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

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Introduction

In Namibia as in most countries where arid rangeland are economically and geographically important authorities and the scientific community are concerned with the loss of biodiversity and of productivity of rangeland due to desertification/degradation (Strohbach 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). Desertification can be triggered by both natural biotic and abiotic factors as well as anthropogenic use. The combination of both is often what drives an ecosystem to degradation: all around the globe resource users are expected to adapt as reactively as possible to the resource available or the changes in resource availability due to short term or long term changes in the abiotic characteristics of the ecosystem such as rainfall patterns and rainfall regimes. In the case of the arid rangelands of southern Namibia considered in this paper, anthropogenic use consists of pastoralism: goat meat and mutton production for the export market in the Republic of South Africa are the main activities. Our work, embedded within a greater researcher effort within the BIOTA- Southern Africa project, has the objective to increase the understanding of human use of natural rangelands resources and understanding its impact.

In the present study we consider the economic-ecological system that are farms with commercial orientation in the Nama Karoo, Karas region in Namibia. Farms in that area face difficult conditions such as particularly erratic rainfalls, increasing prices of inputs and insecure market in the RSA. Rangeland is entirely composed of natural pastures that have to be manage with care since mistakes lead quickly to resource degradation. Our interest in this paper is to depict management options that farmers have to cope with the variability of their resources on the one side. Second we want to describe the interaction between farm economics and resource quality and their degradation. We want to understand how farmers make their decision on stocking rate. According to Batabyal (2005) stocking rate should have a great impact on rangeland or *veld* (word designing both the vegetation, the soil and the grazing capacity of a rangeland). The paper focuses on this issue and the following questions: What are farmers strategies for stocking their farm and maintaining their income? How to model farmers strategies ? What would be the impact on the rangeland resources ?

To answer these questions, we've done a case study of a small sub-urban area in south Namibia. First an explorative farming system research was done. As a complement we developed a bio-economic model using GAMS (Generalized Algebraic Mathematical Software). Indeed bio-economic models have revealed to be a useful tool to address 2 of the issues addressed at the "Ecosystem Valuation Forum" organized by the US Environmental Protection Agency in 1991: understanding more about what determines the action of humans on ecosystems and how this is affected by the change in the resource itself (Bockstael & al 1995).

We will start by introducing briefly the concerned rangeland, its dynamic and implications for management. Then after describing our study area and methods we will present our interviews results on farming system and farmer stocking behaviors. In a fourth part we describe the bio-economic model and its results, before closing with a discussion and conclusions.

1. On rangelands of Keetmanshoop, rangeland ecology and rangeland management

Our case study was done in a small study area, relatively homogeneous for rainfall, vegetation, soil patterns and potential productivity, with an average recommended carrying capacity of 1 small stock on 5 ha (1/5). It is a peri-urban area around the third town of the country: Keetmanshoop located in the Nama Karoo, in the biome of dwarf shrub savannah (Mueller 1985). Rainfall averages 120 to 150 mm per year and decreases rapidly from East to West. There are more below average rainfall years than above average rainfall years. Farmers talk about a drought cycle with droughts occurring every 6 to 9 years (pers. communication with several farmers). The actual vegetation growth period is only 11 to 21 days long; plants are flowering and forming seeds in the end of the summer time, with the end of the rainy season between February and May (MAWF maps 2005). The two main geological features are volcanic dykes and sills with outcrops of dolerite rocks and sandstones and shells of the main Karoo basin sediments (BIOTA S01, 2005). As seen from the farmer's point of view, one distinguishes between hard and soft veld (word designing soil and plants), with a predominance of hard veld in the study area. Vegetation is composed of a little amount of trees, perennial grasses of 60 cm at most (mostly *Stipagrostis* species), characteristic and dominating shrubs such as 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 nutrient requirements are met 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 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* on softer soils or where more water is available. Veld degradation reduces already in the very short term the productivity of the farm. Farmers perceive veld dominated by one shrub specie only as being of low value: "you cannot feed the animals with this veld".

Until the 90's the succession model was used to express the ecological behavior of rangeland in arid and semi-arid areas. It states that grazing pressure is the disturbance factor that keeps a rangeland grass dominated and thus maintains it at a climax - or equilibrium- state. In this model grazing pressure is the main factor affecting directly the vegetation: overgrazing leads to vegetation cover reduction. However rangeland scientists consider increasingly the vegetation succession model to be inadequate in explaining phenomena observed in the field. The non-equilibrium theory was then proposed, relying on evidences that grassland productivity is more correlated with external abiotic factors (interaction between soil, vegetation and rainfall, temperature, and other abiotic factors) than with biotic factors (grazing pressure) (Sullivan & Rhode, 2002, Illius & O'Connor 1999, Ellis & Swift 1988, Vetter 2004). An application of this theory is the State-and-Transition model, which relies on the fact that ecosystems tend to behave towards stables attractors, but that flips can occur, making the ecosystem switch from one stable state to the other. Reversibility of such shifts in condition is not self-evident (Westoby & al. 1989, Bestelmeyer & al. 2003, Stringham & al. 2003, Janssen 2004). We use this concept in our work to consider and represent the dynamic behavior of the dwarf shrubs savanna ecosystem in the region of Keetmanshoop. Implications of rangeland ecological behavior is that the pastoralist must consider both abiotic and biotic interactions when deciding on his management of natural resources in order to avoid degradation threats and use restoration opportunities (Westoby & al. 1989).

2. Keetmanshoop case study: materials and methods

• *Case study :Explorative and descriptive research using in-depth interviews with 20 farmers*
The study area is relatively small counting 700 000 ha, of which 535 000 ha are privately owned and farmed. About 50% of that land was covered by interviews with 20 farmers between March and June 2005. The sampled farmers had to be farming in the study area and were randomly chosen. Farmers were contacted by phone at different days and time of the day to cover all types of farmer (also double active) and were explained on the phone issues that were to be covered during the interview. 2 additional interviews were conducted in the Klein Karas mountains, a bit further away from Keetmanshoop and with relatively more rainfall, and were accounted for in the results in the documentation of farming systems and stocking behavior and not in the calculation of productivity figures. Pretests were done on 4 farms with various activities (goat, sheep and game) in the area of Koes (160 km north east of study area) and Seeheim (60 km west from study area).
We proceeded with structured interviews with mostly open-formed questions, with the following goals: the explorative description of the farming system, the identification of the main challenges for farming in the region, identification of farmers' management and stocking behaviors, the description of input-output relationships and an explorative investigation about perceptions of *veld*. This was completed by a *veld* tour to illustrate issues of *veld* perception restoration and degradation.

• *Bio-economic modeling*
As a complementary approach to help us understand the functioning of the farm resource management system we developed a bio-economic model. The model's general purpose is to depict and quantify the dynamic interactions between the ecology of agro-ecosystems and their managers: farmers/pastoralists. We used the GAMS mathematical programming software to program a dynamic linear optimization model of a typical farm for the study area. The inclusion of *veld* condition and impact of stock numbers on *veld* in the model is the key element of the feedback from the ecological to the economic sub-system.
Bio-economic models have been very creative to model the interaction between economics and ecology:

- detailed modeling of ecological impacts and consequences on level of inputs and the production (Abel 1997, Hahn & al 2005, Bockstael 1997, Cooper and Hufflaker 1997),
- double production function: input/output, input/externality (Wossink & al 2001, van Wenum & al 2004),
- by using the TEV which includes option and opportunity costs in the objective function (Abel 1997, Duraippah and Perkins 1999, Bulte & al 2003, Kreuter and Workmann 1994)
- by using coefficients that reflects expected impact as found in the literature (Costanza and Neumann 1997, Bach 1999).

Typically bio-economic models have 2 modules, the first economic and the second ecological: the outcome is a simulation of the behavior of an ecological-economic joint system that is sensitive to both ecological and economic shocks (Batabyal 1999). Among other goals, bio-economic models are used to define optimal or best management options, considering both resources and utility of the user. Most studies then use optimization and linear or non linear 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 models have become part of the mainstream tool used to compare options concerning resource use as well as to identify the best policies, given the objective function and constraints of the economic system. 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 approach is to stick to the optimal control method using linear programming, with the goal of describing the interactions between veld change and farm economics and complementing farmers views about most influencing factors for on-farm degradation. Our model is very inspired from the work of Buss (2006) and Duraippah and Perkins (1999).

• *Model parameterization and calibration:*
The main limitation of such models is input data. The present model could not rely on already existing data. It was parameterized thanks to information collected on input-output relationships during the interviews of 2005. Model parameterization and calibration was completed thanks to a second interview round. 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. Both group and individual

interviews were conducted in a semi-structured interview form. Interview purposes were the post testing (Flick 1991, Frey and Fontana 1993) of our productivity data and second the further description of farmers' stocking behavior and principles.
2 individual interview pretests as well as one focus group pretest allowed to test the relevance of the questions and the adequacy of the interview process. The focus group pre-test included members of most cultural communities of the area in order to ensure the meaningfulness of the questions. Finally a series of individual interviews with 4 experts were conducted to calibrate and validate the global behavior of the model thanks to discussions held on model results in an iterative manner.

3. Management of natural pastures and veld degradation:

Farming system description

Most of the interviewed farmers come from the Karas region and all grew up on a farm. Half of the interviewed farm households have additional income besides farming, such as pension (1), income from spouse (3), income from tourism (3), income from speculation (3), income from employment in town (1) and main business in town (3) from the most to the least dependent on farm income respectively (some farm households may classify in 2 categories). This is typical for a sub-urban area as also observed on the area of Rehoboth (Ibo Zimmerman and Christiane Neumann, pers. communication 2006).

Commercials farms are about 10 000 ha on average and divided by fixed fences into big camps of about 400 ha. Numerous boreholes (from 6 to 14 functioning boreholes) and a system of pipelines supply all camps with at least one water point if the farm wants to be fully stocked. Revenues are mostly derived from the marketing of live and slaughter animals, and from Karakul pelts (skins). The most important costs are the investments in and maintenance of the infrastructure such as roads, water supply installations, fences, electricity generation and housing. Fuel is also a very important cost. These costs vary with the size of the farm, but are fixed for a given farm. Variable costs are veterinary expenses and complementary fodder such as mineral licks and maize meal. The importance of this post varies according to the farming system: extensive with higher losses and less costs per animals or intensive with higher variable costs but less losses.

The small stock is usually kept in groups, and per breed in separate camps. Farmers practice rotational grazing as defined by Du Toit (2002): Some camps are grazed while the others are rested from 42 to 98 days. Eventually on some farms, the grazing periods can be longer. This system was advocated by both Namibian and South African governments in the last decade and is still used as a basis in the study area. The most limiting factors for production are perceived to be rainfall and water supply, which is a very important cost among other infrastructures.

Veld management dimensions:

Herd and veld management are intimately related : the grazing system chosen such as most often in the study area the rotation of the animals on the veld thanks to the camp system has several purposes:

- using the veld when most nutritive, planning the whole year nutrition pattern,
- prevent or reduce diseases
- maintain, increase or restore veld condition on the farm.

There are 3 dimensions of the grazing management.

Spatial elements of herd-veld management. On all farms one will find some specialized camps: near the farm stead for lambing purposes and depending on the geographic repartition of veld types on the farm, camps can be allocated to specific animals (cow camps – typically on grass veld, goat camps- typically on shrub veld). Finally farmers tend to follow the ripening of the plants on the farm, the more bushy areas being grazed rather in winter and being categorized as winter veld. All these specificities reduce herd mobility on the farm.

Temporal elements of herd-veld management. Rotation timing is important to avoid overgrazing a camp: animals have to be moved because a threshold of biomass eaten is reached if the farmer wants to avoid degrading its veld. Farmers base their decisions on a series of indicators listed in table 3.1. Length and timing of resting (during or after the rainy season) is also important. Many experts now argue that resting is more important than grazing (Lubbe, pers. communication, concept of holistic grazing, von Bach & Groenewald 1991) for instance concept of strategic resting states that a veld rotation should be organized focusing on when is being rested and not when is being grazed, with eh aim of letting the veld rest long enough for all plants to grow fully, makes seeds and for new seedlings to establish before being grazed again. This whole process usually takes a year (Du Toit 2002). Similarly grazing timing (during or after the rainy season) will have a big impact as well: a veld grazed during the rainy season is vulnerable to overgrazing since all plants are depleted from their photosynthetic aerial part before they can regenerate the root resource.

Table 3.1: Nature of indicators used by farmers for spatial and temporal grazing management on the farm (own results):

Indicators cited	Frequency of citation
vegetation indicators	30
livestock	9
Soil	2
Rainfall	2
wild animal	1

Among the vegetation indicators we have:

- Level of biomass left overall
- Level of biomass left grass
- Level of biomass left bushes
- condition of indicator plants

These indicator classes can also serve as sustainability indicators as suggested by Doughill and Reed (2002) in their work with pastoralist of Botswana.

Yearly dynamic of herd-veld management. Each year decisions are taken concerning the maximum number of animals that will stay on the farm. These depend very much on the annually changing veld and especially biomass resources due to the high varying rainfalls, but is also constrained by other factors. Most importantly some farmers may be reluctant to reduce their herd below a minimum herd size. Reasons are keeping the genetic material bred of the farm, difficulties to buy in new sheep when rains are more favorable due to increasing prices. Stocking rate as we have seen has an important impact on the evolution of rangeland condition (Batabyal 2005, Unterschultz & al. 2003). Clearly if too many animals are kept on the farm as compared to the available biomass, overgrazing will cause degradation. Total herd size depends on 3 actions: selling and buying ewes from outside the farm and the number of replacement ewe lambs kept and the number of mating seasons per year, as controlled by the farmer. This paper takes into account only the first 2.

Veld degradation according to farmers

Most farmers agree that rangeland degradation occurs in the area, although not necessarily on their own farm. Perceived motors of degradation are summarized in table 3.2. According to farmers rainfall is the first driver of the quality of rangelands, particularly in drought years, where prolonged droughts can severely damage the grass sward and dwarf shrub layer and weaken the bush layer. Also good and high rainfall years such as in 2005 and 2006 can importantly the quality of the rangeland across the study area. This answer from the farmer community is concordant with the non-equilibrium theory of abiotic factors being driving forces of rangeland ecology. The three other important factors are related to the farmer: his knowledge of the veld, of the animals he farms with and his economic situation. These are descriptives of farm management.

Table 3.2: Motors of rangeland degradation as perceived by farmers (own results)

	Sum
Relationship farmer environment	2
Relationship animal environment	2
farm economics	3
rainfall or climate change	7
special activity (speculation)	0
Size of the farm and *veld* type	1
Number of valid answers	15

Every farmer is subject to degraded rangeland: either he has bought the farm with overgrazed camps, or has committed mistakes for a reason or another and overgrazed. What makes it difficult for farmers to manage the *veld* in a sustainable manner? Table 3.3 presents the factors that farmers consider influences the good and sustainable management of rangeland. Most cited are elements of farm economics such as high costs in water supply or other infrastructures, the dependence on farm income of the household, and the level of private needs – younger farmers needing more cash for the annuities of the loan contracted for land, and for school fees of their children). This justifies the use of a bio-economic model to understand the pattern of *veld* degradation on a farm.
The second most important appears to be the observing capacities of the farmer and its capacities to “read” the *veld*, that is, his ability to read good indicators in the *veld*.

Table 3.3: Important factors for good rangeland management (own results)

	Sum
relationship farmer environment	4
relationship animal environment	**2**
farms economics	**5**
rainfall or climate change	**2**
special activity (speculation)	1
distribution and amount of resource	0
Number of valid answers:	**14**

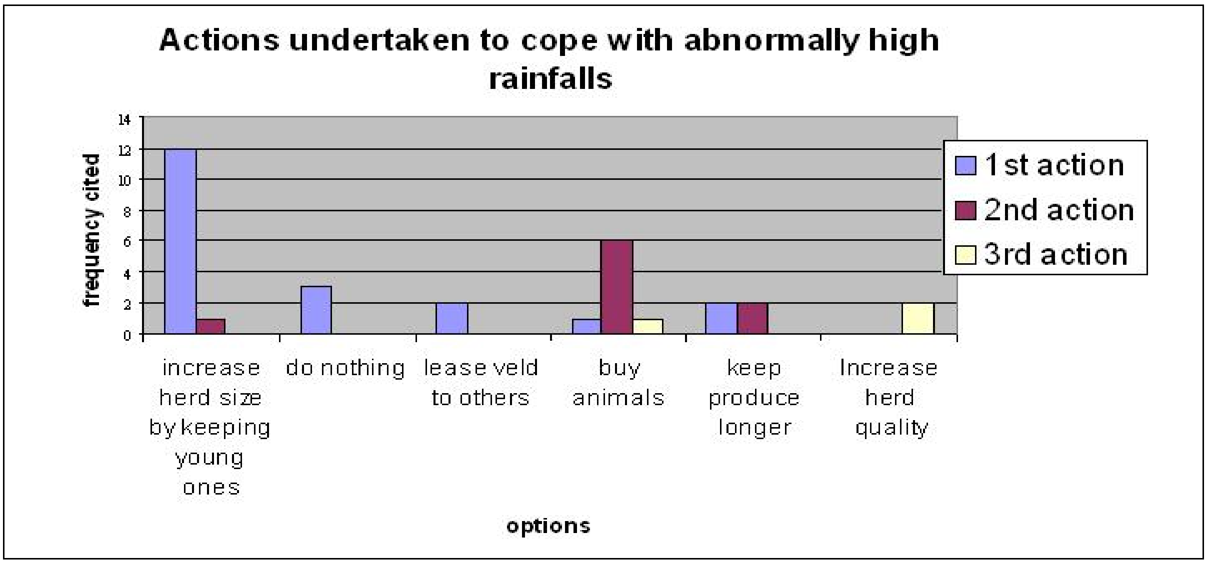
We have seen now which factors farmers perceive to be important for good management of *veld*. Next we want to describe the different strategies that farmers claim to adopt concretely when facing exceptional rainfall conditions since rainfall is the main driver of veld condition and the rangeland must be managed accordingly.

4. Farmer strategies in face of drought and high rainfall years

Farmers all agree that "it is very easy and quick to destroy your veld, but it is much more difficult and long to recover it". However most farmers perceive it possible to recover most of the degraded rangelands, except in extreme bear conditions where soil condition has changed and does not allow seed and water penetration in the first soil layer anymore.

As described by Westoby & al (1989), there are opportunities and threats that the farmer has to recognize and profit from in order to manage his veld successfully. Opportunities are high rainfalls that have an impressive regeneration capacity even on very degraded veld, as illustrated by veld recovery on some farms and communal area north from Keetmanshoop in 2006, after 2 seasons of good and then excellent rainfall. Threats are all situations that can lead the farmer to overgraze his veld, often droughts. Farmers are very well aware of the threats: "you can destroy your veld in 3 months if you don't take care".
We asked farmers how they manage these threats and opportunities in order to describe actual behaviors. 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. 1st reactions consist of increasing number of female lambs kept for replacement or doing nothing. 2nd reactions are most often buying extra ewes to increase herd size and use the importantly grown biomass. These 2 options are key regulatory variables that are available to the model farmer to react to changes in the natural resources environment.



Graph 4.1: Actions undertaken by farmers as a reaction to abnormally high rainfall after years of "normal", average rainfalls.

One can classify reactions of farmers to high rainfalls in 2 groups:

• Increasing the herd, either by increasing the number of female lambs entering the reproductive herd (often done first) and then by buying ewes on the market.

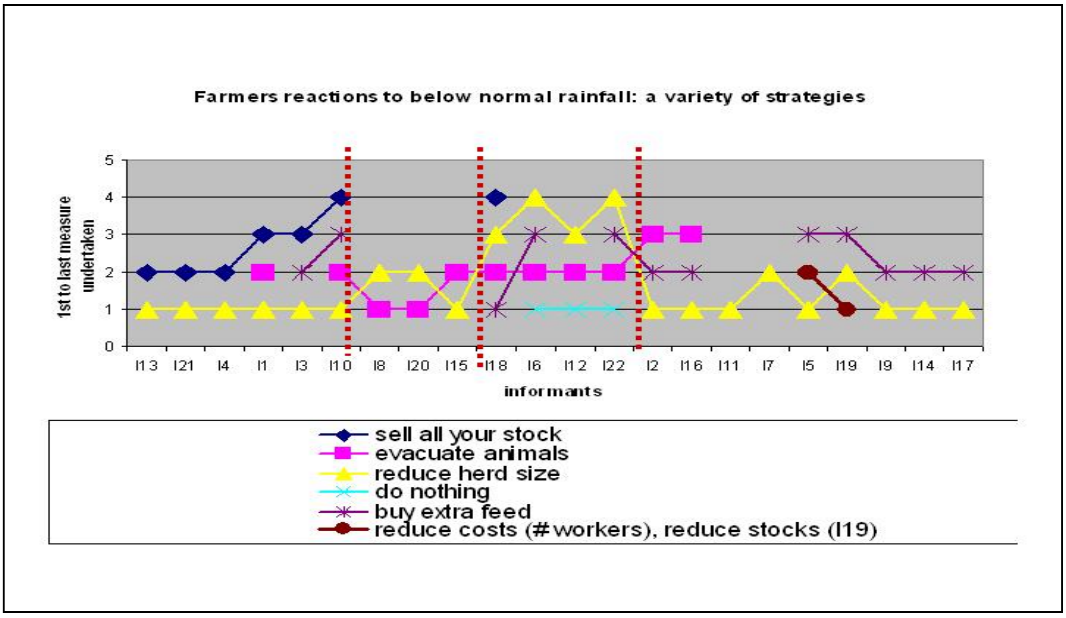
• Doing nothing at first if the herd was at normal size, eventually keep the produce longer on the farm or increase herd quality by buying rams.

One less preferred option is to lease land to other farmers: this option is not included in the model.

The biggest group is the first one, reacting to biomass increase in availability by immediately increasing animal number irrespective from the size of the herd the year before. The second group, less reactive, does not increase his herd in good rainfalls and puts a limit number on the level of animals the farm can carry.

Drought years. Options cited by farmers to cope with drought include from the most responsive action to the more static one:

- destocking (selling all you stock)
- take the animals out of the farm for the time of the drought
- reducing herd size but keeping the heart of the breeding herd
- buy extra fodder such as maize meal and melasse
- reduce costs
- do nothing.



<u>Graph 4.2: Actions undertaken by farmers as a reaction to drought years following “normal rainfall years”.</u>

When looking at the sequence of actions undertaken when a few years of drought occurs 4 behavioral patterns appear (graph 4.2):

• First the very responsive farmers will reduce their herd immediately and eventually destock the whole farm

• Second are farmers that first prefer to evacuate their stock and in case it is not possible, they will reduce their herd, but not sell all

• Third less reactive farmers will start by doing nothing or buying fodder and will take destocking measures only in a later stage.

• Fourth are farmers that will reduce their herd size only to a certain level and will then buy fodder. Concerning the effect on the rangeland, this group and the second group can be considered as the same.

The degree of reactivity was taken into account by Janssen (2004).

At the end of the 1980’s just before Independence of Namibia, carrying capacity of all rangelands of Namibia have been calculated by agricultural staff and communicated as a guideline for farmers to use a basic carrying capacity of their veld.

The relationship between the behavior towards 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.

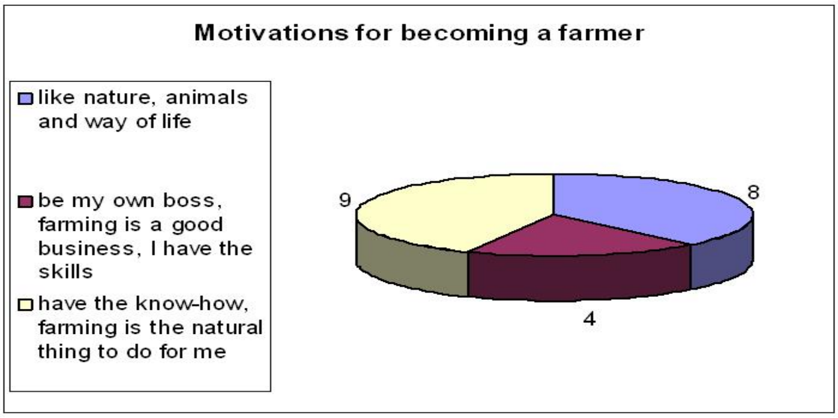
Farmers might be responsive in case of drought and less responsive in case of high rainfall event or vice versa. The combination of choices in both types of events leads to 5 different behavioral groups as described in the table below:

Table 4.1: 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 situations; in case of above rainfall years, dynamic but constrained response	Veld farmer, all is done to protect the veld	I1, I10; I13, I4	4
Category 2	Very reactive to both high and low rainfall. Respondants are mostly double actives or speculents	Highly reactive farmer	I21, I3, I20, I8	4
Category 3	Slower reaction to drought but quite responsive to high rainfall. Respondants are mostly full time farmers.	Risk taking farmer	I11, I16, I2, I17, I5, I6	5
Category 4	Static or limited response to above rainfall years and reactive but delayed or constrained response to low rainfall years	Equally reactive farmer (for drought and rainfall)	I18, I12, I14, I19, I6, I22	6
Category 5	Static response. Full time farmers farming at low stocking rates.	Stable herd farmers	I9, I7	

This descriptive analysis of veld management and farmer behaviors allows us to reveal potential elements of the farming system that influence good veld management. These were rainfall, dependence on farm income, personal financial needs, level of knowledge and understand of the *veld*. Then as suggested by the categorizing of farmers behavior and suggested in the interviews of 2006, the type of farmer, his personality and his values certainly influence his strategy. Some farmers consider it their duty to care for the rangeland and insure its good condition, whereas others see it as a business. This dichotomy is also present when regarding the reasons why farmers decided to engage in farming (graph 4.3).

Graph 4.3: Why did farmers want to become a farmer ?



Interestingly all types of factors revealed here have been described thoroughly and are part of the conceptually framework of Leuuwis (2004) for the analysis of farmers' practices: that is among others: social [and economical] environment, the farmer's knowledge and values, and a feed back from the condition of the resource.

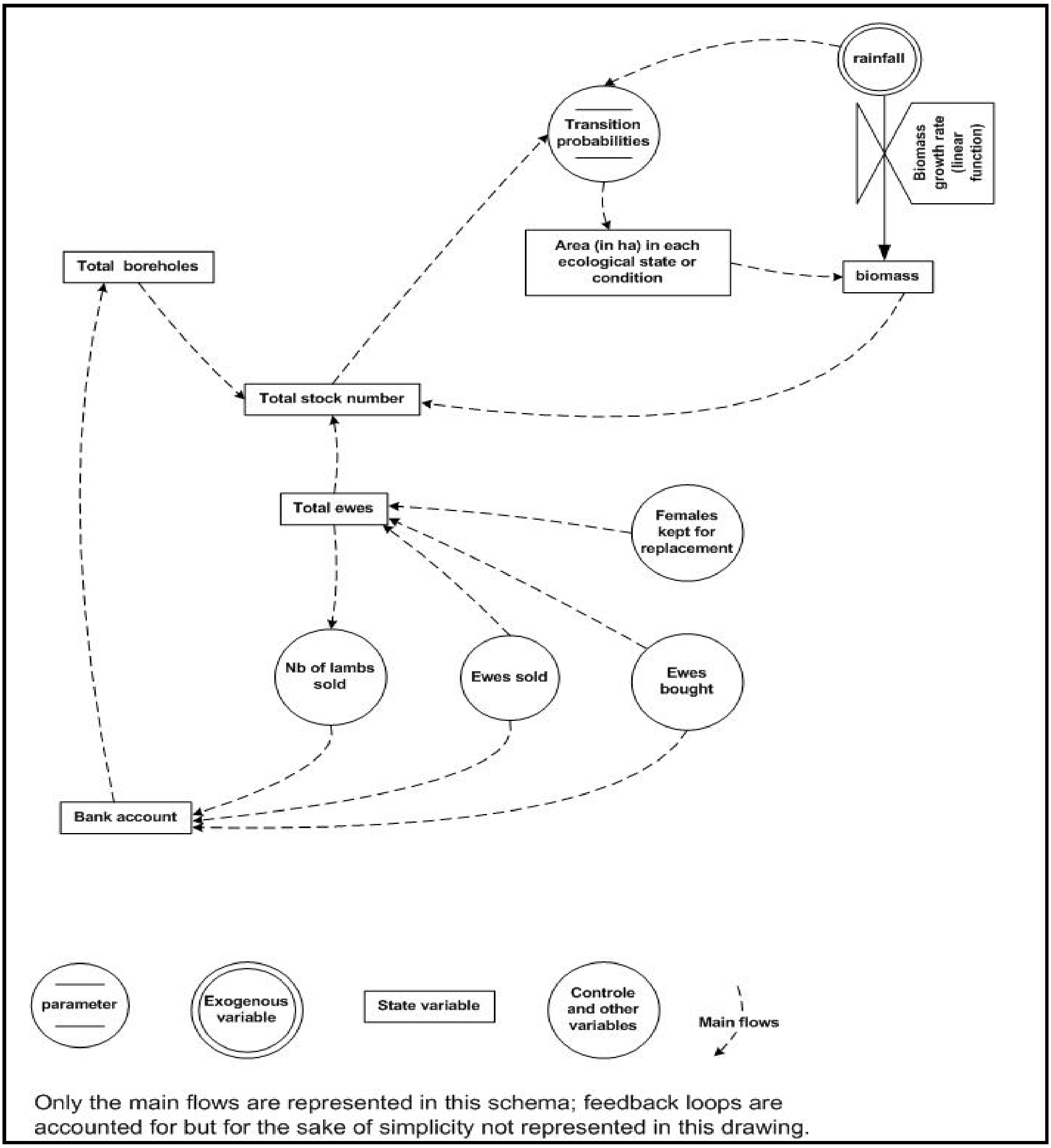
Modeling can help to quantify the impact of some of the those factors. The following chapter is about modeling a typical farm for the area and checking the impact of the level of needs and dependence on farm income on the overall strategy used.

5. A bio-economic model for a typical farm of the Keetmanshoop region

Model goal: The goal of our bio-economic model is to deliver some quantitative information concerning the impact of the level of income needs of farmers and their reluctance to de-stock, which can be related to their dependence on farm income, on long term strategies concerning stocking rate and sustainable veld management.
Type of system: Our system is dynamic, with a stochastic element: rainfall. The system is unstable because of positive feedback that are taking place in animal production and the biomass production module. Finally it is transient, since the condition of the resource changes over time.
System boundaries: The scale of a study, the basic spatial unit chosen for it and the geographical position of the study site have an impact on the results and their validity as both ecological and economic dynamics are influenced by the landscape (Okumu 2004, Bockstael & al 1995). The boundaries of the ecological system has no reason to correspond with the economic system and the same holds for a relevant projection time frame: a compromise must therefore be accepted when modeling only with one module, which can reduce the results' relevance (Bockstael & al 1995). In literature, basic units of model vary from the farm with its specific fields (van Wenum & al 2004) to the landscape (Bockstael 1995) or watershed (Okumu & al 2004). As our research focuses on management practices at the farm level, we define our system boundaries as the farm boundaries themselves. The system is not a real farm, rather it is a hypothetical farm that could exist in the study area. Our farm's soils and topography types are typical for the area. We model over a period of 30 years because farmers most often plan to give the farm over to their children (Buss, 2006).

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.

Diagram 5.1: Simplified flow diagram for the main variables of the farm model (own diagram)



The model is programmed to simulate farmer decisions on stock numbers over a 30 years period, assuming first an income maximization behavior. Pastoral activities include goats and meat sheep (dorper), the 2 most popular productions in order to illustrate the issue of stocking variations on the farm.

Model parameterization was done with interview results on input-output relationships. All data 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).

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)	5	10	0	0	**=< 7680 (3 Working Units)**
Land (ha)	3, 5, 7 ha per 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	**Maximization**

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

1. 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. Droughts occur regularly, with very negative effects on herds of course but also on bushes (Milton and Hoffman 1993).
The region of Keetmanshoop has a very high variability in rainfalls rendering farming a challenging activity. 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. Rainfall data for nearly the last 100 years were collected at the Keetmanshoop meteorological station.

$$Raintr = \ln(Rain)$$

where

Raintr is the transformed rainfall
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

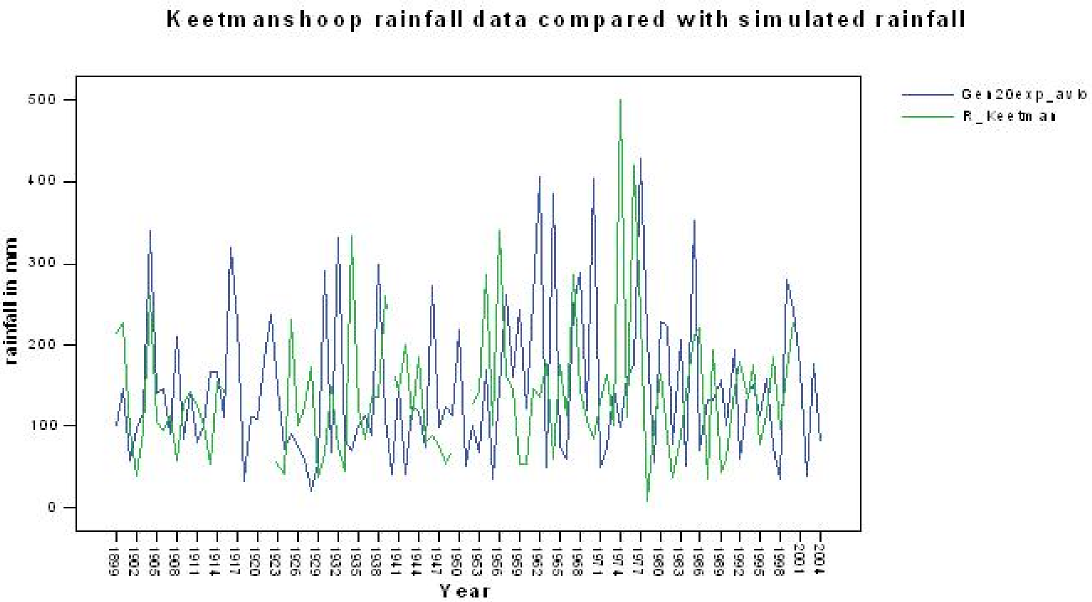
$\sigma(Raintr)$ is the standard deviation of the transformed rainfall data
$m(Raintr)$ is the mean of the transformed rainfall data.

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 :

N	Valid	88
	missing	18
Mean		4,7669
Standard deviation		,63768

We incorporate the “incompleteness” of the gamma distribution of the real rainfalls by adding 20 to the computed rainfall and by altering slightly the mean to the value of 4,7588. The simulated rainfall match relatively well the real rainfall data (Graphic x, in green observed rainfall and in blue simulated rainfall):



<u>Graph 5.1: Simulated versus real rainfall data for the area of Keetmanshoop (own simulation)</u>

Biomass calculation 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.

$$Biomass_{t,ly} = restbiom_{t-1,ly} * 0.66 + \sum_{s} (RAIN_t * biomassCoef_{s,ly} * HAstate_{s,t}) / 1000 \quad (1)$$

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.
$Hastates_{s,t}$	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 (same problematic in 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.

2. Veld 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 stocking. 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 s a series of 6 states based on the grass and bush cover and the presence of bare ground in an interdisciplinary effort jointly with Namibian rangeland experts. These states represent the possible ecological condition of the rangeland. Coefficients representing the impact of rainfall and grazing on the veld were calculated in a detailed dynamic and spatial explicit vegetation model, developed for the study area by A. Popp. This model is described in detail in a paper being drafted at the moment, thus we won't discuss it here. Among other results the model allowed the calculation of a series of probabilities of change in the form of transition matrix. This transition matrix is of the form (for instance) :

	$S1_t$	$S2_t$	$S3_t$	$S4_t$	$S5_t$	$S6_t$
$S1_{t+1}$	0.5					
$S2_{t+1}$	0.5	0.7				
$S3_{t+1}$	0	0.2				
$S4_{t+1}$	0					
$S5_{t+1}$	0	0.1				
$S6_{t+1}$	0					

Columns are showing the state or condition of the rangeland in year t, and lines are showing the condition of the veld in year t+1. Such a matrix is calculated for each type of animal kept and for 4 rainfall classes. Each cell gives the transition probability for one ha of land in state s to change into another state sfin (sfin is the alias set for s) and is rainfall class specific, animal specific and stocking rate specific: this brings the number of transition matrixes included in the model up to 32, when working with 3 different stocking rates plus resting and 4 different rainfall classes (very low, low to medium, medium to high, very high).

In our model, the transition matrix represents the knowledge of the farmer of the chances of switches of the rangeland condition from one state to the other and based on this knowledge they can make use of opportunities or avoid threats in the management of their rangeland (Westoby & al 1989, Bestelmeyer & al. 2003, Bestelmeyer & al. 2004).

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

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

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:

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

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: 400 ha

3. 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 third constraint over animal numbers is labor availability.

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 ($lambuse_{P,\text{"replace"},t-1}$), as described in equation 6.

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

In order to introduce the fact that some farmers will never sell all their herd even in case of severe drought, we introduced a parameter HERDHEART, which prevents the selling of the whole herd.

$$eweSell_{P,t} =< ewes_P * (1-HERDHEART); \quad (7)$$

4. 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 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).

$$Fingains_t = CR * (Receipts_t - Payments_t) \quad (8)$$

With :

$Receipts_t$	yearly brut income in N$
$Payments_t$	yearly payments in N$
$Fingains_t$	financial gains (interest on surplus at the bank) or losses due loans to cover up needs.
CR	capital costs: interest rate if the cash status is positive, cost of capital in the case of a negative cash status.

The objective function gives the value to be maximized (Obj2). It is composed of 4 parts:
The discounted sum of the receipts minus payments. Prices used in the objective function for the ewes bought from the market is higher than the real financial price that can be expected: this is to account for the reluctance of the farmer to sell its herd due to the genetic material and health quality lost in the process of selling and buying fully new animals for the farm (ecpayments). Comparatively to the sell price this value is higher for the karakul than for meat animals, since it requires important breeding efforts to produce quality pelts.
The discounted financial costs or gains, as explained above**.**
The discounted value of land reflects the value of the land in each range quality, including all potential uses, at the end of the simulation period. It is given initially by the shadow price of each quality of range. The value of land in its specific range quality is attributed through an iteration process as done by Buss (2006). In a first run marginal values are assigned to the land in the optimization process. In a second run the land’s marginal value of the first time period is assigned to the last period of the second run and the model is run again. It is to be expected that the marginal value of the land in the first period is affected by the value assignment in the last period. We repeat the process 2 times, the value is already stable, as Buss observed in his own work (2006).
The discounted value of home consumed animals estimated at selling price + transport costs.

$$obj2 = \sum_t [\ (receipts(t)- ecpayments(t)) + fingains(t)$$
$$+ \sum_p Lambuse_{p,"selfcons",t} * SELFCONSVAL$$
$$+ \sum_s (T\_C_{s,t} * HAstates_{s,t}) \ ]$$
$$* (1/((1+IR)**ord(t))) \quad (9)$$

with

$ecpayments_t$ variable of total yearly payments using "economic" prices for sheep bought.
$Lambuse_{p,"selfcons",t}$ the number of lambs kept on the farm for self consumption
SELFCONSVAL economic value of self consumed lambs.
$T\_C_{s,t}$ value of the land depending on its ecological state.
IR the discount rate, reflecting the time preference of farmers.

Time preference is related to how important short term income is to the person versus long term income. This discount rate is difficult to estimate correctly and is often taken as equal to the interest rate in a stable country where financial markets work well. In case of political uncertainty or high poverty this rate can change. We use the actual interest rate in this baseline scenario.

6. Model results and discussion:

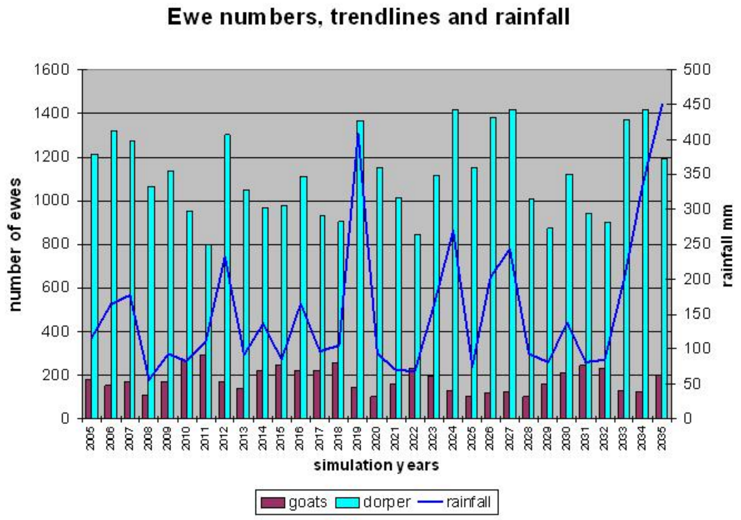
Model calibration was done thanks to a second round of interviews with experts, where model results were discussed. Interviews consisted of individual interviews of experts and 2 group interview, the one with the members of the regional NAU (National Agricultural Union) council during their meeting in May 2006 in Keetmanshoop. All comments were recorded and used together with the analysis done in the previous paragrpah to adjust the model's behavior to a realistic pattern. Validation by expert knowledge has been used by Unterschultz (2006) and Buss (2006).

Our goal is to test the impact of 2 parameters, which according to the previous analysis should have an importance on the rangeland condition. These are the level of fixed costs, indebtness, personnal household needs to represent farmers at different stages of their carrier and life on the one side, and the reluctance to destock on the other which represents different types of farmers as described in the previous chapter: reactive to drought (farmer would sell all, parameter HEART HERD = 0), relatively reactive but within limits (parameter HEART HERD = 0.6) and the relatively static reaction (parameter HEART HERD = 0.8).

Baseline scenario

In a first time we use the described model with its classical objective function that maximizes income over the 30 years of the simulation period. Our baseline scenario is defined by :

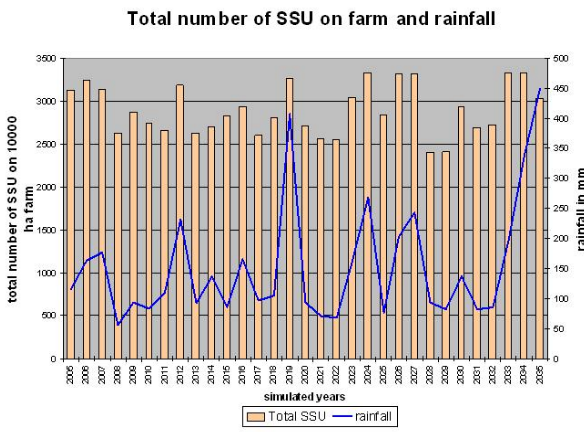
- relatively low fixed costs at the level of the farm (fixed size) and low personal needs for the farmer and his household (156 000N$ and 90 000N$ respectively). This is the case with farmers who do not account for their children's livelihood anymore, who have already invested in a good infrastructure in terms of water supply equipments and camping (fencing camps), and have already paid back all or most of their agriloan for the land.
- A value of 0,6 for the parameter HERD HEART, which means that the farmer never reduce his breeding herd of more than 40%.



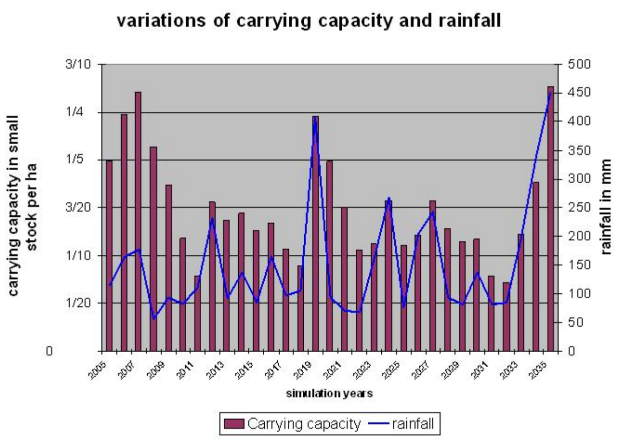
The model farmer both sheep and goats keeps as observed on the field.
The goat herd is increased relatively to the sheep herd in the drought and the sheep number is then reduced. This pattern follows the availability of fodder and supported by the fact that goats are more resistant to drought. Total ewe numbers are following the rainfall pattern, as ewes are being sold in the drought years.

Graph 1: Simulated ewe numbers and rainfall

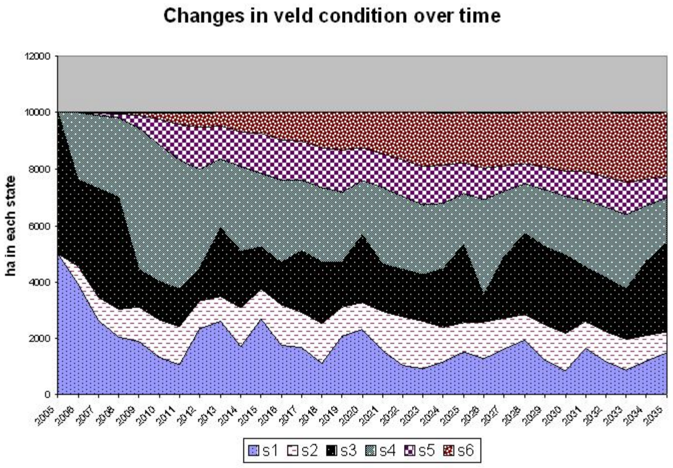
Total stocking intensity is given in Small Stock Units and accounts for all lambs, rams and ewes present on the farm in each period. The applied stocking rate is following rainfall but relatively stable on the long term, although the calculated carrying capacity decreases. The stocking rate of 2500 to 3500 SSU on the farm is slightly high compared to what is observed on the field. The brut income varies between 400 000 and 800 000 N$, which is high but still acceptable from a validation point of view, however the balance is always positive, which is usually not observed. These results are rendered possible by the purchase of fodder to a lesser extent but to a greater extent by the extraction of resources: indeed the result is veld degradation with far lower land productivity (graph 6.3) and poor range condition (graph 6.4) at the end of simulation period.



Graph 6.2 : Simulated stocking rate in small stock units and rainfall



Graph 6.3: Simulated carrying capacity and rainfall



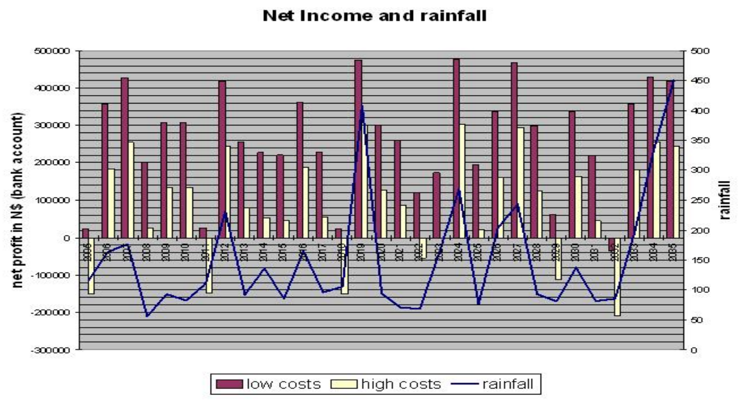
S1 and S3 are the most productive states of rangeland and also potentially the most bio-diverse. However under dry conditions and important stocking rates they degrade quickly to s2 and s4. This trend can be reversed if the farmer uses lower stocking rates. As we can see in our case, this is seldom the case and the range of the model farm degrades quickly to the fully degraded states 5 and 6..

Graph 6.4: Simulated rangeland condition changes in time

Note that the model farmer never makes use of resting and seldom of low stocking rates.

Second scenario:
We now increase the level of fixed costs on the farm that account for the payback of loans for the land at first, for additional infrastructure and renovation of housing for instance. The price of the land depends on its condition and carrying capacity, following the agroecological zooning of Namibia and valuations of experts on the terrain. In our case the carrying capacity at the beginning of the simulation approximates one small stock unit on 3 to 4 ha (1SSU/3 to 4 ha) which is a good carrying capacity for the area. Following examples of transactions obtained at the ministry of lands and resettlement in Keetmanshoop (exact source is confidential), an probable price would be 180 N$ per ha, so 1 800 000 N$ for the farmland. An additional 400 000 N$ for the existing infrastructures brings the total to 2 200 000N$ which is a payback of 120 000 N$ per year for 20 years if we use an interest rate of 10% as obtained at the agribank (source: interview data). We also increase the needs of the farmer from 90 000 N$ per year to 150 000 N$ which seems more realistic for younger farmers.

The result is that the stocking strategy does not change, the stocking load is the same, and the degradation caused to the veld exactly comparable. However the bank account changes and the farmer simply makes less profit over the 30 simulation years (graph 6.5).



Graph 6.5 : Simulated net profit in the case of low fixed costs and higher fixed costs

Such a strategy and its consequences on veld condition can be considered to illustrate behaviors of farmers in category 2, since the model farmer reacts to both drought years and above rainfall years, still he does not sell all his stock nor buys extra stock from outside the farm more than 3 times. Behaviors of category 3 and 4 can maybe also be related to this type of strategy on the veld. This is a maximization strategy where farming is seen as a business and risks are taken in order to increase the income: indeed following rainfall by increasing the herd importantly always involves taking a risk regarding rainfalls of the following year, and needs to de-stock.

Third scenario:
We now introduce variation in the parameter HEART HERD, which limits the model farmer in the selling if his stock in case of drought as to represent reluctance of farmers to reduce their breeding herd and loose the breeding characteristics of their herd. As a result we observe no change in the stocking strategy where the farmer increases and decreases his stock according to the same pattern but with less variability as the parameter heart herd increases. The impact on rangeland condition is also extremely similar to the baseline scenario. Table 6.1 shows the difference between the final deposit in the bank account at the end of simulation time. According to this criteria the best option is the one that gives the more freedom to the farmer. Note that although the farmer has the freedom to sell his whole stock when the parameter herd heart is set to 0, he does not : apparently the optimum strategy when maximizing income is to always keep some stock on the farm, but to reduce the stock immediately in important proportions which is uncommonly done by farmers. However the difference between the scenarios is minimal.

Parameter Heart Herd value	Bank account in N$
0	33 767 358,7
0,6	32 151 871,9
0,8	29 780 340,4

Table 6.1: Level of liquidities in the simulated bank account of the model farmer at the end of the 30 years of simulation time.

The level of liquidities in the simulated bank account can appear to be very important: note that the model does not take into account extra needs for investments on the farm such a new farm house or vacation or new personal car, which can temper this result. More importantly we have to bare in mind that this result was achieved by mining the resources: the level of degradation on the farm after the 30 years of simulation is very important. At the end of simulation nearly 2000 ha are turned into desert and the change is only very slowly reversible. Many interviewed farmers claim 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 (veld condition 2) (14/16 interviewed farmers). In addition we have seen that the level of needs and fixed costs that have to be supported by the farm are not affecting models outputs in terms of stocking strategy and veld degradation. This leads us to question the validity of the commonly used approach to attribute a maximization behavior to the farmers. This behavior might apply to some farmers, but others – and not exceptions – might have another approach.

Adjustments to the objective function for a better fitting to farmer behavior:
We choose to redefine the objective function to fit our vision of the so-called veld farmer, as a farmer stated:

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

Batabyal (2005) also suggests that farmer will tend to minimize the time that their rangeland veld is in a middle condition with the risk of shifting to a worse one.

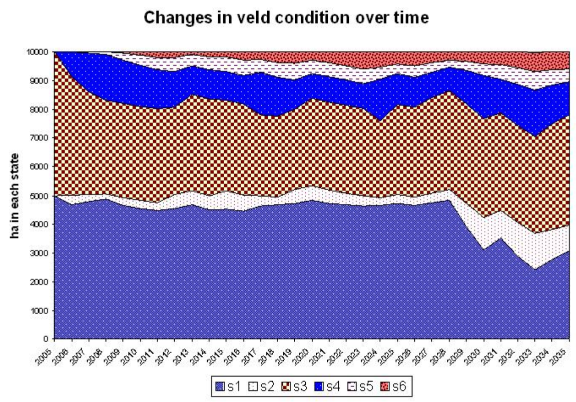
The new objective function is fairly simple and maximize the amount of land in state 1 and 3: the 3 range conditions that are the most bio-diverse and profitable for farming. We do not use a discount rate.

$$obj3 = \sum_{t} Hastates_{"s1", t} + Hastates_{"s1", t} \qquad (10)$$

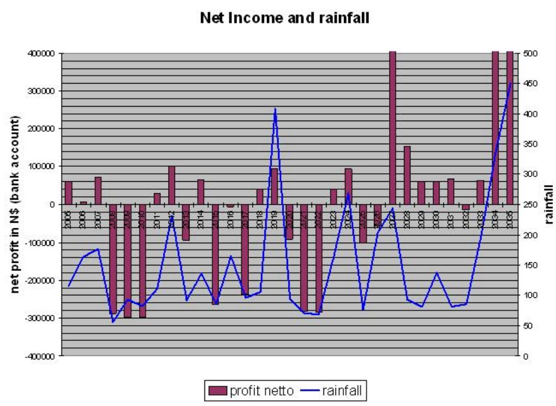
We also introduce a complementary constraint on the income that must be generated :

$$\sum_{t} (receipts_t + fingains_t) =G= \sum_{t} payments_t \qquad (11)$$

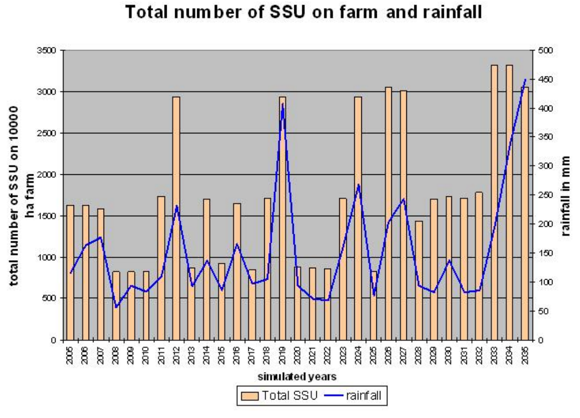
baseline scenario
We use the same baseline scenario as previously for comparison. With low costs, a farmer is able to maintain his farm to a very good state of his rangeland and still covers his costs over the simulation period. The impact on the income is expected: annual profit rises to levels of 700 000 N$ occasionally but can also be lower than 100 000 N$. According to the results of group interviews with experts one can expect to have nearly as many years of losses as years of gains. In the presented case we have slightly more years of losses than of profit, which indicates s weakness the model. However it is closer to reality than the maximization model taken under the same constraints (Heart Herd = 0.6).



Graph 6.6 : Simulated veld condition change in time (baseline scenario).



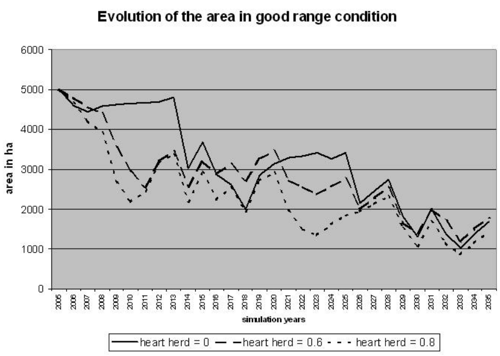
Graph 6.7 : Simulated net profit and rainfall (baseline scenario)

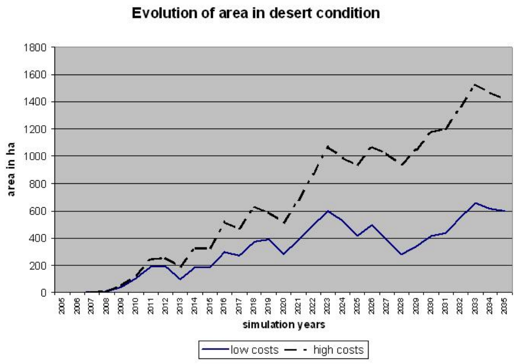


The stocking rate is relatively low (1000 to 2500) compared to what is observed in the field (between 2000 and 2500 SSU depending on the season), it is following the very low needs of the farm in the baseline scenario. However in the case of the higher needs scenario, the model delivers values of 1500 to occasionally 3000 SSU, which seems probable.

Graph 6.8: Simulated stocking behavior in SSU per ha and rainfall (baseline scenario)

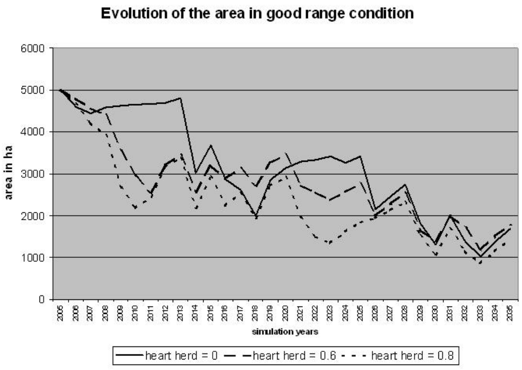
We test the impact of the 2 same parameters using this new objective function on the baseline scenario. They both appear to be sensitive as far as veld degradation and stocking strategies are concerned.

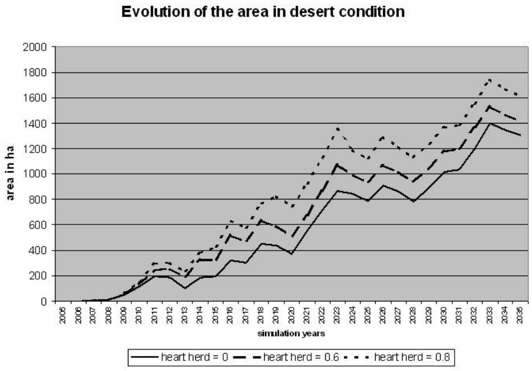




Graph 6.9: Impact of the level of fixed costs on the veld condition: evolution of area in range condition 1 with high and low needs, and evolution of area in range condition 6 with high and low needs.

The level of fixed costs on the farm affects negatively the rangeland condition in the long run: desertified areas increase from simple to double.





Graph 6.10: Impact of the reluctance to destock on veld condition when fixed costs are high

The optimal veld condition is found in cases where stock numbers can be seriously reduced, so presumably in reality on farms that do not represent the sole income of the owner. Where the stock number must be kept high we found in greater area of degraded range and smaller portion of range in condition one. Even with a static behavior though the negative impact on the veld is significantly less than in the case of the maximizing behavior.

None of the 2 objective function deliver perfect imitations of farmers decision making. It might be advantageous for further work to keep both types of model in mind. The use of the second objective function maximizing income completed by a constraint on income allows to reproduce the different farmer behavior identified. If we consider the behavior towards drought alone, we can simulate here thanks to the heart herd parameter the different strategies that different farmers would adopt and see the consequences of them. Parameters suggested by farmers to have an impact on degradation such as the 2 tested here appear to be sensitive only when modeling with the biodiversity objective function completed by an income constraint. As a result we suggest that this objective function might a better tool as for identifying other parameters of the system that will influence farmers' strategies.

In the literature most farm optimization model use income maximization for commercial enterprises (Buss, 2006, Unterschultz, 2003, Farm resource allocation model, anonymous, are some examples) and utility maximization in the case of subsistence farmers (Mudhara, 2000, Manez 2003, Hecht, being drafted). It is a basic assumption in economic to assume that agents are maximizing their utility. The use of a bio-diversity maximizing objective function in the presented model is thus a deviation. This deviation is justified by the fact that farmers might see another dimension in their work. Stoeckel & al (1997) name it "duty of care". Their interviews with Australian farmers revealed that the Duty of Care of the farmer towards the land he manages was an emerging concept. This concept can be of great importance in countries such as Namibia and Australia where most of the surface and natural resources are being managed by a very small percentage of the population.

8. Conclusion

This paper suggests that 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. This paper suggest that income maximizing behaviors have severe impact of rangeland quality. However farmers possibly act rather as income securers and tend to maximize rangeland condition when their income needs are satisfied. In that case, farmers if facing low fixed costs might be able to manage their rangeland sustainably in the long term. It is suggested in all cases that reluctance to de-stock quickly affects the veld negatively.

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