DETERMINING GRAZING CAPACITY IN NAMIBIA WITH THE AID OF REMOTE SENSING

CELESTE ESPACH[1], L.G. LUBBE[1] and N. GANZIN[2]

[1]Ministry of Agriculture, Water and Forestry, Private Bag 13184, Windhoek, Namibia
[2]Ifremer, 83507 La Seyne, France, nganzi@ifremer.fr

INTRODUCTION

We live in an ever-changing environment, where every action or decision made by people has a reaction or consequence, be it good or bad. In a country like Namibia, many people are dependent on the environment for survival or generating an income. The interaction between farmers and their environment, which includes their social and economic circumstances and the natural world, have an influence on the sustainability of our natural resources. In turn this might also determine what type of farming can be successfully practiced in parts of the country where it is viable.

Namibian farming is practiced in different areas with a high variation in rainfall, resulting in a diversity of farming systems occurring in the country. Livestock production is the main income generating farming system in Namibia. Most farming between the 100 and 350 millimetre isohyets is limited to sheep and goats, while farming activities focusing more on cattle and crops occur in the wetter areas further north and east (Mendelsohn, 2006). As Namibia is not producing its beef and mutton intensively, grass production from natural veld is considered to be the main forage for livestock.

In 2005 the Ministry of Agriculture, Water and Forestry, more specifically as a result of collaboration between the Pasture Science and Analytical Services subdivisions in the Directorate of Agricultural Research and Training (DART), initiated a pilot project where various approaches and methodologies were tested to determine grazing capacity (GC). This pilot project ended in April 2010, even though the period of 5 years is considered insufficient to capture all the variations in the rainfall pattern and its effect on grass production.

During the 5-year period (2005/06 to 2009/10) the applied approaches and methodologies became clearer as well as more practical. A number of lessons were also learned; not only from the actual work itself but also from and of the people involved. More specific but still subjective parameters were defined for refining the Total Seasonal Biomass Production (TSBP) corrected with Woodiness (W), Accessibility (A) and Palatability (P) methodology. Some land cover units changed, while some no longer existed (some land cover units were not there from the beginning) or just did not exist according to the classification that was done in 2005.

This is the final article on the work that was done over the past 5 years. The methodology used for each of the components will be fully explained, except for the land cover mapping component since an article regarding this aspect was already published in the Agricola of 2006. However, more focus and emphasis is placed on a better description of the pilot area, especially on environmental factors such as rainfall, vegetation and soil, all of which have a tremendous influence on grazing capacity.

BACKGROUND

Pilot study area overview

The pilot study area is situated in the eastern part of Namibia, between Windhoek and Gobabis. The area covers a one- by one-degree square (S22°–23° and E18°–19°) which is approximately 100 km² in size.

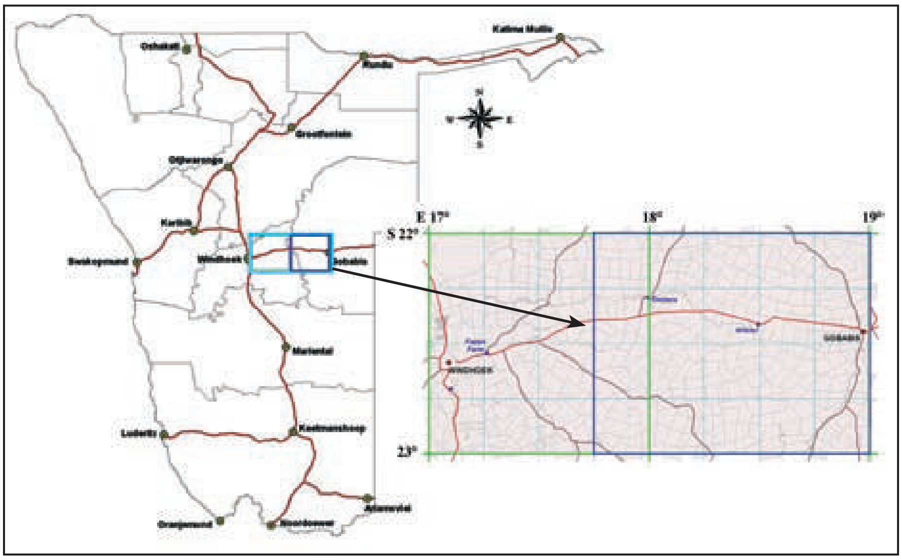

Figure 1. Pilot study area in the eastern part of Namibia. Grazing capacity pilot study area is indicated in dark blue, whilst the light blue indicates the "Quantification of Land Production Potential" pilot project area.

The pilot study area (Figure 1) formed part of a bigger study area which in turn was part of the Quantification of Land Production Potential (QLPP) project which commenced in 2005. The QLPP was a project initiated by the Ministry of Lands and Resettlement and carried out by the Ministry of Agriculture, Water and Forestry. The aim of this project was to develop practical methodologies, with the aim of expanding it to a national level, for the production of quantitative data on land productivity as inputs for land use planning, land valuation and the land taxation programme in Namibia. This specific area was considered most suitable for the QLPP pilot area, for the following reasons:

- The area contains a wide range of vegetation types and landscape habitats;
- it is located within easy reach of Windhoek in terms of travelling distance and time;
- it is located within the associated soil, vegetation, infra-structural, biomass and socio-economic components; and
- various land tenure and land use systems exist in the area.

The QLPP consisted of several components, of which the land cover mapping and Total Seasonal Biomass Production Estimations formed an essential part for the grazing capacity pilot project.

1. Land Cover Mapping

The land cover mapping was done using Landsat 7 ETM+ satellite imagery. The QLPP pilot area is covered by two satellite paths of the Landsat 7 sensor. To reduce the costly and time-consuming task of accurately edge-matching the sets of digital data from different acquisition dates covered by these two paths, it was decided to focus only on path 177 and its two corresponding row scenes (075 and 076 with the same acquisition date) for the land cover mapping component.

Multi-temporal, by definition, implies at least more than one image acquisition date, and often – in terms of global or continental land cover (vegetation) mapping – refers to an entire sequence of images over several seasons (Townsend and Justice, 1988). The objective is to define periods which will maximize the variation between important (but not necessarily dominant) cover types, whilst minimizing any possible error-inducing effects, such as enhancing cloud and shadow coverage, or rainfall-induced local abnormalities in vegetation conditions (Thompson *et al.*, 2001).

The result was the identification of ten satellite images which represented the wet and dry periods of 2001 and 2002. A Tasselled Cap Transformation was applied to these ten selected images, which offers a way to optimize data viewing for vegetation studies. After various calculations and graphs, it was decided that the Tasselled Cap greenness median values would be used as prime indices for spectral vegetation class delineation.

Through the signature separability function, reports were generated for two-, three-, four- and five-band combinations (where the band is the respective satellite image). The result was a combination of three bands which gave the best separability between the different land cover classes. These bands were represented by satellite imagery of 2001/11/21, 2002/01/08 and 2002/04/30.

The maximum likelihood algorithm was chosen as the parametric decision rule on which to run the supervised classification. One advantage is that it is the most accurate of all the classifiers (if the input samples have a normal distribution), because it takes the most variables into consideration by making use of the covariance matrix.

The land cover mapping project provided an additional dimension towards enhancing the accuracy of the information generated on rangeland resources by allowing differences in vegetation types and, therefore, rangeland types that had to be taken into account. This information was used to improve the methodology for estimating seasonal biomass production, as it contributed to one of the WAP parameters. Land cover information is the basic, indispensible layer of information that allows the further processing of total (raw) biomass production, and to differentiate between the grazable and non-grazable vegetation (Figure 2).

2. Farming Systems and Landownership

Namibia can be broadly divided into four major farming systems to illustrate the variety within the agricultural sector.

According to the Food and Agriculture Organization (FAO), as cited by Mendelsohn (2006), "A farming system is defined as a population of individual farms that have broadly similar resource bases, enterprise patterns, household livelihoods and constraints, and for which similar development strategies and interventions would be appropriate".

The pilot study area falls within the farming system of cattle ranching. The main purpose of cattle ranching is the commercial production of beef. About 315 000 km^2, or 38 % of Namibia (Figure 3), is used for cattle ranching.

Cattle are farmed for beef on a substantial scale in three distinct areas of land tenure within this specific farming system. The first and most widely recognized area is the extensive, freehold, titled cattle ranches that cover much of central Namibia. There are about 2 400 of these farm units. Those in areas formerly allocated to white owners have an average size of about 7 300 ha. The farm units are bigger than the registered farms. For example, among the 53 owners of registered farms between Windhoek and Gobabis, 16 of them leased other farms or sections of farms. By leasing farms or sections of farms, these 53 owners have enlarged their farming units from an average of 5 248 ha to 8 459 ha (Mendelsohn, 2006).

A second area comprises farms that have been fenced off into exclusive ranches in communal areas, each of which

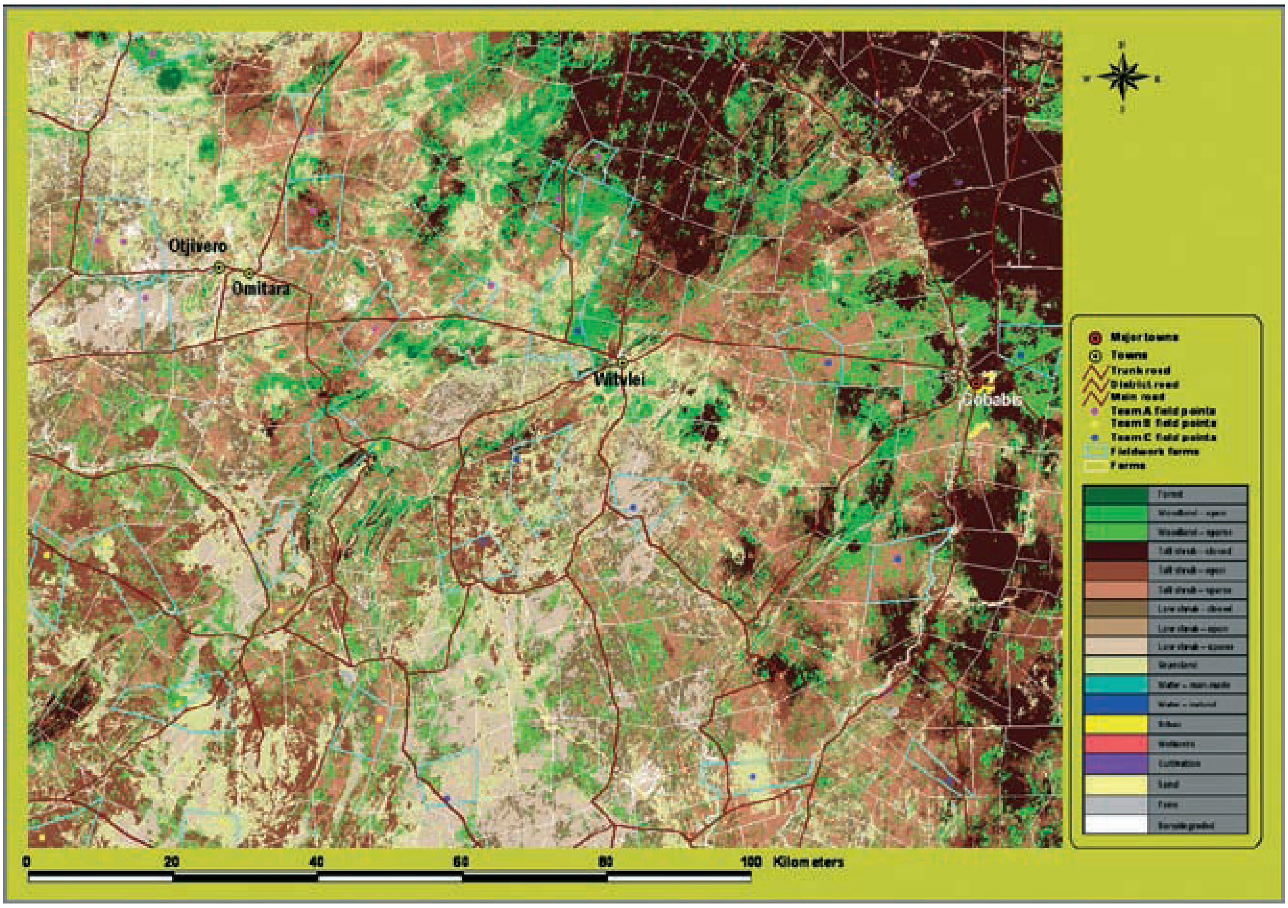

Figure 2. Land cover map of pilot area produced during 2005.

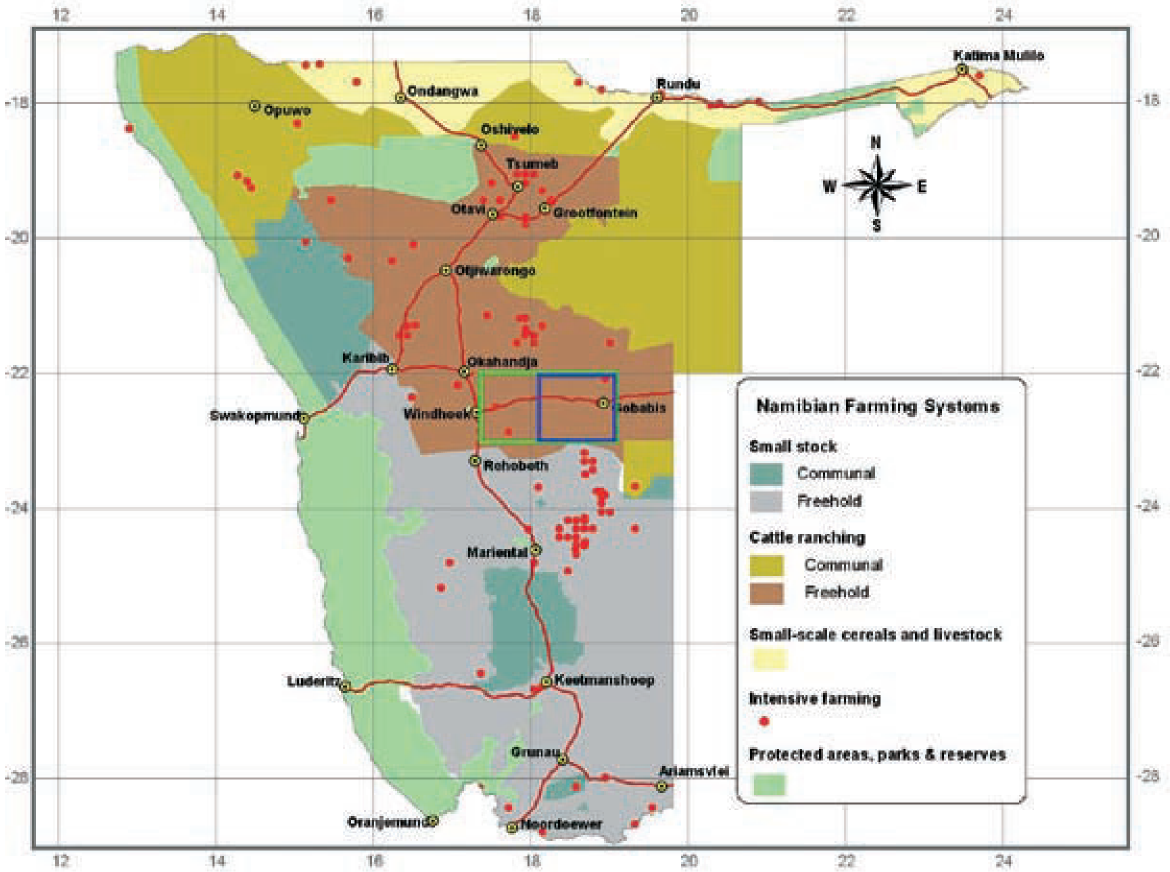

Figure 3. Cattle ranching as a farming system, which is divided into communal and freehold land. The QLPP study area is indicated in green, whilst the grazing capacity pilot study area is indicated in blue.

ranges between approximately 1 000 ha and 8 000 ha. Some were demarcated by the previous government and allocated to farmers between the 1960s and 1980s to encourage commercial agriculture on communal land (Mendelsohn, 2006).

The third area is made up of farmers using open access grazing on communal land, mostly northern Kunene, eastern and northern Otjozondjupa, northern Omaheke and the Aminuis Block. Little infrastructure is available for cattle farming in this area. Water is supplied from boreholes, most of which are found at widely separated points close to villages. All the people and all the livestock share these water points, causing overgrazing and trampling close to the water.

Conditions on the exclusive ranches in communal areas are better. The originally demarcated farms were fenced and each was supplied with a borehole and reservoir. Some owners of the newer ranches have established water sources, housing for labourers and fenced off camps to manage grazing on a rotational basis.

Infrastructure on freehold farms is far better than the other two groups. Good roads provide easy access to most of these farms, which have telephones and electricity from the national grid, or even generators. Each freehold farm has a relatively dense network of water resources (Mendelsohn, 2006).

Although three groups are distinguished within this specific farming system of cattle ranching (as opposed to the two indicated on the map), the differences between them are disappearing. Farmers in communal areas fence off big ranches, farming more as commercial producers on freehold farms than owners in open access rangelands. The opposite of this is where freehold farms are used to resettle people from communal areas (Figure 4). The farming units allocated to each family are generally too small to produce beef on a sustainable or economically viable scale. Many former freehold farms are now functioning as subsistence rather than commercial units (Mendelsohn, 2006).

From the foregoing, it is clear that different types of landownership exist. The importance of this aspect is that it also affects the way land is managed, and therefore it can be expected that huge variations in grazing capacity will exist amongst the different landownership forms.

Some major factors that influence grazing capacity

1. RAINFALL

Rainfall has a major impact on vegetation in Namibia, as it is a semi-arid to arid country. The role and importance of rainfall dominates all other climatic factors. The amount of rain declines in a rather smooth gradient from the wettest and most tropical areas in the north-east (± 700 mm) to the extremely arid Namib Desert in the west (< 50 mm) (Figure 5). Rainfall occurs mostly during sporadic thunderstorms in the summer months from October to April. Much of the moisture that finds its way into Namibia does so infrequently and unpredictably. Namibia is a country in which low and variable rainfall is normal, and droughts are frequent and to be expected (Mendelsohn *et al.*, 2002). This makes it difficult for a farmer as he must constantly adjust his livestock numbers to available forage.

The predominant effect of rainfall on farming is simple: rain determines how much water is available for plants to grow, and subsequently, the number of animals that can be supported in any one area. Each millimetre of rain results in the production of between 1,2 kg and 2,3 kg of grass per hectare, as measured on several farms in Namibia.

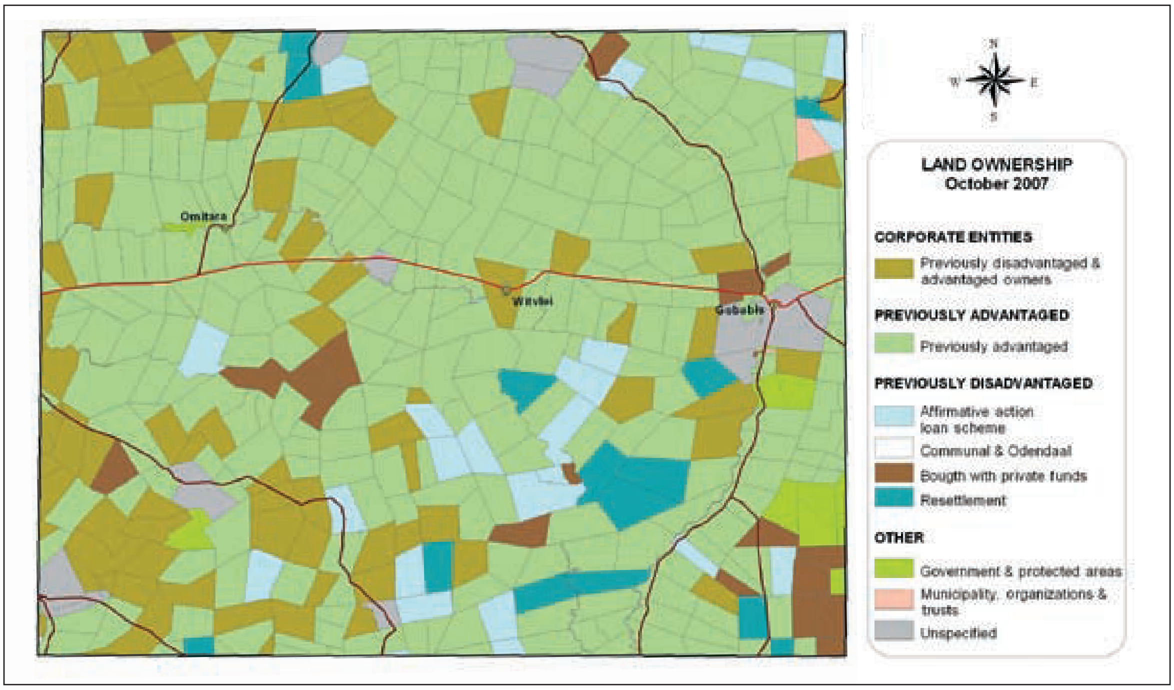

Figure 4. Landownership (October 2007) in the pilot study area.

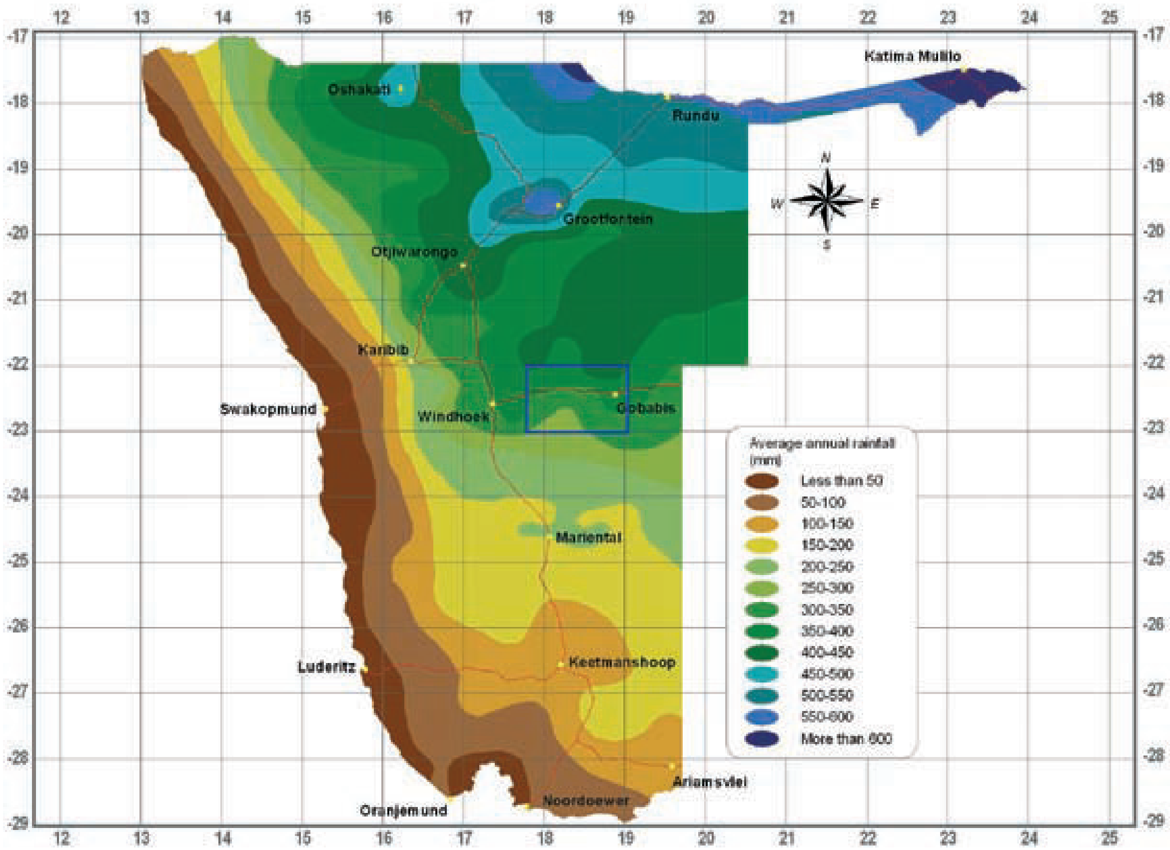

Figure 5. Average annual rainfall of Namibia.

Differences between the lowest and highest figures are mainly due to differences in soil fertility and degree of bush density (Mendelsohn, 2006). More rain leads to more forage, which allows for higher stocking rates, faster livestock growth and production, and quicker marketing of cattle, sheep or goats. A succession of wet years may lead farmers to build up their herds. When conditions become drier, they might be reluctant to reduce the livestock. It is often said that the degradation of farms is due to continued over-stocking after farmers had optimistically increased their livestock numbers during good years. Furthermore, depending on the condition of the rangeland (which is often a reflection of the managerial skills of the land user) at the onset during and after a drought, grazing capacities may vary hugely from farm to farm in the same area.

Evaporation has a counteracting effect on water availability. The greatest volumes of water generally evaporate in areas of the lowest rainfall where the air is driest. Subtracting evaporation from rainfall can be a measure of water deficit. The distribution of water deficit is broadly a mirror image of rainfall. The highest water deficits occur in the south-east of Namibia, rather than the very arid Namib (Mendelsohn, 2006).

2. Soils

Namibia is an arid country and therefore its soils are not well developed. If the conditions had been wetter, the soils would have been better developed and would have contained more nutrients (Mendelsohn *et al.*, 2002). The absence of good soils do have a constraining influence on farming in Namibia, perhaps just as limiting as the low and variable rainfall. This is true for both crops and the natural vegetation on which farm animals graze.

Based on soils, the country can be divided into two zones: soils derived from rocky areas in the south, central and much of the western regions; and the Kalahari Sands that dominate the eastern and northern regions.

The pilot area falls within the Kalahari Sands group which dominates the eastern and northern regions. In the pilot area, there are four major contributing soil groups (apart from the rocky outcrops and the fluvisols).

Arenosols are formed from wind-blown sand and usually extend to a depth of at least one metre. Sand makes up more than 70 % of this group. The sandy texture allows water to drain through the soil rapidly, leaving very little moisture at depths to which the roots of most plants can reach, and therefore few nutrients are retained. The loose structure of sand means there is little run-off and water erosion, although it makes the soils susceptible to wind erosion (Mendelsohn *et al.*, 2002).

Cambisols are soils that were formed mainly from medium- and fine-textured parent material deposited during sporadic flooding. Since the parent material is only slightly weathered, there is an absence of clay, organic material, aluminium and iron. Nevertheless, cambisols are usually moderate or high in fertility, because of their good water-

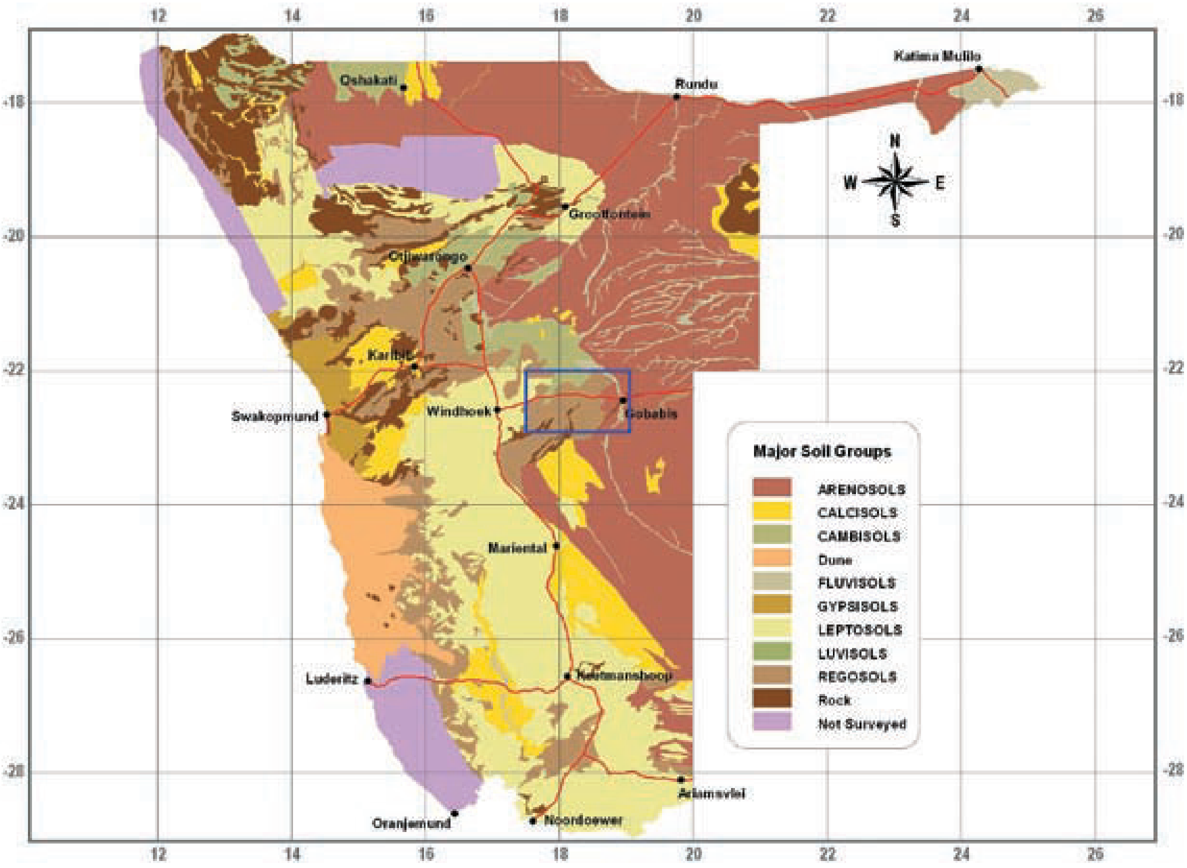

Figure 6. Soil characterisation of Namibia.

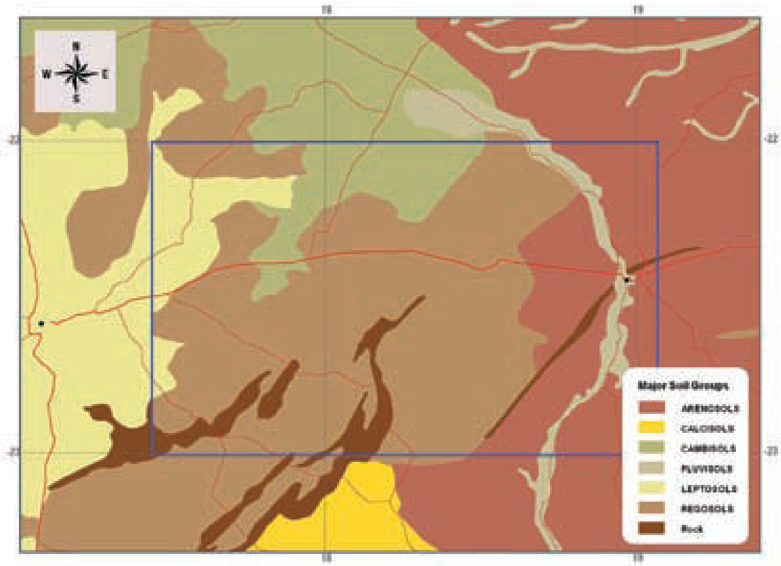

Figure 7. Soil characterisation of pilot area.

holding capacity and internal drainage (Mendelsohn *et al.*, 2002).

Leptosols typically form in actively eroding landscapes, especially in hilly or undulating areas that cover much of the central, north-western and southern parts of Namibia. These coarse-textured soils are characterised by their limited depth caused by the presence of predominantly hard rock which is highly calcareous within 30 cm of the surface. Leptosols are the shallowest soils in Namibia and they often contain significant amounts of gravel. As a result, their water-holding capacity is low, and vegetation is often subject to drought. Rates of water run-off and water erosion can be high when heavy rains fall. At best, these soils can support low densities of livestock and wildlife (Mendelsohn *et al.*, 2002).

Regosols are medium- or fine-textured soils of actively eroding landscapes, the thin layers lying directly above the rock surfaces from which they formed. Although not as shallow as leptosols, these soils never reach depths of more than 50 cm. Vegetation cover on these thin soils is generally sparse because they cannot provide most plants with sufficient water or nutrients. Areas with regosols are able to support low-density stock farming or wildlife (Mendelsohn *et al.*, 2002).

3. Vegetation

Physical features, such as climate, soils and topography largely determine the abundance and diversity of plants and animals. Most plants and animals have developed mechanisms to survive and even thrive in Namibia's arid conditions and unpredictable rainfall. Plant growth often varies a great deal from month to month and year to year depending on the amount and distribution of precipitation. This has huge implications for humans, livestock and all

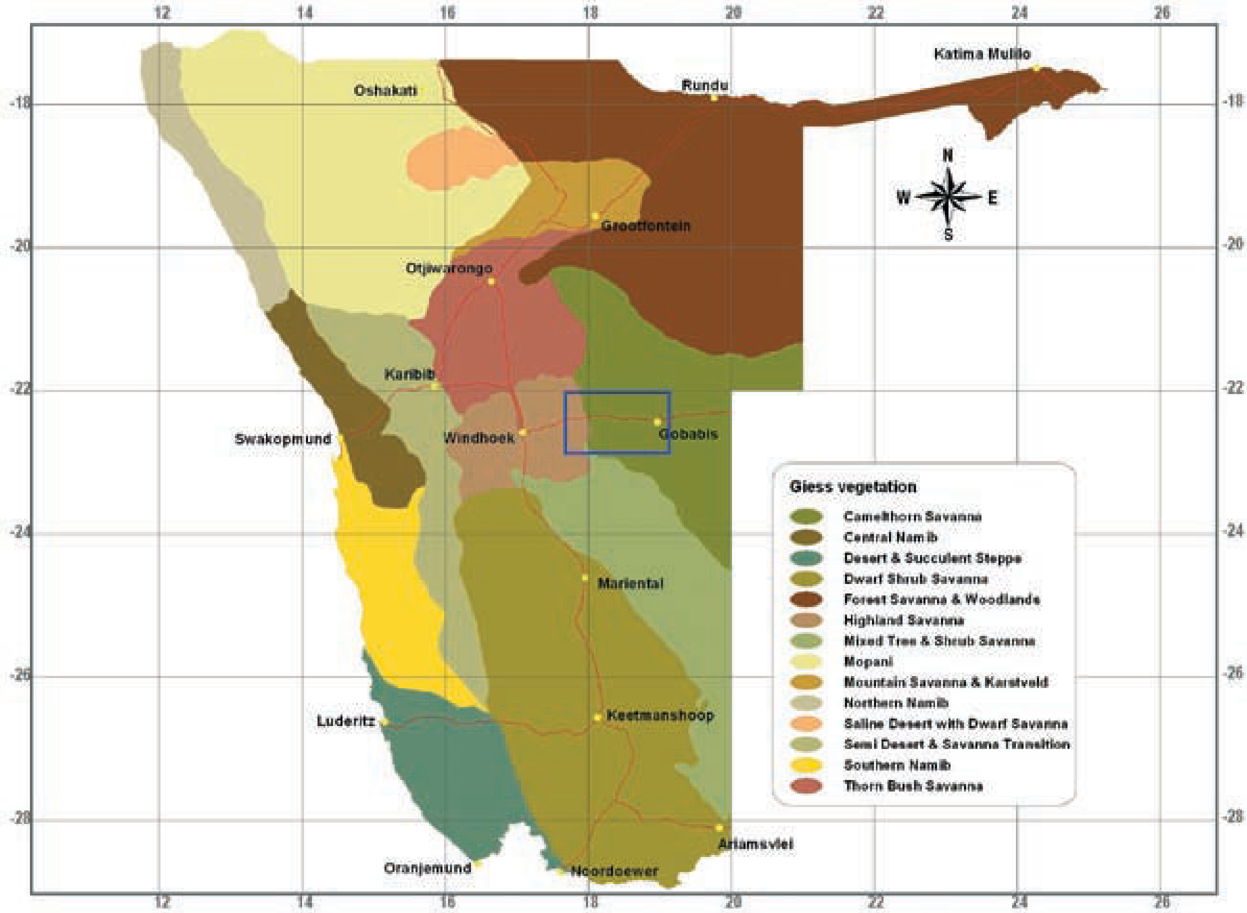

Figure 8. Giess vegetation map (1971).

other animals that depend on plant production for their existence.

The pilot area covers mainly two vegetation groups as defined by Giess (1971). These are the Camelthorn Savanna, which is also the more dominant vegetation group, and the Highland Savanna, occurring on the western side of the pilot area.

By definition, the Camelthorn Savanna is characterised by large, open expanses of grasslands dotted with Acacia trees. These trees are tallest in areas of deeper sands in the east, with plant growth becoming progressively shrubbier further west into the Highland Savanna, where the soils are shallower and the landscape more hilly and rocky.

Within the Camelthorn Savanna, the occurrence of Eragrostis pallens and Aristida stipitata is common. Both are fairly unpalatable. The plant succession pattern here is usually from *Schmidtia kalahariensis* to *Stipagrostis uniplumis* and *Schmidtia pappophoroides*, and from thereon to climax species such as *Anthephora-*, *Brachiaria-* and *Digitaria* species.

Common tree species of the Highland Savannah are *Combretum apiculatum*, *Acacia hereroensis*, *Acacia reficiens*, and *Acacia erubescens*. The original grass cover consists of climax grasses like *Anthephora pubescens*, *Brachiaria nigropedata*, *Digitaria eriantha* and other nutritious grasses which are excellent for grazing. Some areas show a decline in these grasses, usually because of selective- or overgrazing (Giess, 1971). The various types of vegetation differ, and therefore it can be expected that farms with different vegetation types would also have varying grazing capacities.

4. Bush Encroachment

Bush encroachment is taking on proportions that are already impacting catastrophically on Namibia's red meat industry. Huge tracts of land in the northern commercial farming areas are just about useless from a cattle/goat farming point of view, and has necessitated investigations into alternative sources of income from these rangelands. Not only does this phenomenon impact negatively on the carrying capacity of the land, but recent studies show that the encroaching species intercept rainwater to such an extent that the groundwater is not being recharged, resulting in the decline of groundwater tables.

On farms where bush has been eradicated, the grazing capacity has increased dramatically. Adjacent farms can therefore have radically different grazing capacities.

MATERIALS AND METHODOLOGIES

The methodologies discussed following hereon are still the original ones that were decided on at the beginning of the project. There has been a slight modification in the definition of the WAP parameters. Although these modifications, or rather additions, have been subjectively determined, they are based upon expert opinions within the pasture science field.

Total Seasonal Biomass Production (TSBP) estimations

The basis on which rangeland resources are evaluated is an assessment of seasonal biomass production (Figure 9). In arid and semi-arid climates, this production is mostly related to rainfall and is, therefore, extremely variable in time and space. Such production can be measured in the field through sampling or be estimated from rainfall data. Results obtained from either these processes are, by the nature of their acquisition, not sufficiently accurate and not representative of spatial and temporal variation (Prince and Tucker, 1986).

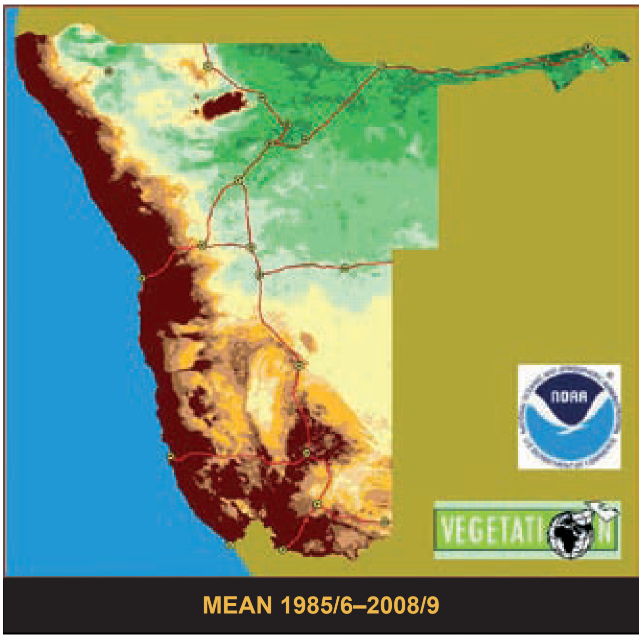

Figure 9. Total seasonal biomass production estimation map of Namibia, 1985/06 to 2008/09.

Field measurements mainly indicate the standing plant biomass at a single point in time, usually at the end of the growing season. This is not considered viable, as it involves a great deal of effort, expenses and time. Most importantly, it needs to be applied regularly at the same time and place throughout the country every year. Satellite imagery may therefore be a practical and efficient alternative source of data acquisition for capturing variation in biomass production over time (Ganzin *et al.*, 2005).

The Normalized Difference Vegetation Index (NDVI) provides a simple and practical approach to estimate biomass production. An integration of the vegetation index over the entire season gives a direct indicator of the production, taking into account both the greenness and the duration of the vegetation activity (Ganzin *et al.*, 2005).

The Satellite Monitoring of Arid Rangelands (SMAR) image-processing software processes and computes, from a series of multi-temporal NDVI imagery, the seasonal biomass production estimation. The core module of SMAR implements the vegetation-production model proposed by Monteith (1972) to calculate total seasonal biomass production (Monteith, 1972; Kumar and Monteith, 1981). The Monteith model, which is often referred to as an "efficiency" model can be summarized as follows:

$$BP_{season} = \Sigma_{season} (\varepsilon_i.\varepsilon_c.\varepsilon_b.GR.\delta t)$$

Where BP (season) = seasonal biomass production (kg/ha)

ε_i = efficiency of interception of solar radiation by leaves (%)

ε_c = fraction of solar energy suitable for photosynthesis ($\pm$ 48 %)

ε_b = efficiency of conversion of solar to chemical energy (g/MJ), (which varies with vegetation type but is fixed here to the value 0,8 g/MJ, a value found in the literature for tropical herbaceous covers)

GR = global radiation from the sun (Watts/m^2)

δt = time step (10 days)

Above-ground seasonal biomass production can be considered as the amount of forage produced during a specific growing season, which serves as basic information in estimating grazing capacity. Total Seasonal Biomass Production (TSBP) estimations are made annually at the end of the growing season (May), and averaged for the accumulative years.

Such production represents the renewable resources necessary for animal production, and should not be confused with standing biomass (Ganzin *et al.*, 2005). For savannah types in southern Africa with a significant woody cover and a grass layer dominated by perennial species, the standing biomass can be significantly higher than the seasonal production due to a part of the biomass having been carried over from previous years (Tainton, 1999).

Methodology for generating WAP parameters

1. Point Sampling

Point sampling provides a rapid, accurate and objective method to determine botanical composition and basal cover of herbaceous vegetation (Figure 10). A botanical survey, incorporating the nearest plant approach (Foran *et al.*, 1978) in conjunction with 'strike data', was conducted through a 500 m point line transect at randomly selected sites within the six vegetation-cover units and generated through the land cover mapping exercise to acquire values for the respective WAP parameters. These values were extrapolated to the specific vegetation-cover units. Points were spaced 1 m apart on the transect, which made it possible to express the occurrence of species on a percentage basis.

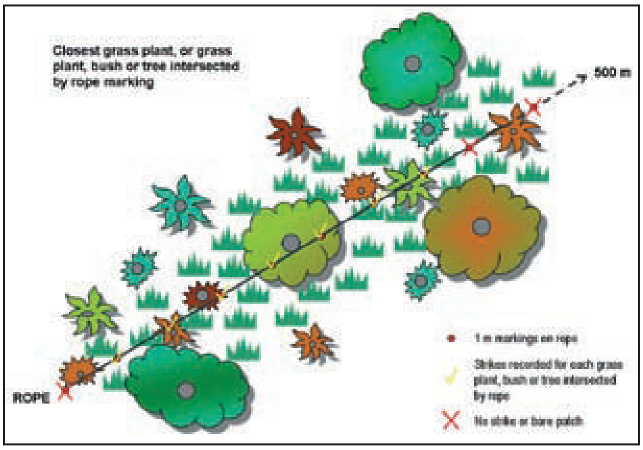

Figure 10. Schematic representation of how the botanical survey was carried out.

2. Woody Cover and Accessibility

Counting bushes (density) and classifying them into height classes was useful in the allocation of a woody cover and accessibility value (expressed as percentage). A bush count was carried out concurrently with the botanical survey along the same 500 m transect line, and within 1 m on either side of the transect (Figure 11).

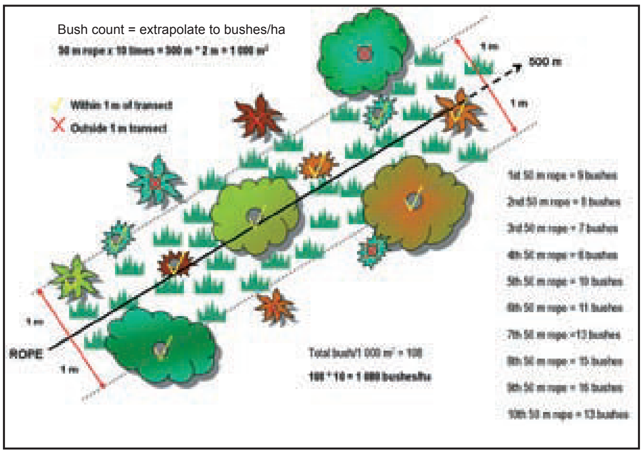

Figure 11. Schematic representation of how the bush count was carried out.

All bushes within 1 m on either side of the transect line were tallied and classified according to the following height classes: ≤ 50 cm, 0,5–1 m, 1–2 m, 2–4 m and ≥ 4 m. For determining accessibility, it was necessary that cut-off points be established in terms of density, as well as height. The following density classes were used, and a factor was assigned to each:

- Accessible (penetrable) ≤ 6 000 bush/ha = 1
- Inaccessible (impenetrable) > 6 000 bush/ha = 0

The figure of 6 000 was subjectively chosen, and is arbitrary. Very little data is available on the point at which bush becomes inaccessible to domestic animals. On the other hand though, all of the 6 000 bushes can be higher than 2 m and thus be accessible to the animals in terms of penetrability.

Bush exceeding 2 m in height were considered to be inaccessible, while those below 2 m were considered to be accessible in terms of forage. As the woody species were classified into height classes during the survey, it was possible to calculate the percentage of bushes lower than 2 m. This percentage was then multiplied by the density class factor (0 or 1) to arrive at a final accessibility figure.

After completion of the botanical composition and bush-density surveys, data for each site were summarized and then transferred to a specially designed WAP Parameter Field Measurement Form (Figure 12), which enabled workers to objectively calculate woody cover and accessibility parameters.

3. Palatability

Since palatability varies over time, it was decided to divide palatability of grasses into three periods: P1, P2 and P3, where:

- P1 = 1 month of the year (January), expressed as a % ($^1/_{12}$) = 8 % ≈ 10 % (very palatable)
- P2 = 3 months of the year (February to May), expressed as a % ($^3/_{12}$) = 25 % ≈ 30 % (palatable)
- P3 = 8 months of the year (June to December), expressed as a % ($^8/_{12}$) = 66 % ≈ 60 % (fairly palatable)

Each of these percentages was multiplied by the subjectively estimated (expert opinion) palatability (Table 1) of species encountered during the survey. Different palatability factors were allocated to the different grass species encountered during the surveys. The palatability factors for all grass species at the respective sites resulted in a total palatability factor for the herbaceous component (Table 1).

An example is *Schmidtia pappophoroides*, which was considered to be very palatable (factor of 100) during January. It was multiplied by 10 %, resulting in a figure of 10. It was subjectively decided that palatability decreased to a factor of 70 for four months of the year (February to May), and further decreased to a factor of 50 for seven months of the year (June to December). Therefore, its overall palatability was calculated to be:

10 (Factor 100 x 10 %) + 21 (Factor 70 x 30 %) + 30 (Factor 50 x 60 %) = 61

This calculation is illustrated later to show where it fits in with the rest of the Field Measurement Form, and how it contributes to the overall palatability for a specific farm, and for a specific vegetation-cover (derived from Land Cover Map) unit.

Palatability for bushes followed a similar approach to that described for grasses, with the exception that all bushes are considered to be equally palatable, but retain this palatability for various periods during the year. The palatability factors for all woody species at the respective sites resulted in a total palatability factor for the woody component (Table 2).

Table 1. Subjectively estimated palatability figures for grasses occurring in the pilot area

Specie	Palatability						Overall palatability
	1 month = 10 %		3 months = 30 %		8 months = 60 %		
	Period 1		Period 2		Period 3		
Schmidtia pappophoroides	100	10	70	21	50	30	61
Eragrostis omahekensis	60	6	40	12	0	0	18
Stipagrostis uniplumis	70	7	30	9	20	12	28
Aristida spp	40	4	10	3	0	0	7
Urochloa brachyura	100	10	10	3	0	0	13
Aristida stipitata	20	2	0	0	0	0	2
Eragrostis pallens	30	3	10	3	0	0	6
Eragrostis rigidior	80	8	50	15	20	12	35
Eragrostis lehmanniana	100	10	60	18	30	18	46
Schmidtia kalahariensis	100	10	10	3	0	0	13
Melinis repens	60	6	20	6	10	6	18
Pogonarthria fleckii	60	6	10	3	0	0	9
Cenchrus cilliaris	100	10	50	15	10	6	31
Panicum coloratum	100	10	80	24	50	30	64
Forbs (palatable)	100	10	20	6	0	0	16
Forbs (unpalatable)	10	1	10	3	0	0	4
Tricholaena monachne	100	10	40	12	20	12	34
Eragrostis nindensis	100	10	60	18	40	24	52
Panicum lanipes	100	10	80	24	40	24	58
Eragrostis trichophora	100	10	40	12	20	12	34
Microchloa caffra	20	2	0	0	0	0	2
Anthephora pubescens	100	10	80	24	50	30	64
Heteropogon contortus	60	6	20	6	10	6	18
Stipagrostis obtusa	80	8	40	12	20	12	32
Eragrostis echinochloidea	80	8	40	12	10	6	26

Grewia for example, was considered to be very palatable (100) for a period of about ten months of the year (80 %). Its palatability was then weighed (100 x 80 %) to give a factor of 80. The incorporation of this figure in the Field Measurement Form will be explained at a later stage.

The contribution of each component (herbaceous and woody) to palatability was then assessed by multiplying its percentage contribution to total species composition by the total palatability factor for each component. The two assessed percentages were added to arrive at an overall palatability figure.

Explanation of the Field Measurement Form

What follows refers to the WAP Field Measurement Form (Figure 12) used during the fieldwork. It specifically relates to data captured on and processed for the farm Nuwe Orde, situated in the pilot area.

1. Herbaceous Layer

Species occurring less than 10 % of the time, was discarded.

Explained using *Schmidtia pappophoroides* as an example.

- Count/500 (count per 500 point survey)
  341 = the actual count of *Schmidtia pappophoroides* on the 500 point survey
  548 = out of the 500 point survey, 548 plants belonged to the herbaceous component (548 indicates more than 1 plant counted at a specific point)
- % of H (herbaceous percentage)
  (341 ÷ 548) x 100 = 62,23 %
- Palatability Periods 1, 2 and 3 (Table 3)
  Keeping in mind the Palatability Periods discussed previously, the following palatability figures were calculated:

Table 2. Subjectively generated palatability figures for trees and shrubs occurring in the pilot area

Specie	Month palatable	Palatability when green	% period	Palatability
Acacia mellifera	1	100	10	10
Acacia hebeclada	2	100	20	20
Acacia hereroensis	3	100	25	25
Acacia erioloba	2	100	20	20
Acacia karoo	2	100	20	20
Grewia spp.	10	100	80	80
Catophractes alexandri	4	100	30	30
Rhigozum trichotomum	2	100	20	20
Phaeoptilum spinosum	6	100	50	50
Dichrostachys cinerea	1	100	10	10
Rhigozum obovatum	2	100	20	20
Commiphora spp.		100		
Boscia albitrunca	10	100	80	80
Tarchonanthus camphoratus	6	100	50	50
Ozoroa spp.	0	0	0	0
Elephantorrhiza elefantina	0	0	0	0
Ehretia alba	3	100	25	25
Ziziphus mucronata	4	100	30	30
Rhus tenuinervis	4	100	30	30
Lycium spp.	3	100	25	25
Terminalia sericea	4	100	30	30
Diospyros spp.	4	100	50	50

Table 3. Palatability determined for the herbaceous layer

Specie	P1	P2	P3	Palatability	Weighed palatability
Schmidtia pappophoroides	100	70	50		
	(10)	(21)	(30)	61	37,96
P1 = 1 month is 8 % = 10 % x 100 = (10)					
P2 = 3 months is 25 % = 30 % x 100 = (21)					
P3 = 8 months is 66 % = 60 % x 100 = (30)					

- for 1 month it is considered to be Very Palatable: 100 x 10 % = 10 (P1)
- for 3 months it is considered to be Palatable: 70 x 30 % = 21 (P2)
- for 8 months it is considered to be Fairly Palatable: 50 x 60 % = 30 (P3)

The Weighed Palatability was determined as follows: (341 ÷ 548) x 61 = 37,96 (where 61 = 10 + 21 + 30)

- All the Weighed Palatability figures for each of the recorded herbaceous species were added to arrive at an overall herbaceous layer palatability.

2. Woody Layer

The palatability of the woody layer was done exactly the same way as for the herbaceous layer. With regard to the Accessibility calculation, five parameters were considered in calculating this attribute.

- Height
  0–2 m deemed to be accessible (100 %)
  > 2 m deemed inaccessible (0 %)

- Density
  < 6 000 bush/ha = 100 % accessible, allocated a factor of 1
  > 6 000 bush/ha = 0 % inaccessible, allocated a factor of 0

WAP Parameters Field Measurement Form

Date: ________ **Plot Number:** Nuwe Orde

GPS: **Lon (X):** S 22 06 57.38 **Lat (Y):** E 18 05 14.19

Vegetation type: Tall Shrub sparse

Herbaceous layer:

	Count/500	% of H	Palatability Period 1	Period 2	Period 3	Palatability	P-weighed
1. *Schmidtia pappophoroides*	341	62,23	100	70	50	61	37,96
2. *Stipagrostis uniplumis*	54	9,85	70	30	20	28	2,76
3. Forb – unpalatable	54	9,85	10	10	0	4	0,39
4. *Aristida congesta*	34	6,20	40	10	0	7	0,43
5. *Eragrostis lehmanniana*	30	5,47	100	60	30	46	2,52
6. Other	35	6,39	60	40	10	24	1,53
Total →	548	100				Overall herbaceous pal →	45,59

Woody layer:

	Count/500	% of W	Palatability Pal.green	Period %	Palatability	P-weighed	Accessibility % < 2 m	density	% < 2 m	Access
1. *Grewia* spp.	14	41,18	100	80	80	32,94	83 %	670 / ha	1	83 %
2. *Tarchonanthus camphoratus*	10	29,41	100	50	50	14,71				
3. *Acacia erioloba*	7	20,59	100	20	20	4,12				
4. Other	3	8,82	100	30	30	2,65				
Total →	34	100	Overall woody pal →			54,42	Woody acc			83

Woody cover (W): (total woody counts ÷ 500) x 100 → **7**

Accessibility (A): $(100 \times H_{proportion}) + (Acc_{woody} \times W_{proportion}) \rightarrow$ **99**

Palatability: Herbaceous **45,59** Woody **54,42**

Overall Palatability (P): $((P_{herb} \times H_{proportion}) + (P_{woody} \times W_{proportion})) \rightarrow$ **46,12 = 50**

Figure 12. Field Measurement Form used to enter final figures for each of the WAP parameters.

- Number of plants per height class (from actual survey)

- Crown canopy diameter
  (A list was generated which estimated crown canopy per height class. This was done on the assumption that there is a positive correlation between canopy cover and biomass production.)

- Broad or narrow leafed
  (It was assumed that broad leafed species contributed three times as much plant biomass as narrow leafed species.)

Explained as per example *Grewia* spp. (Table 4)

- Count/500 (count per 500 point survey)
  14 = the actual count on the 500 point survey
  34 = out of the 500 point survey, 34 plants belonged to the woody component

- % of W (percentage woody layer)
  (14 ÷ 34) x 100 = 41,18 %

Palatability

The following assumptions were made:

- *Grewia* is 100 % palatable for about 10 months of the year, thus 80 % of the year.
- The weighed palatability of *Grewia* is therefore:
  (14 ÷ 34) x 80 = 32,94

Accessibility

During the 5-year period three parameters were identified by the researchers which they regarded as important and that played a role in the penetrability of the bush, as well as determining the biomass production estimates. These factors are as follows:

Table 4. Palatability determined for woody layer

Specie	Palatability	Period	Palatability	Weighed palatability
Grewia spp	100	80 %	80	32,94
Period: 10 month ≈ 80 % * palatability = 80 (palatability)				
Weighed palatability = 80 * % occurrence (41,18 %)				

Table 5. Crown canopy diameter estimates of trees and shrubs on Nuwe Orde

Specie	Height Classes					Leaves: 3 or 1
	≤ 0,5 m	0,5–1 m	1–2 m	2–4 m	≥ 4 m	
	crown canopy diameter estimates in metre					
Acacia mellifera	0,6	1	3	4	5	1
Acacia hebeclada	0,5	1,2	2,5	4	–	1
Acacia hereroense	0,4	0,8	1,5	2,5	–	1
Acacia erioloba	0,3	1	1,5	6	10	1
Acacia karoo	0,3	1	1,5	3	–	1
Grewia spp.	0,5	1,2	3	4	–	3
Catophractes alexandri	0,3	1	1,5	–	–	3
Rhigozum trichotomum	0,5	1	2	–	–	1
Phaeoptilum spinosum	0,5	1,2	2,5	3,5	–	1
Dichrostachys cinerea	0,3	1	2,2	3	–	1
Rhigozum obovatum	0,5	1,2	1,5	2	–	1
Commiphora spp.	0,3	0,8	1,5	3	–	3
Boscia albitrunca	0,2	0,8	1,5	3	–	3
Tarchonanthus camphoratus	0,3	1	2	4	–	3
Ozoroa spp.	0,4	1	1,2	–	–	3
Elephantorrhiza elefantina	0,3	0,4	-	–	–	1
Ehretia alba	0,3	1	1,5	–	–	3
Ziziphus mucronata	0,4	0,8	2	3	–	3
Rhus tenuinervis	0,5	0,7	1,5	–	–	3
Lycium spp.	0,3	0,8	1,2	–	–	3
Terminalia sericea	0,7	1,2	2,5	3,5	4,5	3
Diospyros spp.	0,5	1	1,5	3	–	3

- Number of bush in a specific height class
- Crown canopy diameter of species in each height class
- Broad (3) or narrow (1) leafed (3 and 1 are weighed values)

Explained as per Table 6, using *Grewia* spp. as an example.

- Number of bush in height class ≤ 50 cm = 2 (actual count)
- Crown canopy diameter at ≤ 50 cm = 0,5 m
- Broad leafed = 3
- Mark allocated to *Grewia* spp.: 2 x 0,5 m x 3 = 3

A *Grewia* with a crown diameter of 1 m contributes about three times as much leaf biomass as a 1 m diameter *Dichrostachys cinerea* (arbitrary).

The number of bushes in a specific height class can have an influence on the accessibility to and for livestock. The other two factors (crown canopy diameter and broad or narrow leafed) again have an influence on the reflective properties when determining the seasonal biomass production estimations with remote sensing.

The preceding calculations were applied to each of the species in each of the height classes. These marks were then added to a total mark for that specific height class. The totals for the height classes up to the 1–2 m height class were then added and expressed as a percentage of the total marks for all height classes.

Table 6. Example to determine the species percentage of the woody layer below 2 m expressed as a percentage of the total woody layer

Height Classes	≤ 0,5 m	0,5–1 m	1–2 m	2–4 m	≥ 4 m
All species	8,4	52,6	213	48	10
Total			274		332

Table 7. Example to determine height, density, penetrability and accessibility on *Nuwe Orde*

Farm	Height	Density	Penetrability	Accessibility
Nuwe Orde	83 %	670	1	83 %
Height = If < 2 m = reachable for animal i.t.o. height (in this case 83 % of the woodies were < 2 m)				
Density = Actual count				
Penetrability: If > 6 000 bush/ha = 0				
Penetrability: If < 6 000 bush/ha = 1				
Accessibility = height x penetrability				

Accessibility = number of bush < 2 m/total number of bush
= (274 ÷ 332) x 100
= 83 % of bush < 2 m

Density = total number of bush counted (number of bush per ha)
= 67 (actual count) in the 1 000 m^2 quadrat (500 m long, 2 m wide)
= 670/ha

Penetrability = bush per ha < 6 000 bush per ha
= 670/ha < 6 000/ha
therefore, penetrability factor:
= 1

Accessibility to woody layer = height x penetrability
= 83 % x 1
= 83 %

3. Calculation of Final WAP Parameters

- Woody cover = (total woody counts ÷ 500) x 100
  = (34 ÷ 500) x 100
  = 6,8
  (W) ≈ 7

- Accessibility = $(100 \times H_{proportion}) + (Acc_{woody} \times W_{proportion})$
  = (100 x (548 ÷ 582)) x (83 x (34 ÷ 582))
  = 94,6 + 4,85
  = 99,45
  (A) ≈ 99

- Palatability
  Herbaceous = 45,59
  Woody = 54,42

- Overall palatability (P) = $((P_{herb} \times H_{proportion}) + (Pw_{oody} \times W_{proportion}))$
  = ((45,59 x 0,95) + (54,42 x 0,05))
  = 43,3105 + 2,721
  = 46,03
  (P) ≈ 50

The reflected values for respectively Woodiness (W) = 7, Accessibility (A) = 99, and Palatability (P) = 50, were used to generate masks, which were applied to the average biomass production starting at the 1985/86 growing season and ending at the 2005/06 growing season. These masks reduced the total biomass according to the value of that specific mask. The three masks are image information format layers obtained by vector-raster conversions at the same resolution as the average BPE image in order to have exact pixel by pixel correspondence.

Methodology to determine Grazing Capacity from WAP-corrected Total Seasonal Biomass Production (TSBP) image

After the WAP layers were applied, an image was generated from which seven Seasonal Biomass Production classes could be distinguished:

- < 200 kg/ha
- 200–400 kg/ha
- 400–600 kg/ha
- 600–800 kg/ha
- 800–1 200 kg/ha
- 1 200–1 600 kg/ha
- 1 600–2 000 kg/ha

Each of these classes was converted to Grazing Capacity as follows:

- A kilogram of animal biomass (kg AB) needs 3 % per day in dry material to sustain itself. For a period of a year this equates to: 1 x 3 % x 365 = 10,95 kg DM/year.
- Proper utilisation of available biomass was set at 50 %, therefore the 800–1 000 kg is divided by 2 resulting in 400–500 kg plant biomass.
- The remaining figure is divided by the dry material required per kilogram AB per year (i.e. 10,95) to give a maintenance range of 36,5–45,7 kg AB/ha.
- If a Large Stock Unit weighs 450 kg AB (arbitrary), then a unit would require between 12,32 ha (450/36,5) and 9,84 ha (450/45,7) to maintain itself.

Determination of Grazing Capacity utilising the land cover classification quadrat clipping methodology

A joint effort between the Pasture Science and Analytical Services sub-divisions, in the Ministry of Agriculture, Water and Forestry, ensured the acquisition of yearly grazing capacity data for the pilot area from the 2005/06 to 2009/10 growing seasons. Thirty points were randomly selected within six prominent vegetation-cover units (land cover map) for fieldwork, which took place during April of each year.

This process allowed for data to be collected over the five year period in order to generate a grazing capacity for each of the land-cover units. The randomly selected points resulted in the following land cover units being selected:

- Grassland – 7 farms selected
- Woodland sparse – 4 farms selected
- Low shrub sparse – 4 farms selected
- Tall shrub sparse – 7 farms selected
- Tall shrub open – 5 farms selected
- Woodland open – 3 farms selected

Out of a total of 30 farms, observations on one of these farms (situated in the woodland sparse land cover unit) were discontinued in 2006. Observations continued on the remaining 29 farms for a period of five years.

The first ground-truthing for the remote sensing based land cover classification image generated in early 2005 took place in April 2005. The ground-truthing for each of the six land cover classes, as found spread over the 29 farms, took the form of the clipping of 40 quadrats along a transect of 1 km in length. The starting point for each transect was more or less in the middle of the land cover units, and the direction of the transect was subjectively chosen so as to best represent that land cover unit.

Plant material collected was dried and the grazing capacity calculated for each of the 29 sites according to the methodology described by Bester (1988). No attempt was made to separate palatable from less palatable grass species. All *Aristida* spp. were excluded from the grazing capacity calculations. The yields of taller shrubs, such as, for example *Tarchonanthus camphoratus*, *Grewia* spp. and others were also excluded, while the yield of prostrate creepers such as *Oxygonum delagoense* and *Tylosema esculentum* were included. Any forb having a strong aromatic flavour, or displaying thorns or excessive hair, was deemed unpalatable and therefore discarded.

Ground-truthing at each site was repeated each year for a period of five years until April of 2010. April is perceived to be the end of the growing season in Namibia. The average grazing capacity from 2005/6–2009/10 growing seasons, as per land cover classification/clipping of quadrats methodology is depicted in Table 8.

RESULTS AND DISCUSSION

Each of the tested methodologies will be discussed in such a way that their respective explanations, results and discussions appear together under each methodology.

Determination of grazing capacity utilising the land cover classification quadrat clipping methodology

The results are displayed in Table 8.

Table 8. Average grazing capacity from 2005/6 to 2009/10, as well as grazing capacity as per "old" grazing capacity map for 29 sites (farms) in the pilot area east of Windhoek

29 Sites including Alt Hartebeesvlei and Groot Okapanje	27 Sites excluding Alt Hartebeesvlei and Groot Okapanje	Land cover unit and corresponding farm		Average GC:2005/06 to 2009/10 quadrat clipping (ha/LSU)	Old GC map (ha/LSU)
1		GRASSLAND	Alt Hartebeesvlei	119,7	12
2	1		Kanabis	11,1	12
3	2		Orumbo Nord 2	18,4	10
4	3		Otjiwarumendu	22,8	10
5	4		Smalhoek	5,8	12
6	5		Volmoed	37,3	10
7	6		Wiesesrus	6,0	10
8	7	WOOD-LAND SPARSE	Grunenthal	10,7	10
Discontinued			Merino	Discontinued	
9	8		Owiniekiro	6,2	10
10	9		Spandau	11,1	10
11		LOW SHRUB SPARSE	Groot Okapanje	537,6	10
12	10		Saaleck	5,3	10
13	11		Olive	14,5	12
14	12		Orumbo	43,2	10
15	13	TALL SHRUB SPARSE	Golden Aue	14,0	12
16	14		Helene	29,9	10
17	15		Kaukurus Ost	14,6	10
18	16		Nuwe Orde	11,6	10
19	17		Orumbo Nord 1	26,4	10
20	18		Sandkraal	8,7	10
21	19		Scheidthof	53,3	10
22	20	TALL SHRUB OPEN	Autabib	7,9	12
23	21		Duvenhage	8,9	10
24	22		Eliza	5,3	12
25	23		Gross Osombahe	19,5	10
26	24		Kameelboom	40,0	10
27	25	WOOD-LAND OPEN	Herzwalde	9,1	10
28	26		Mountain View	11,5	12
29	27		Wendelstein	9,3	10

Discussion

During the clipping of quadrats in April 2007, the sites at Alt Hartebeesvlei (site 1, column 1, Table 8) and Groot Okapanje (site 11, column 1, Table 8) yielded very little plant material. As a result of this, the grazing capacity calculated for these two sites resulted in two values considered to be outlying when compared to the values of the remaining 27 sites. These two outlying values (119 ha/LSU and 537 ha/LSU), were discarded and the graph redrawn. In the resulting figure the variation between the remaining 27 sites with regard to the land cover classification quadrat clipping methodology can be seen more clearly. The grazing capacity as per "old" map also appears clearer (Figure 13).

In the case of grazing capacity calculated as per land cover classification quadrat clipping methodology, seven sites had a better grazing capacity than depicted by the "old" grazing capacity map; 13 sites showed a poorer grazing capacity; while seven sites had virtually the same grazing capacity as the old grazing capacity map. From this it would seem that in spite of an above average rainfall during the data collection period, the grazing capacity of the land in the pilot area seems to be poorer in general than indicated in the "old" grazing capacity map. This would seem to be borne out by data contained in Figure 14, where the average grazing capacity per land cover unit, also seems to be poorer that what is indicated by the grazing capacity of the "old" map. It is only the average grazing capacity of those sites situated in the woodland sparse land cover unit that is somewhat better than the grazing capacity of the "old" map.

There can be a number of reasons for the variation seen in Figure 13, the most obvious being rainfall, soil type, the production systems applied, infrastructure and how these farms are managed. Worth mentioning at this point is that sites with a predominantly annual grass cover were treated no differently than sites with a more predominant perennial grass cover when grazing capacities were calculated. In good rainfall years, predominant annual and predominant perennial grass sites performed equally well in terms of utilisable grass production (Table 9). However, in poorer rainfall years, like 2006/7, predominantly annual grass sites, for example Volmoed and Alt Hartebeesvlei had a considerably poorer yield than for example Saaleck and Smalhoek, where the perennial grass *Stipagrostis uniplumis* occurs abundantly (Table 9). With the exception of Saaleck, all these sites fall within the grassland land cover unit.

During the data gathering period, all years, with the exception of 2006/7, received above average rainfall. In general, the study area received slightly below average rainfall during the 2006/7 season. Although 2009/10 was a good rainfall year, rains stopped early in February. It is therefore clear that the data collection period was not long

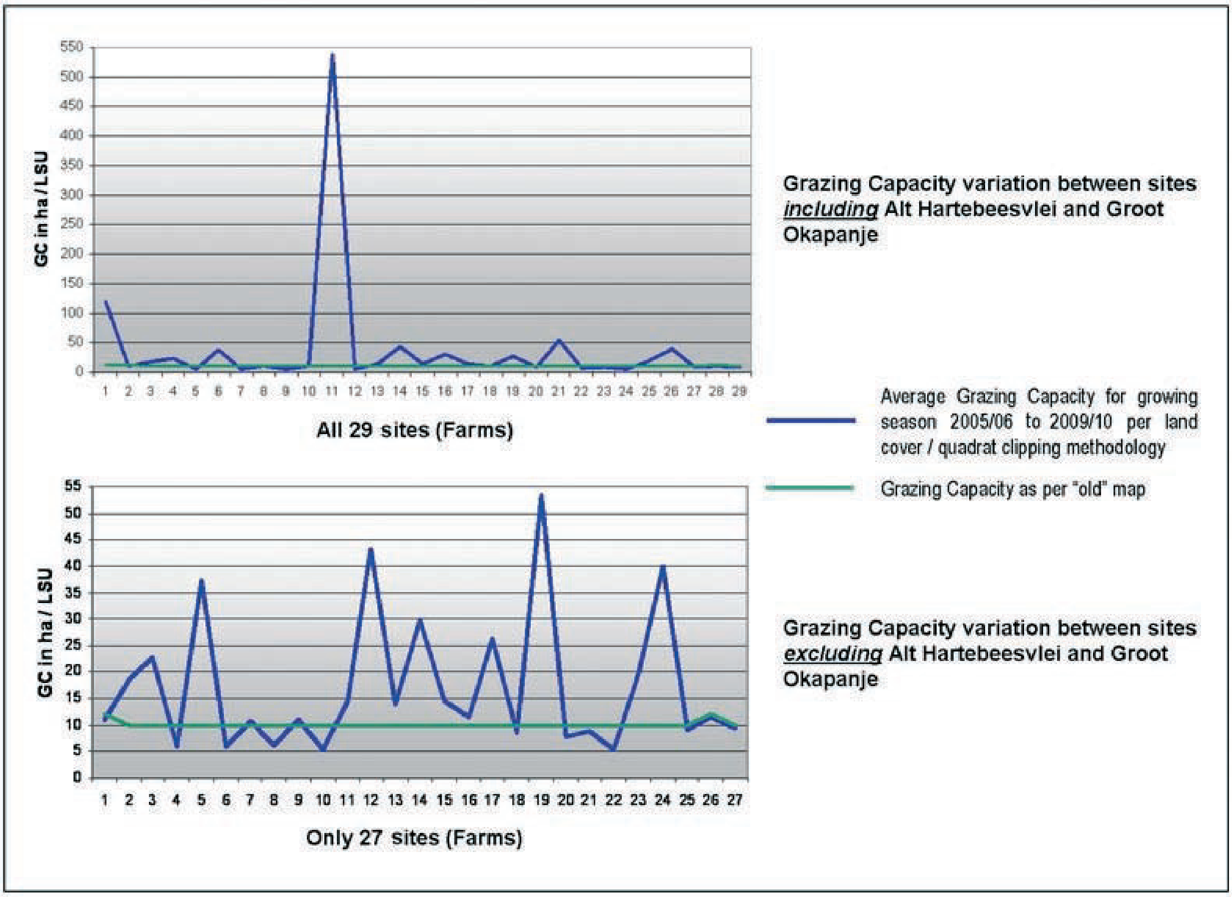

Figure 13. A graphic representation of Table 8 showing the grazing capacity variation between the different sites: (top) with all farms included and (bottom) with the two "outliers" excluded.

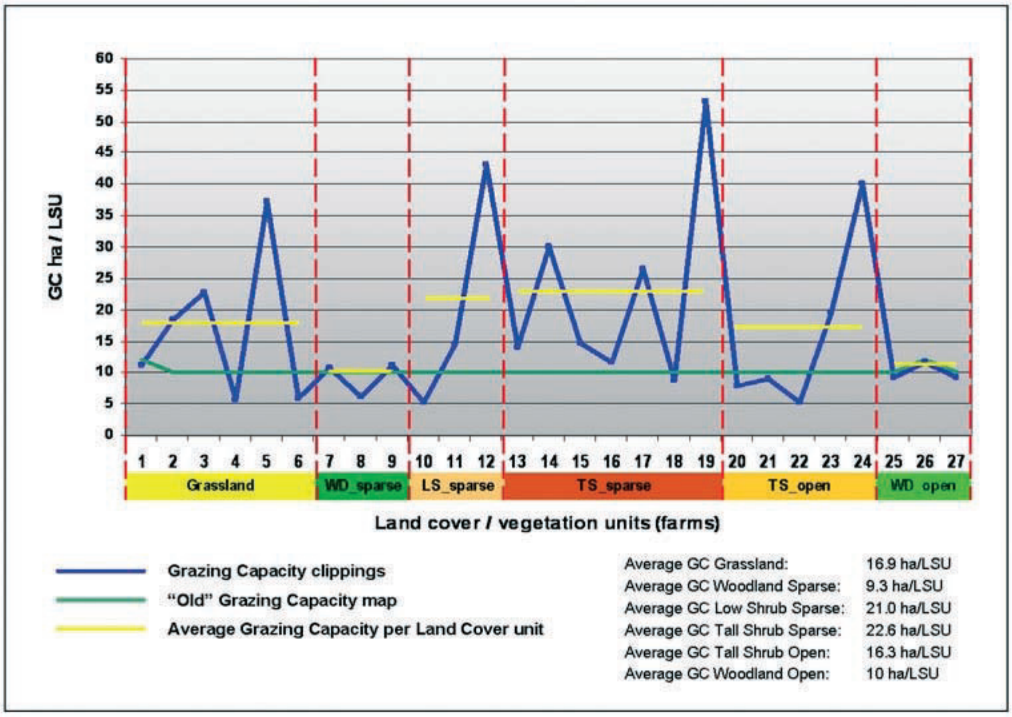

Figure 14. Average grazing capacity for each land cover unit (vegetation class) for the period April 2005/6 to April 2009/10.

Table 9. Comparison between the grazing capacities of predominantly perennial grass sites with predominantly annual grass sites in the pilot area for five consecutive years (the predominant grass is indicated between brackets)

Site and predominant grass	GC 2005/06 ha/LSU	*GC 2006/07 ha/LSU	GC 2007/08 ha/LSU	GC 2008/09 ha/LSU	GC 2009/10 ha/LSU
Smalhoek (perennial grasses)	4,07	5,61	6,97	7,25	4,92
Volmoed (annual grasses)	5,84	163,91	6,57	4,30	5,66
Saaleck (perennial grasses)	5,23	5,87	6,51	4,15	4,68
**Alt Hartebeesvlei (annual grasses until 2008/9)	5,18	528,42	48,54	10,52	5,62

* The only season slightly below the average rainfall year
** During the clipping of April 2010, the site showed a remarkable recovery with very little annual grasses.

enough to adequately capture variation in dry material production. There were, for example, no periods of poor rainfall, or drought. grazing capacity figures generated over the 5-year period are probably overly optimistic.

From the land cover unit image (Figure 2), and by looking at the farm boundaries overlay, it can be seen that in many instances a farm contains two and in some cases three land cover units (vegetation classes). This of course implies that such a farm can have more than one grazing capacity figure. This holds true in practice, since a farm may have different soils (which is probably one of the primary reasons for the occurrence of different land cover units), while there may even be differences between camps on a farm, since different camps may, for various reasons, receive different treatments from the landowner.

Methodology to determine grazing capacity from WAP corrected TSBP image

The results are displayed in Table 10.

Table 10. Grazing capacity determined with the TSBP corrected with WAP, as well as per "old" grazing capacity map

Column 1	Column 2	Column 3		Column 4	Column 5
29 sites including Alt Hartebeesvlei and Groot Okapanje*	27 sites excluding Alt Hartebeesvlei and Groot Okapanje*	Land cover unit and corresponding farm		GC as per TSBP corrected with WAP (ha/LSU)	GC as per "old" GC Map (ha/LSU)
1		GRASSLAND	Alt Hartebeesvlei*	13–17 (15)	12
2	1		Kanabis	8–13 (10,5)	12
3	2		Orumbo Nord 2	13–17 (15)	10
4	3		Otjiwarumendu	13–17 (15)	10
5	4		Smalhoek	13–17 (15)	12
6	5		Volmoed	13–17 (15)	10
7	6		Wiesesrus	13–17 (15)	10
8	7	WOOD-LAND SPARSE	Grunenthal	17–25 (21)	10
			Merino**	6–8 (7)	10
9	8		Owiniekiro	6–8 (7)	10
10	9		Spandau	13–17 (15)	10
11		LOW SHRUB SPARSE	Groot Okapanje*	13–17 (15)	10
12	10		Saaleck	8–13 (10,5)	10
13	11		Olive	13–17 (15)	12
14	12		Orumbo	< 50	10
15	13	TALL SHRUB SPARSE	Golden Aue	5–6 (5,5)	10
16	14		Helene	25 0 50 (37)	12
17	15		Kaukurus Ost	13–17 (15)	10
18	16		Nuwe Orde	13–17 (15)	10
19	17		Orumbo Nord 1	13–17 (15)	10
20	18		Sandkraal	13–17 (15)	10
21	19		Scheidthof	13–17 (15)	10
22	20	TALL SHRUB OPEN	Autabib		12
23	21		Duvenhage	6–8 (7)	10
24	22		Eliza	8–13 (10,5)	12
25	23		Gross Osombahe	17–25 (20,5)	10
26	24		Kameelboom		10
27	25	WOOD-LAND OPEN	Herzwalde	13–17 (15)	10
28	26		Mountain View	13–17 (15)	12
29	27		Wendelstein	8–13 (10,5)	10

* See "Discussion" of land cover classification quadrat clipping methodology

** Although clipping of quadrats on Merino was discontinued due to the owner not wanting to participate after the first year of data collection, data collection with regard to the TSBP corrected with WAP methodology could continue since this method did not require physical entry to and presence on the farm.

Discussion

It was possible to generate the percentage figure needed to create the woodiness mask, as described by Espach *et al.* (2006) in an objective way along the 500 m long transect, and the surveys yielded fairly accurate figures since it was easy to count bush and allocate a height class to each bush or tree encountered along the transect. However, it must be borne in mind that the outcome of the bush or tree count in the 1 000 m^2 quadrat is also subject to the inherent error attached to any sampling procedure.

Although it was fairly easy to calculate a percentage woodiness figure, as well as the accessibility of the vegetation to animals in terms of whether it is within reach of the browsing and/or grazing animal (< 2 m height deemed within reach), the accessibility in terms of animals being able to penetrate dense bush populations, proved to be much more difficult. Very little information seems to be available in the literature with regard to the point at which bush density becomes a problem for domesticated animals in terms of penetration. The figure of 6 000 bush was therefore chosen arbitrarily.

Table 11. Grazing capacity determined with the actual clippings, the TSBP corrected with WAP, as well as per "old" grazing capacity map

Original no.	Analysis no.	Land cover unit and corresponding farm*		Average GC: 2005/06 to 2009/10 (ha/LSU)*	Old GC Map (ha/LSU)**	GC with WAP (ha/LSU)***
1		GRASSLAND	Alt Hartebeesvlei	119,7	12	13–17 (15)
2	1		Kanabis	11,1	12	8–13 (10,5)
3	2		Orumbo Nord 2	18,4	10	13–17 (15)
4	3		Otjiwarumendu	22,8	10	13–17 (15)
5	4		Smalhoek	5,8	12	13–17 (15)
6	5		Volmoed	37,3	10	13–17 (15)
7	6		Wiesesrus	6,0	10	13–17 (15)
8	7	WOOD-LAND SPARSE	Grunenthal	10,7	10	17–25 (21)
Discontinued			Merino	Discontinued		
9	8		Owiniekiro	6,2	10	6–8 (7)
10	9		Spandau	11,1	10	13–17 (15)
11		LOW SHRUB SPARSE	Groot Okapanje	537,6	10	13–17 (15)
12	10		Saaleck	5,3	10	8–13 (10,5)
13	11		Olive	14,5	12	13–17 (15)
14	12		Orumbo	43,2	10	<50
15	13	TALL SHRUB SPARSE	Golden Aue	14,0	10	5–6 (5,5)
16	14		Helene	29,9	12	25–30 (37)
17	15		Kaukurus Ost	14,6	10	13–17 (15)
18	16		Nuwe Orde	11,6	10	13–17 (15)
19	17		Orumbo Nord 1	26,4	10	13–17 (15)
20	18		Sandkraal	8,7	10	13–17 (15)
21	19		Scheidthof	53,3	10	13–17 (15)
22	20	TALL SHRUB OPEN	Autabib	7,9	12	13–17 (15)
23	21		Duvenhage	8,9	10	6–8 (7)
24	22		Eliza	5,3	12	8–13 (10,5)
25	23		Gross Osombahe	19,5	10	17–25 (21)
26	24		Kameelboom	40,0	10	13–17 (15)
27	25	WOOD-LAND OPEN	Herzwalde	9,1	10	13–17 (15)
28	26		Mountain View	11,5	12	13–17 (15)
29	27		Wendelstein	9,3	10	8–13 (10,5)

* Grazing capacity as per land cover quadrat clipping methodology
** Grazing capacity as per "old" map
*** Grazing capacity as per TSBP image corrected with WAP methodology

De Klerk (2004) points out that at populations of 400 bush per hectare, the selection of plant species by animals are already influenced, since at this point the botanical composition of grass plants in terms of palatability and perenniality, begins to deteriorate. The question that must be answered is: at what point, in terms of bush per hectare, does rangeland become unproductive in terms of beef and mutton production? Should penetrability of vegetation be considered a factor at all, since many farms still produce beef in areas with bush in access of 6 000 bush/ha, although the economic viability is probably questionable. Accessibility in terms of height remains an important factor since it is recognised that cattle in especially the Kavango and Caprivi regions have browse as an important component in their diet.

In retrospect, the inclusion of palatability was a brave, but somewhat foolish undertaking. Although, again, it was possible to generate the required percentage figure needed for the creation of the palatability mask, the information used was based purely on subjective expert opinion. Espach *et al.* (2006) shortly discussed the factors influencing palatability, from which it is clear that palatability is a factor subject to huge variations over time, which makes it difficult to incorporate this variable sensibly in the calculation of grazing capacity.

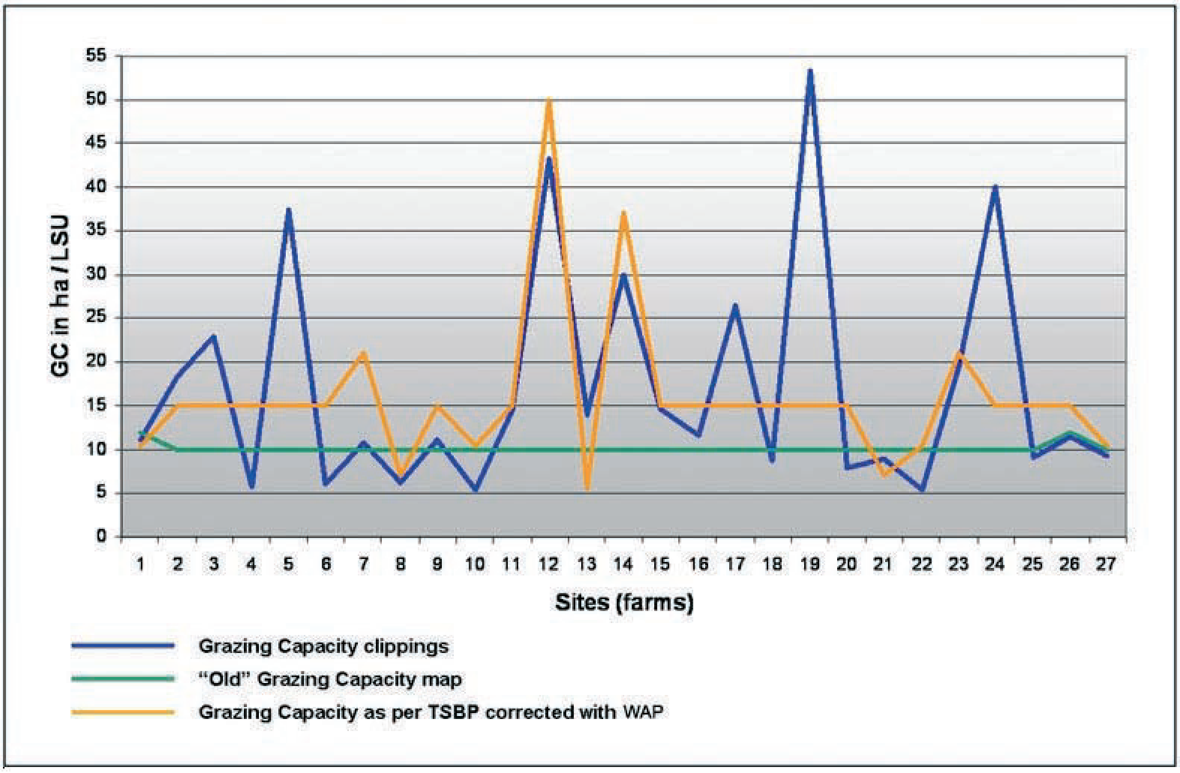

Figure 15. Comparison between the grazing capacities generated through the land cover classification quadrat clipping methodology, TSBP corrected with WAP methodology and the grazing capacity as per "old" grazing capacity map.

With reference to Figure 15, the grazing capacities on some sites calculated by both methods are remarkably close (sites 1, 8, 11, 15, 21, 23 and 27), while at others there are considerable deviations (5, 7, 13, 17, 19 and 24).

CONCLUSION

The question now remains: Which of these methodologies are the closest to the true grazing capacity (if there is such a thing)? What seems to be true is that in both the tested methodologies, grazing capacities are, generally speaking, poorer than those indicated by the "old" grazing capacity map. As was always said when the clipping of quadrats were introduced on a farm or in a farming community in earlier years, once the grazing capacity has been determined through the clipping of quadrats, then the accuracy thereof must be tested through the actual stocking of the farm to that of the calculated capacity, and the veld closely monitored so as to determine the correctness of the calculations.

What is also true is that huge variations in grazing capacity were found on all sites in the pilot area ranging from 53,3 ha/LSU to 5,3 ha/LSU with the clipping of quadrats method (if the outlying values of Alt Hartbeesvlei and Groot Okapanje are ignored), and from 50 ha/LSU to 5,5 ha/LSU with the TSBP corrected with WAP method.

In the case of the TSBP corrected with WAP methodology, we believe the methodology to be sound, but the data on which the methodology is based, is extremely variable, generated subjectively and therefore subject to error. However, it is much quicker than the land cover classification quadrat clipping methodology, while the methodology used to generate the TSBP images are advanced and proven worldwide. The idea to correct the TSBP with certain parameters such as woodiness and accessibility is also sound, but needs refinement. At this point it is doubtful whether palatability can be used sensibly in the correction of the TSBP.

Towards the end of the project, the researchers became increasingly concerned with the fact that, with regard to the land cover unit: grasslands, no distinction could be made between predominantly annual or predominantly perennial grasslands. This is one aspect that was not taken into account when the land cover map was generated in 2005. The next (logical) step is to take the current land cover map and try to differentiate between annual and perennial grasslands, and make that part of the Namibian Land Cover Classification Scheme (NLCCS).

A homogenous grassland area with dominantly annual and perennial grass respectively will be identified, where it is certain that these areas have not acquired a woody component (shrubs and trees) during the last five years. High resolution satellite imagery will then be used to get the reflectance properties (spectral signatures) for both annual and perennial grasses and to up-scale this to medium resolution imagery (Landsat), which was used during the pilot land cover mapping project.

In future, with the national land cover mapping project, these spectral signatures can then be used to identify annual and perennial grassland areas in Namibia. It all depends which type of satellite imagery will be used. If the original land cover classes want to be retained, which will have a greater significance for the determination of grazing capacity, then Landsat imagery will be sufficient. If it is just a question of differentiating between the woody and herbaceous component within Namibia, then coarser resolution satellite imagery will be used. It is then necessary to see whether it is possible to up-scale the spectral signatures from medium resolution satellite imagery to coarser resolution satellite imagery.

The purpose of this project was to investigate the possibility of using remote sensing as a tool to determine grazing capacity in Namibia. It is well known that there is no area consisting out of purely woody- or herbaceous vegetation. Areas with a lesser percentage woody canopy cover will have a herbaceous component, and areas which we consider as grasslands will have some shrubs or trees occurring in them. This is why it is necessary to get as much information as possible of Namibia's rangelands, and in turn from satellite imagery. The coarser the imagery the less information one can extract from it.

When it is possible to distinguish between grasslands consisting mainly of annual or perennial grasses, it will contribute tremendously in getting closer to a more reliable figure for the grazing capacity of grasslands in Namibia. For this however, funding is required.

ACKNOWLEDGEMENTS

The authors would like to thank Basil van Rooyen, Gerhard Mouton, Jossie Katjihuapira, Jefta Karipata, Elizabeth Campbell, Alberta Sipopo and Alois Katiti, all from the Ministry of Agriculture, Water and Forestry, without whose help the gathering of quantitative yield data would not have been possible. Also a word of thanks to all those farmers who allowed us free access to their farms, for their hospitality and especially to those who in some cases provided us with additional hands which made our job much easier. Our thanks too to Hartmut Kölling for aiding us in the surveys from which we were able to generate the WAP correction figures.

REFERENCES

BESTER, F.V., 1988. Die bepaling van grasproduksie van natuurlike weiveld. *Agricola* 6, 26–30.

DE KLERK, J.N., 2004. Bush Encroachment in Namibia. *Report on phase 1 of the Bush Encroachment, Monitoring and Management Project*. Ministry of Environment and Tourism, Windhoek. Namibia.

ESPACH, CELESTE, LUBBE, L.G. & GANZIN, N., 2006. Determining Grazing Capacity in Namibia: Approaches and Methodologies. *Agricola* 2006, 28–39.

FORAN, B.D., TAINTON, N.M. & BOOYSEN, P. DE Vos., 1978. The development of a method for assessing veld condition in three grassveld types in Natal. Proceedings of the Grassland Society of Southern Africa 13, 27–33. *African Journal of Range & Forage Science*, 10 (2), August 1993.

GANZIN, N., COETZEE, M.C., ROTHAUGE, A. & FOTSING, J.M., 2005. Rangeland Resources Assessment with Satellite Imagery: An Operational Tool for National Planning in Namibia, Geocarta International, *A Multi-disciplinary Journal of Remote Sensing and GIS*.

KUMAR, M. & MONTEITH, J.L., 1981. Remote Sensing of crop growth in plants and the daylight spectrum, edited by H. Smith, 131–144. London, Academic Press.

MENDELSOHN, J., JARVIS, A., ROBERTS, C. & ROBERTSON, T., 2002. *Atlas of Namibia. A portrait of the land and its people*. Published by New Africa Books (Pty) Ltd, Cape Town, South Africa.

MENDELSOHN, J. (with contributions by El Obeid, S., De Klerk, N., and Vigne, P.), 2006. *Farming Systems in Namibia*. Published by RAISON, Windhoek, Namibia.

MENDELSOHN, J., 2006, *1. Farming Systems in Namibia*. Published by RAISON, Windhoek, Namibia.

MONTEITH, J.L., 1972. Solar Radiation and productivity in the tropical ecosystems. *Journal of Applied Ecology* 9, 744–766.

PRINCE, S.D. & TUCKER, C.J., 1986. Satellite Remote Sensing of rangelands in Botswana. II. NOAA AVHRR and herbaceous vegetation. *International Journal of Remote Sensing* 7 (11): 1555–1570.

TAINTON, N.M., 1999. The ecology of the main grazing lands in South Africa. In: N.M. Tainton (ed.): Veld Management in South Africa, Ch. 2. Natal Univ. Press, Pietermaritzburg, South Africa.

THOMPSON, M.W., VAN DER BERG, H.M., NEWBY, T.S. & HOARE, D., 2001. *Guideline procedures for national land cover mapping and change monitoring*. Internal document of CSIR.

TOWNSHEND, J.R.G. & JUSTICE, C.O., 1988. "Selecting the spatial resolution of satellite sensors required for global monitoring of land transformations". *International Journal of Remote Sensing* 9,187–236.