stock that can be kept on the farm by reducing the grazeable area since land without water points cannot be used in the considered labor extensive farming system (Duraiappah and Perkins, 1999).

$LA_{borehole}$ the amount of land around a borehole, that is the amount of land that can be grazed if the borehole is functioning, in ha.

Fodder can also be purchased by the model farmer as an alternative for biomass consumption in order to satisfy the needs in overall fodder of his herd.

Rangeland dynamic

This module is the key element of the bio-economic model and simulates the changes in veld condition as a result of rainfall and depending on stocking intensity (stocking rate) and stocking nature (type of grazer). In return the new state of the rangeland will affect the production of biomass and thus the maximum number of animals that can be kept on the farm in the following years. For modeling purposes we have defined a series of 6 states based on grass and bush cover and taking into account which species are found in an interdisciplinary effort jointly with Namibian rangeland experts (fig 4.1). These states vary in productivity as well. Farmers tend to prefer state 1 and 3 because of the mixed composition between shrubs and grasses, the presence of perennial grasses, the high density and number of species. As explained above these states provide both productivity and buffer in case of drought (table 4.2).

Veld conditi on	%cover grass	% cover bush and bossies	Description
S1	50-100	0-39	**Goeie kondisie** – **Meer gras** Min bos of bossies
S3	30-100	40-100	**Goeie kondisie** – **Balans** tussen gras en bos-bossies
S2	10-49	0-39	**Meer eenjarige** as meerjarige gras – **Sommige** bos-bossies
S4	0-29	40-100	**Digte bos bedekking** – Geen of min gras
S5	0-9	10-49	**Kaal grond met sommige** bos-bossies – Skaars/dun gras
S6	0-9	0-9	**Kaal grond** – byna **GEEN** plantegroei

Fig 4.1. Definition and illustration of the 6 states of rangeland for the area of Keetmanshoop.

Importance (citation frequency / sqr(ranking coefficient)	Characteristics of a "Good" veld	Importance (citation frequency / sqr(ranking coefficient)	Characteristics of a "BAD" veld
3,1	grass quantity	2,12	no grass left
1,9	shrub quality	2	annual grasses
1,8	shrub quantity	1,7	bare ground
1,7	high quality veld regarding animal needs	1,44	dry vegetation
1,5	grass quality	1,41	no rain
		1,41	no vegetation

Table 4.2. Characteristics of rangeland, perceived as good and perceived as “bad” by interviewed farmers.

To model the dynamic with a damage function, a *TRANSITION* parameter was calculated for each activity and stocking rate and four rainfall classes. This parameter was calculated with the use of a detailed dynamic and spatial explicit vegetation model (Popp et al. being drafted). In our model, the farmer has complete knowledge over the damage function.

Equation 2 describes the transitions taking place for areas in each rangeland conditions yearly in the model:

$$Hatransformed_{sfin,t} = \sum_{P}\sum_{st}\sum_{s} (animIntens_{P,st,s} * LANDREQ_{st} * TRANSITION_{P,st,s,sfin,t}) + \sum_{re}\sum_{s} regeact_{re,s,t} * TRANSIREST_{s,sfin,t} \quad (2)$$

With

$Hatransformed_{sfin,t}$	area in each state given in ha at the end of the transition from initial to final state as reaction to use and rainfall, summed up for year t.
$animIntens_{P,st,s}$	number of animals kept at different stocking rates st in year t. The sum over P gives the total amount of animal of each breed.
$LANDREQ_{st}$	land required per small stock at each stocking rate : st3 3 ha, st5 5ha , st7 7ha.
$TRANSITION_{P,st,s,sfin,t}$	transition coefficients of a state(s) to another state (sfin), depending on animal type (P), intensity of use (st), initial state (s) and yearly rainfall (rainfall in t).
$Regeact_{re,s,t}$	resting activity.
$TRANSIREST_{s,sfin,t}$	transition coefficients of a state to another state, depending on rainfall and initial state if it is rested.

The stock of land in each quality thus changes in time as defined by the following equation:

$$HAstates_{s,t} = HAtransfoFIN_{s,t} + HAstates_{s,t} - [\sum_{P}\sum_{st} (animIntens_{P,st,s} * LANDREQst) + \sum_{re} (Regeact_{re,s,t} * RegeActCOEF_{"land",re})] \quad (3)$$

With:

$HAstates_{s,t}$	amount of land in ha in each range quality or state at time t
$RegeActCOEF_{"land",re}$	amount of land rested at once (1 unit = 400 ha)

Herd dynamic

The total number of animals on the farm is first constrained by the availability of biomass:

$$biomass_{t,ly} + fodder_t / FODNEEDS >= \sum_{p} (animact_{P,t} *(BIONEEDS * lyFEEDING_{P,ly})) \quad (4)$$

Second it is constrained by the land available in case boreholes are not being replaced regularly, as shown in equation 5:

$$boreholes_t * LA_{borehole} =< \sum_{P,st,s} animIntens(P,st,s,t) * LANDREQ(st)) \quad (5)$$

The number of breeding ewes and thus animals on the farm fluctuates with the number of ewes sold ($eweSell_{P,t}$), ewes bought ($ewebuy_{P,t}$), the number of ewe lambs kept for replacement in the previous years ($lambuse_{P,"replace",t-1}$), as described in equation 6.

$$ewesfin_{P,t} = ewes_{P,t} + lambuse_{P,"replace",t-1} - eweSell_{P,t} + ewebuy_{P,t}; \quad (6)$$

Farm economics

As commercial farmers of the study area have full access to financial markets they use credit possibilities quite commonly to cope with the high variability of production patterns following rainfall. The value of capital $fingains_t$ is taken into account in this model thanks the introduction of an “interest rate” *CR*, which we use to give the costs or gains of having a negative or respectively positive saldo at the bank (Buss 2006) at the end of the year’s activities. This rate was estimated at 4%, mirroring interests made in a saving account.

$$Fingains_t = CR * Bankaccount_t \quad (7)$$

Financial gains are important because they play a role in the possibilities of increasing the herd in case of opportunities. So the commercial farmer in comparison to the farmer that has no access to financial markets has two possible strategies to ensure maximum peak productions: maximize the number of animals (Roe & al 1997) and maximize the financial gains at the bank.

We have defined 2 objectives of maximizing income and maximizing range in good condition. Corresponding maximands are :

$$U1 = \sum_t (balance_t + fingains_t + Landvalue + Selfcons) * (1/(1+IR))^t \quad (8)$$

where

balance	is the discounted sum of the receipts minus payments.
Landvalue	reflects the value of the land in each range quality, including all potential uses, at the end of the simulation period. It is given by the shadow price of each quality of range (Buss 2006).
Selfcons	is the discounted value of home consumed animals
IR	the discount rate.

$$U2 = \sum_t (Hastates_{"s1", t} + Hastates_{"s1", t}) * (1/(1+IR))^t \quad (9)$$

Both functions are discounted because of time preference and the dynamic character of the model. We chose to discount both functions at the same rate *ir* of 14% to reflect the instable political climate Afrikaaner commercial farmers are confronted with. Although we are ware of the discussion around social discounting rates ((Weitzman M.L., 1994)) when dealing with environmental goods and social welfare, we opt for a more simple consideration: that both objectives are private.

We also introduce a constraint to define the minimum level of activity on the farm.

$$U1 =G= 0. \quad (10)$$

5. Model results: trade-offs between objectives of range conservation and income optimization

In order to investigate the trade-offs between the two objectives of rangeland condition and income, we use the constraint programming method as described by Romero and Rehman (1989) and used by Thankappan & al. (2006). This consists in optimizing one objective, while using the second objective as a constraint. We vary the value of the constraint between its ideal and anti-ideal points, identified in the calculation of the pay-off matrix. The process is then reversed. A series of points belonging to the Pareto optimal solution set are obtained: a Pareto solution is defined by achieving the best score possible on one objective without making the other objective worse off (Ponce-Hernandez R. et al., 2004). The Pareto solutions are used to draw the frontier efficiency of our ecological-economic production system (fig 5.1). The ideal point indicates the ideal but impossible situation where both objectives are at their optimum value.

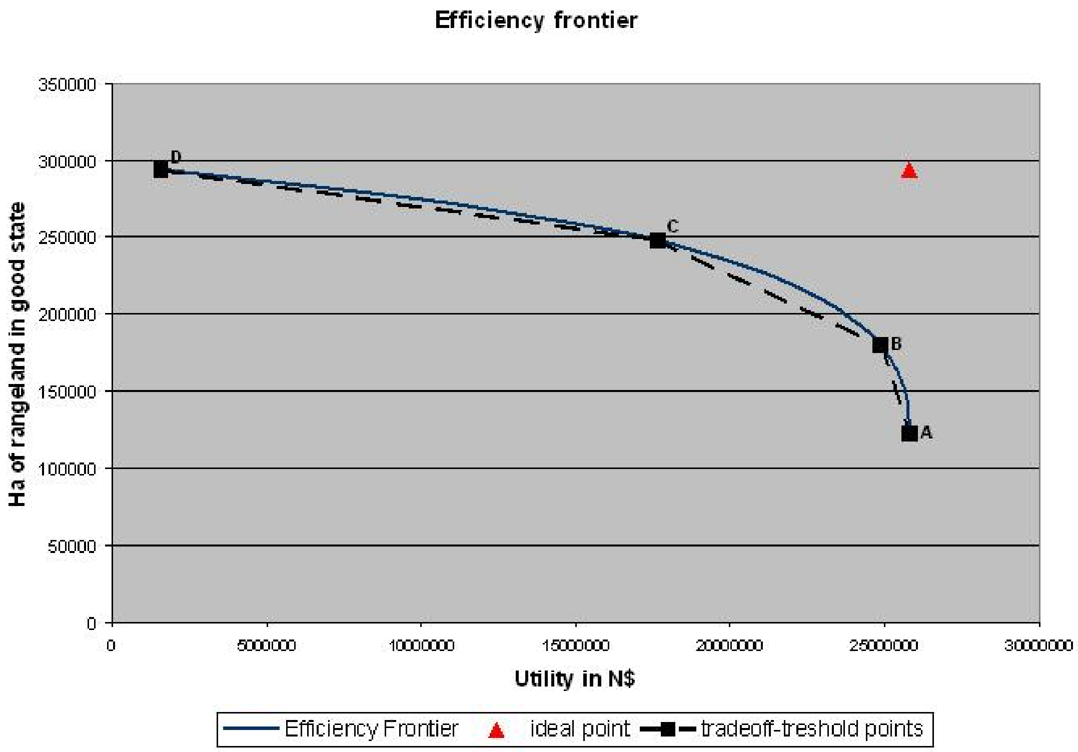


Fig.5.1. Frontier Efficiency for a typical full time farm of the area of Keetmanshoop

The numerical calculation of the marginal values for this curve gives us the trade-off values between the objectives. Similarly we calculate the rate of change of the trade-off values. The highest rates deliver inflection points of the frontier efficiency. These points are turning points where the nature of the trade-off changes. We will therefore use them as benchmarks to observe the change in activities and strategy (Thankappan S. et al., 2006). On the trade-off curve, A represents the maximum income, B and C are turning points and D is the maximum area of range in good condition.

The efficiency frontier obtained for the study area has a classical shape where increasingly more of the first objective has to be given up in order to increase the second. The strong slope between points A and B indicate that small sacrifice in income will lead to important improvement of the range's condition. This result was also found by Buss (2006) in his calculation of optimal biodiversity on central Namibian ranches. From B to C and then to D the efficiency of the sacrifice in income reduces; finally between C and D any improvement in rangeland condition will be achieved only at great costs. Table 5.1. shows the trade-off numerically in terms of discounted income in N$ given up to obtain one discounted hectare of good condition range. This is the price to pay for giving from little to much importance to range condition. Of course the strategy used at each benchmark point changes accordingly.

Table.5.1. Changing trade-offs along the efficiency frontier between range condition and income.

A-B	B-C	C-D
14	99	352

Table 5.2 presents results in stocking, degradation and income levels at maximums and turning points of the efficiency frontier. We rely on these variables to describe the stocking strategy chosen and their consequences.

Table5.2:Objective, state and control variables at ideal, anti-ideal and turning points of the efficiency frontier

	A	B	C	D
Objectives				
Average balance	6772	671548	821396	873104
Av nb lambs sold	726	1556	1865	2192
Range good condition	7825	6550	5650	4249
Range poor condition	206	1554	2552	3415
Activities				
Total ha rested	4700	3335	626	1186
Av stocking rate	1/9	2/9	¼	2/7
Av goat number	145	213	194	292
Av sheep number	534	1173	1444	1584
Control variables				
Av ewes sold	223	267	288	269
Av ewes sold % herd size	0,33	0,19	0,18	0,14
Av ewes bought	48	13	15	16
Av ewes bought % herd size	0,071	0,009	0,009	0,009
Av replacement ewe lambs	202	321	350	353
Av replacement rate in % female lambs	0,30	0,23	0,21	0,19
Total fodder	0	1	191	878

Apart from the profitability of the solution, the average profit per year also indicates the capability of the farmer to face big investments such as new fences or extra boreholes or the pay back of loans for stock or land. Indeed those are not accounted for in the actual form of the model which includes only family basic needs and minimum fixed costs. The average annual balance and the number of lambs sold increase as income maximization is given more weight. Although they are feasible, the values given might appear high; this is linked to the fact that the “model farmer” has complete knowledge over the rainfall in the actual state of the model. This allows best decision making at each position of the efficiency frontier.

Rangeland in conditions 1 and 3 are summed up under the term good condition range. They are productive and show a high perennial grass cover which increases the chances of sustaining your herd in case of drought. Range condition 4 has a high cover of annual plants which only produce when rainfall is sufficient. Vegetation of range condition 2 is composed of bushes mainly, which produce also in the drought but cannot alone feed sheep, the main production. Range in conditions 5 and 6, summed up in the table as range in poor condition, is poor both in plant diversity and in productivity and will reduce the long term ability of the farm to produce. Logically, the range area under good condition follows the opposite trend as the balance variable, but of course not at the same rate: the degraded area increases regularly by around 1000 ha between each point.

The practice of resting camps to enable rangeland regeneration is part of all strategies but stays relatively marginal: At its highest level in case A, less then the half of the farm was rested one year in a period of 30 years. Stocking rates increase as more weight is given to income maximization but vary only slightly between points B and D. On this part of the efficiency frontier stocking rates vary between 1 SSU on 4,5 ha (B) to 1 SSU on 3,5 ha (D), which are relatively sustained stocking rates for the area (average recommended carrying capacity being 1/5). Small variations in stocking rate thus seem to have an important impact on range condition when high stocking rates are concerned. Finally both goats and sheep are kept for breeding in all cases. Total number of ewes is a bit higher than the recommendations stipulate (1000) in relation to the stocking rate. Sheep is much preferred and herd size varies from simple to triple between A and D. Goats are present in all strategies but never appear at their upper limit of 400 ewes, fixed exogenously because of the actual situation of lack of reliable labor for goat production. The preference for sheep can be related to browse availability which is often binding in cases C and D and to the fact that purchase of does on the market are more limited that that of ewes.

Control variables show the options used to manage the herd. Fodder purchase enables animals to be kept on a farm although the range does not supply enough biomass for their maintenance. Thus herd size and range capacity are de-coupled: abiotic factors alone don't determine the stocking rate. Pressure of grazers is sustained and this results in higher degradation probabilities. In addition degraded areas produce less biomass so that the purchase of fodder is needed to maintain stock level. Thus a risk of entering a spiral of degradation arises if the reliance on external fodder is high. While no extra fodder is purchased in cases A and B, 200 t of fodder are purchased in C and nearly five times this amount in case D. Next, because we limited the purchase of ewes at 500 sheep (reflecting market availability), keeping replacement ewe lambs is strategic when working at low stocking rates. The more important the replacement, the greater the capability of the farmer to achieve peak production when the opportunity comes. The share of the ewe lambs kept for replacement decreases as expected from A to D.
Attempts to reach peak production also explain the purchase of stock, but due to its high costs (ewes at purchase are more expensive than ewes at selling), this option is more preferred at point A. Apparently it is economically not worth to invest in external stock in all other points, where stock purchase remains anecdotic.
Finally the number of ewes sold shows the acceptance of the farmer to reduce its herd in case of necessity. We have defined a lower bound of 13% for this variable, simulating the fact that all ewes older than 7 years must be sold because of their decreased productivity. This compensates the fact that changes in ewe productivity in time are not modeled explicitly. Figures above 13 % indicate that a strategic important reduction of herd size occurred. As expected, this variable shows higher values at points where range condition is a priority. Especially, a positive difference between the number of lambs kept for replacement and the number of ewes sold indicates a tendency of the herd to increase over time. This difference also increases smoothly along the efficiency frontier as income gains in weight. This is an expectable effect of the time preference.

By summarizing the control variables we draft the strategies represented by each benchmark point on the efficiency frontier and check for similarities with the behavior categories identified in part 3.

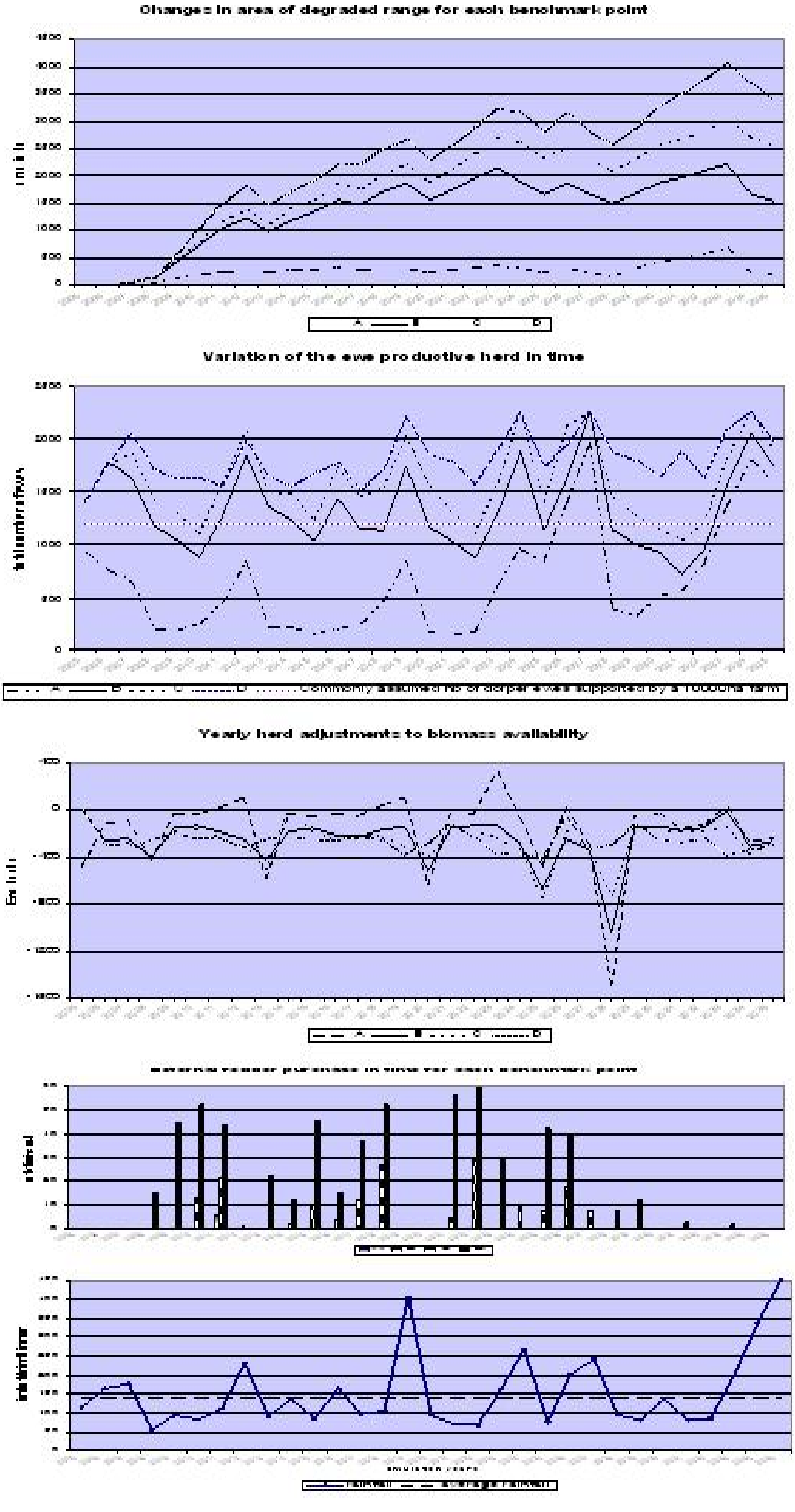


Fig 5.2. Time series results simulation for degradation, herd size, adjustments in herd size, fodder purchase and rainfall.

Table 5.3. Strategy profiles, consequences on veld condition and associate farmer behavior categories

Bench-mark points	Main state and control features of strategy	Impact on range	Analog category identified in case study
A	Very low stocking rate. Herd adjustment to yearly available biomass are high. (fig 5.2). High replacement rate No fodder bought. Biomass is not a binding variable.	Degraded area is less than 1 camp (400 ha)	C5
B	Stocking rate near the recommended 1SSU / 5Ha. Very reactive to drought events by selling ewes importantly. No fodder purchase.	Area in poor condition seems to stabilize around 1500 ha	C1
C	Stocking rate of 1SSU/ 4 ha, above recommended. Adjustment takes place by selling but also relies on fodder purchase occasionally.	Increasing degradation in time	Resembling C3 and C4
D	High stocking rate, above 1 SSU / 4ha. Adjustments are the least of all strategies, indicating reluctance to sell in droughts. High reliance on external fodder especially in later years.	Important area degraded, productivity seriously reduced, reliance on fodder to compensate.	Between C4 and C2

The variety of responses of farmers to threats and opportunities is fairly well represented in the analysis of benchmark points. Of course because we lack data on long term stocking rates at the farm level we cannot directly associate each farmer of the behavioral categories to the patterns of land degradation found along the set of efficiency frontier. However some trends are derived here and can be further analyzed in future research.

First, reliance on fodder and its de-coupling effect has the negative impact on rangeland condition that is expected in the range dynamic conceptual framework this work builds on.

Second, if the relationship between stocking rates and degradation is the same as between income and stocking rates -as the results suggest-, then stocking rates below the recommended 1/5 will not improve range condition much and will rather limit the possibilities of farmers to invest in necessary infrastructures such as borehole and fence maintenance.

Third, the relative importance of income and range condition has a big impact on the chosen strategy and the level of degradation of the range.

6. Discussion

On the one side, the qualitative analysis reveals that there is a diversity of strategies to cope with the extremely erratic abiotic conditions among the farmers of the study area. At the level of the landscape these farmers form a matrix of complementarities: some farmers rather sell their stock, some rely on purchase at auctions to meet peak productions, some rent land, and some rent out their herds. Our qualitative data and number of cases does not allow us in this exercise to define the impact of the various strategies of farmers on range condition nor to define factors causing this diversity, although we have suggested some possible factors such as dependency on farm income.

On the other, the MOP approach delivers complementary information because it is able to make the link between strategy and resulting range degradation or conservation. However, we have no means to make an absolute link between the various strategies obtained by using the MOP technique and the behavioral categories defined with the qualitative analysis. Long-term stocking rate data as well as the modeling of each separate farm would be needed. This is not attempted here. Rather we want to stress the similarities between results of both methods:

qualitative results illustrate the existence of the various farmers behaving at various points of the efficiency frontier, or in various parts of the solution area (see fig 5.1 for illustration).

There are some draw backs to the method. Since the modeling exercise is done for an isolated farm, contacts with the economic outside world omitted. This means that prices are assumed as static and the interactions between farms are neglected. These draw backs have an influence on the model's outcome. In addition, rainfall variability has been modeled quite successfully but not yet its stochasticity so that the "model farmer" is able to plan ahead knowing what rainfall it will encounter. Thus modeled income levels are probably higher than what can be achieved in real life. But this research is in continuation and the impact of stochasticity of rainfall on farmer incomes and strategy will be determined in further work. Finally, as explicated by Thankappan & al. (2006), linear models are far from being able to mirror and model the complexity of farmer decision making and all interactions that take place in such complex ecological-economic systems. However the strength of this approach is that it delivers the monetary importance (thus a valuation) of the objective of range conservation through the value of the trade-offs.

This is the level of investment that the farmer is ready to comply with in order to conserve the resource at optimal "response" capacity. From a social welfare point of view, one could consider the trade-off value as the necessary investment in resource conservation needed in order to maintain constant consumption of income in time, as suggest by the Hartwick rule (Hediger W., 2003;Asheim G.B. et al., 2003). However we will not engage in this discussion here.

Rather we want to reflect on the many factors other than/beside the economic one of ensuring high reliability that might affect preference for range conservation. Leeuwis (2004) has developed a conceptual frame for the formation of farmers' practices. The discussion of some of the elements can reveal interesting here. First, *values* contribute in shaping practices. The concept of duty of care, emerging in range research in Australia (Stoeckel A. et al., 1997), points to the moral obligation of land users to maintain the quality of the resource they use. Although not stated explicitly, the concept of duty of care for the land is present in the minds of interviewed farmers. When asked if it was their duty to maintain range in good condition, two farmers stated that this depended on strength of one's Christian beliefs: farmers are given the resource by God for their livelihoods and are to take care of it during their lives and keep it ready to the next person (generation) to use. Two farmers also mentioned the pleasure derived from having range in good condition. Second -and very important in the *political* post-Apartheid *context* of land redistribution-, farmers see in their good management a justification for having the rights to keep on farming the land. They see their management methods as scientific and basically good. Third, farmers believe they have an efficient control over range condition and 14 out of 16 farmers asked claimed that "*one should not let his farm degrade to state 5 nor 6*", and that they would "*always attempt to regenerate a camp that is degraded, especially if it is only starting* [meaning range condition 2]". So farmers feel they have a high *self efficacy*. Finally most farmers agree that degradation is taking place, but not on their farm. As strong overgrazing and degradation is associated with farming practices in communal areas (own results and supported by (Hongslo E. and Benjaminsen T.A., 2002), there is a strong *social pressure* among farmers not to "turn landscapes into *nothing*" (Hongslo E. and Benjaminsen T.A., 2002).

At last, differences in objectives can also be related to reasons why managers are involved with farming. Some involve in farming activities because they see it as a way to "be with nature" (N=8), others consider it as the only thing or the best thing they could or had to do (N=9), while a third group considered they had the skills for this type of business (N=6). Some farmers have given 2 answers. These quite different reasons for getting involved in farming activities might be a starting point for further investigation of the trade-off issue with a qualitative research approach.

7. Conclusion

This paper shows that commercial farmers are very diverse in the way they manage their rangeland, although only few control variables are available to them in term of adjustments of stocking rate to rainfall. Farmers differ in their reactivity to the highly varying availability of rangeland resources and maybe also in their objectives. The variety of responses of farmers to threats and opportunities can be addressed by a multi-objective approach under a high-reliability paradigm where both range condition and income are part of the objective function. This paper argues that income maximizing behaviors have severe impact of rangeland quality. However, some farmers act rather as income securers and tend to invest in the quality of their range. The level of this investment might be affected by many factors, a few which can surely be found in the social context of the farmers.

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