DETERMINING GRAZING CAPACITY IN NAMIBIA: APPROACHES AND METHODOLOGIES

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ABSTRACT

Namibia's rangelands consist of a mixture of herbaceous and woody components. The main income-generating farming system is livestock farming, while grass production is considered the main forage for livestock. For rangeland managers to utilise this source sustainably, determining grazing capacity accurately is vital since it allows for adapting the animal load and, therefore, the grazing pressure to the actual capacity of the land. Various practical approaches and methodologies are investigated to update the existing Namibian grazing capacity map that was compiled more than three decades ago from the expert – but nonetheless subjective – opinions of farmers, extension officers and pasture scientists. These methodologies include the estimation of seasonal herbaceous biomass production using satellite imagery, land cover mapping, and the quantitative yield method of determining available forage. It is expected that combining all these methods – information from remote sensing, adjusted in terms of scientifically established coefficients for woody cover, accessibility and palatability, and the incorporation of the clipping technique (quantitative yield method) as a ground-truthing mechanism – will provide a tool to objectively establish rangeland productivity and, thus, grazing capacity in Namibia.

INTRODUCTION

Namibia is a sparsely populated semi-arid to arid region of south-western Africa. In size, Namibia covers an area of about 823 680 km^2 and spans some 1 320 km and 1 440 km at its longest and widest points, respectively. It has an Atlantic coastline of approximately 1 570 km (Figure 1).

Rainfall occurs mostly during sporadic thunderstorms in the summer months from October to April. 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). 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).

There are numerous important and unusual forms of plant and animal life in Namibia, which is flanked by the Namib and Kalahari Deserts in the west and east, respectively. Most of these features are linked to the dry, variable and relatively harsh environment. The more moist and tropical areas in north-eastern Namibia have the greatest overall diversity of plant species, but most species endemic to Namibia occur in the more arid areas in and around the escarpment and on isolated highlands. Plant life is dominated by tall woodlands in the north-east, from where the vegetation becomes progressively shorter and sparser to the west and south. Much of the country consists of shrubland in one form or another. Dwarf shrubs dominate areas in the extreme south-west and on the eastern edge of the central Namib, while much of the Namib Sand Sea is characterised by a combination of dwarf shrubs in the dune valleys and gravel plains and grasses on the dunes (Mendelsohn *et al*., 2002).

The predominant land use is agriculture, where people depend directly on natural rangeland resources for their economic well-being and food security. Agriculture and many other human activities are severely limited by the shortages of moisture due to the variable and low rainfall. Much of Namibia is sparsely populated because of this harsh and arid environment where livestock farming is an extremely important activity, as about 70% of the population are directly or indirectly involved in this industry. More land is used for agriculture than for any other purpose: mostly for cattle, goat and sheep farming. In overgrazed areas, livestock are less productive than in well-managed areas, where they will grow faster and become more productive. Overstocked areas occur mainly in north-central Namibia, along the Okavango River, on the eastern floodplains in

Figure 1. Namibia's position within Africa.

Caprivi, and typically around large settlements. Overstocking in these areas occurs due to the presence of large numbers of cattle and goats. In total, about 3.7% of the land (excluding protected areas) is overstocked at levels that are roughly double the accepted grazing capacity of the land (Mendelsohn *et al.*, 2002).

Taking into consideration that the livestock industry in Namibia depends primarily on natural vegetation, the accurate determination and application of grazing capacity are important tools in ensuring that rangeland managers utilise their land sustainably. Seasonal production of herbaceous biomass in the arid and semi-arid savanna regions of Africa is highly variable and directly determines the grazing capacity of the range and its condition. Biomass production is influenced primarily by rainfall and, to a lesser extent, by previous grazing treatment. Due to its extreme variability in time and space, seasonal herbaceous biomass production is difficult to measure accurately on the ground, as it requires a huge investment in manpower, time and skill. It is seldom measured in practice, therefore, ranchers and pastoralists often fall back on fixed grazing capacities set a number of years ago. This information is of limited use in Namibia simply because grazing capacity changes continuously over the years due to the high variation in rainfall, while rangeland condition has deteriorated considerably in recent times due to widespread bush encroachment. It is estimated that approximately 12–14% of the surface area of Namibia suffers from bush encroachment (Bester, 1996). As a result of the pre-Independence political system, much of the population had limited access to information, leaving subsistence farmers and communal pastoralists without an understanding of basic range management as a tool in extensive animal production.

The Namibian Government is currently implementing a National Land Reform Programme, using a structured and systematic approach to land use planning that requires land valuation, assessment of land productivity, and recommendations on resettlement and rehabilitation. There is an urgent need for timely, accurate data on land, water, grazing capacity and other natural resources, as well as socio-economic data for planning purposes. Information on grazing capacity is the responsibility of the Directorate of Research and Training within the Ministry of Agriculture, Water and Forestry (MAWF). The Directorate has been working towards an updated National Grazing Capacity Map for some time now, using various kinds of techniques and types of data. In addition to subjective 'expert opinions' from pasture scientists, extension staff and farmers, the Directorate also adopted more modern methods related to remote sensing and a geographic information system (GIS). Satellite images are increasingly used to estimate rangeland production, using tools developed through programmes such as the Estimation of Seasonal Biomass Production Project funded by French Cooperation between 1998 and 2003, with technical assistance from the *Groupement pour le Développement de la Télédédection Aérospatiale* (GDTA), a subsidiary of the French National Space Agency, *Centre National d'Etudes Spatiales* (CNES).

More recently, the Land Cover Mapping Project provided an additional dimension towards enhanced accuracy of the information generated on rangeland resources by allowing differences in vegetation types and, therefore, rangeland types to be taken into account. Land cover is one of the most important elements for describing and studying the environment, as it is the main source of primary production in terrestrial ecosystems. Land cover changes quickly over time and can be used as a simple indicator of human interventions on the environment; therefore, it can be an important parameter for environmental databases. The patterns that one sees on the earth's surface are products of many years of natural and human influences (Lillesand and Kiefer, 1994). With its geographic features, land cover can serve as a reference base for other environmental applications such as soil and vegetation.

Land cover information can be used to improve the methodology for estimating seasonal biomass production. It can be the basic, indispensable layer of information that allows for further processing of total (raw) biomass production, and to differentiate between grazable (grass, forbs, some bush) and non-grazable vegetation (bush, trees, unpalatable grass). Land cover maps will enable MAWF to eliminate these shortcomings.

Both the Estimation of Seasonal Biomass Production and Land Cover Mapping Projects require ground-truthing: bringing the reality of what is going on in the field in line with satellite-generated data.

METHODOLOGIES

The basis on which rangeland resources are evaluated is an assessment of seasonal biomass production. 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, but results are often insufficiently accurate, and not representative of spatial and temporal variation (Prince and Tucker, 1986). Field measurements – which not only involve great effort, expense and time, but also need to be applied regularly – mainly indicate the standing plant biomass at a single point in time, usually at the end of the growing season. 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).

Estimating seasonal biomass production using satellite imagery

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. Such production represents the renewable resources necessary for animal production, and should not to 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

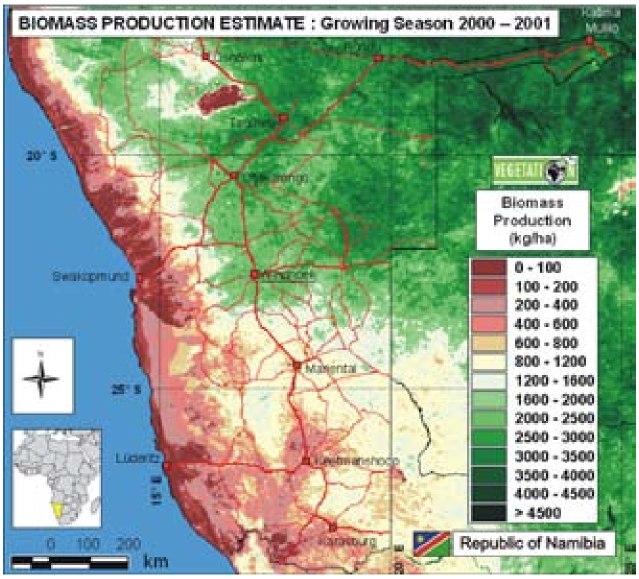


Figure 2. Biomass Production Estimation for the 2000–2001 growing season.

species (Tainton, 1999), the standing biomass can be significantly higher than the seasonal production due to a part of the biomass having been carried over from previous seasons.

Low-resolution satellite sensors, with acquisitions almost every day and with a complete geographic coverage of large areas, appear to be very suitable for vegetation monitoring and production assessment at national level (Ganzin *et al.*, 2005). Even though the spatial resolution is limited, the data remain suitable because the high temporal resolution is the most important element for the evaluation of fast-changing seasonal vegetation conditions (Prince and Tucker, 1986). Satellite imagery from two such sensors was used in the computation of seasonal biomass production. These were:

- the National Oceanic and Atmospheric Administration (NOAA) series of satellites, which carries the Advanced Very High Resolution Radiometer (AVHRR), and
- SPOT (Systeme Pour l'Observation de la Terre) VEGETATION, two polar-orbiting and sun-synchronous earth observation systems, each with a spatial resolution of approximately 1 km.

The NOAA/AVHRR satellites provide twice-daily coverage of practically the entire surface of the earth as they pass during a morning, afternoon, early evening and night cycle. The VEGETATION instrument is a large-scale earth observation sensor with a resolution of 1 km on board both the SPOT 4 and SPOT 5 satellites, with a field of view of 2 200 km. The instrument gathers information in four spectral bands (Blue, Red, Near Infra-red and Short Wave Infra-red). (www.spotimage.fr) For both instruments, the red and near infrared bands allow the computation of vegetation indices, the value of which is related to the 'greenness' of the vegetation cover. The most applied index is the Normalised Difference Vegetation Index (NDVI), which can be calculated daily, but is usually compiled as a ten-day synthesis. The ten-day synthesis is obtained by merging data strips (segments) acquired during a specified ten-day cycle. All these segments are compared to pick out the 'best' ground reflectance value; in this way, the influence of cloud cover is favourably reduced (www.iwmi.org).

Satellite-derived vegetation index images provide a simple and practical approach to estimating biomass production with remote sensing. This relies on the fact that the vegetation index, related to the green cover, is linked to photosynthetic activity and, therefore, total plant production. It is widely accepted that plant production is related to absorbed photosynthetically active radiation (APAR), and that satellite vegetation indices are good indicators of APAR (Hanan *et al.*, 1995; Prince, 1991; Ruimy *et al.*, 1994). In other words, an 'integration' of the vegetation index over the entire season gives a direct indication of biomass production, taking into account both the greenness and the duration of the vegetation activity (Ganzin *et al.*, 2005).

This principle has been put into practice to develop an operational image processing system based upon the Satellite Monitoring of Arid Rangelands (SMAR) image processing software developed by the GDTA between 1992 and 2002, within cooperation and technology transfer projects funded by French Cooperation services in Kenya, Namibia and Zimbabwe. The software consists of a set of programs that enable users to process low-resolution satellite imagery for the monitoring of vegetation resources in arid and semi-arid environments. The program uses a series of vegetation index images indicating seasonal changes in vegetation activity, and processes these multi-temporal sets of satellite data in an easy and quick way to compute estimates of seasonal biomass production.

This computation is achieved using SMAR's core module, namely the Biomass Production Estimation (BPE), which implements the vegetation production model proposed by Monteith (1972) to calculate total biomass production during a season by simulating the photosynthetic process of using solar radiation as a source of energy for vegetation growth and production (Kumar and Monteith, 1981; Monteith, 1972). The Monteith Model postulates that the biomass produced during a specific time interval is related to the solar radiation intercepted and absorbed by green plants that is to be converted into chemical energy in the form of biomass. In other words, the SMAR software computes the seasonal biomass production in a specific season according to the APAR, which is indicated by the satellite-derived vegetation index images that represent the main input of the model. The fractional biomass productions, calculated every ten days based on the ten-day vegetation index synthesis images, are summed up to represent the entire season (Ganzin *et al.*, 2005).

The Monteith model, which is often referred to as an 'efficiency' model (the model's parameters were called *efficiencies* by the author), can be summarised 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 (± 48%)
ε_b = efficiency of conversion of solar to chemical energy (g/MJ) (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 (w/m²)
δt = time step (ten days)

The method was applied and found successful in Kenya and Zimbabwe, where it gave reasonably accurate estimations of above-ground herbaceous production. The method was then applied in Namibia, first using NOAA/AVHRR data from the 1985/6 until the 1997/8 seasons. In 2000, because the NOAA satellite system was giving trouble, the SPOT/VEGETATION data from the 1998/9 rainy season onwards were used. Data from the two different satellites proved to match seamlessly.

The comparison between field measurements made between 1999 and 2001 with results derived from satellite imagery gave a good statistical correspondence (Ganzin *et al.*, 2005).

The estimated seasonal biomass production obtained through the simple process described above should be considered as a preliminary result only. Although it serves as an excellent basis from which range production can be evaluated, 'raw' biomass production estimates need additional processing in order to give a realistic indication of the resources in all situations. Indeed, the Monteith model in SMAR is applied in a simplified way, as if the vegetation cover were entirely homogeneous. Knowing that woody species are less productive than herbaceous species in terms of forage, this leads to an overestimation of what is really produced when the vegetation has an important woody component. Moreover, in terms of height and density, the biomass produced is not necessarily accessible to animals, and is not necessarily liked or well digested by them.

Considering the great variety or range types in Namibia in particular and in Africa in general, with very diverse structures and species compositions, further processing is clearly needed in order to correct the values of biomass production and obtain a reasonably accurate estimate of the forage available to animals. Dr. Nicolas Ganzin, who initiated the Biomass Production Estimation project with MAWF in 1998, proposed an original method based on three correction parameters to readjust these values. The method was named the *WAP Correction*, according to the three chosen correction parameters: woody cover (W), accessibility (A), and palatability (P). The WAP Correction is a GIS-related method in which SMAR's BPE module makes use of background information (derived from geographic information) on the vegetation types and structure described by the three WAP parameters. The process can be summarised as follows:

$$BPE_{WAP} = BPE * ((1-W) + W/2) * A * P$$

Where BPE_{WAP} = corrected biomass production estimation value from images
BPE = satellite-derived seasonal biomass production estimation
W = woody cover parameter (if the area consists of 80% grass and 20% shrubs/trees, then *W* would be 0.8)

The method assumes that woody species are half as productive as herbaceous species. Therefore, an uncorrected value for the herbaceous component (1–W%) is applied, and the woody component (W%) is divided by 2.

A = accessibility parameter (if the veld is 95% accessible in terms of vegetation, then *A* would be 0.95)
P = palatability parameter (if vegetation is 95% palatable for grazing animals, then *P* would be 0.95)

In terms of image processing over the entire zone, it consists of three consecutive correction steps, as illustrated in Figure 3.

The above operation is applied to every pixel of the biomass production image, while the values of the W, A and P parameters are extracted from 'masks' derived from the background geographic information – ideally, a land cover

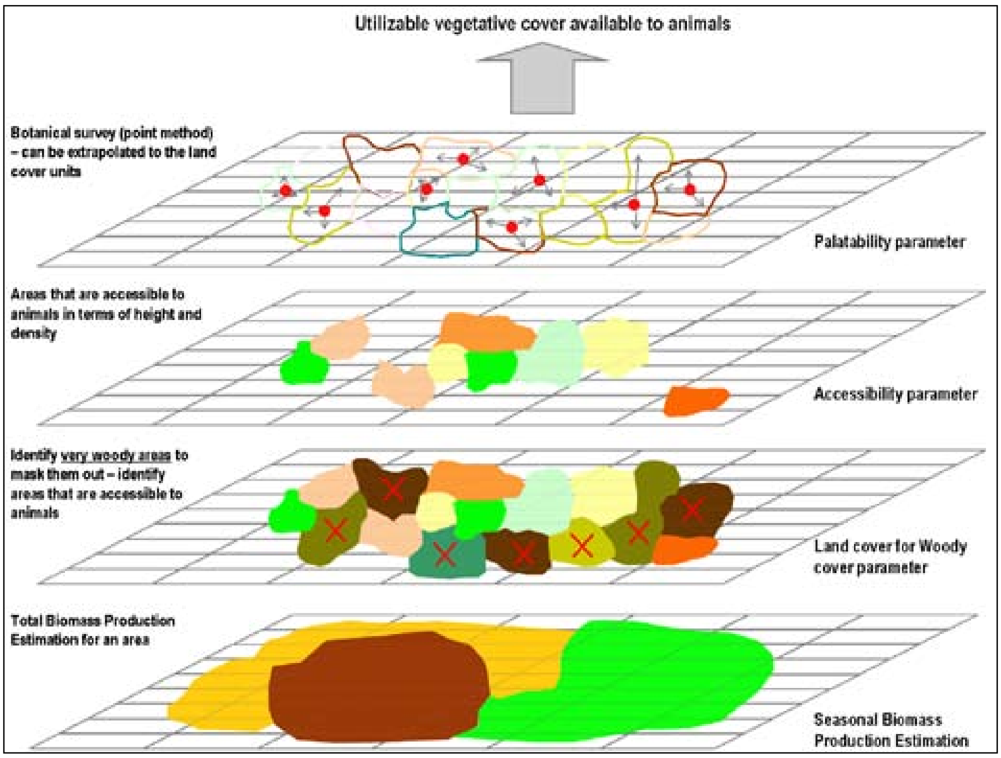


Figure 3. An illustration of the WAP correction method which is investigated to correct the raw total seasonal biomass production to get to realistic values for the utilizable vegetative cover which is available to animals.

map in GIS format that includes information on woody cover, accessibility of the veld and palatability of the grazing to animals. The three 'masks' are simply image format layers of information obtained by vector-raster conversions of the original map for the three WAP attributes, at the same resolution as the Biomass Production Estimation images, in order to have exact, pixel-by-pixel correspondence. This conversion is done using ArcView 3.2 GIS software and its Spatial Analyst extension.

The land cover image is essential for identifying very woody areas (woody cover parameter) in order to mask them out, and as a result have areas that are accessible (accessibility parameter) to animals in terms of height and density. Botanical surveys carried out by means of the point method (as described later), and in certain vegetation cover units, can be used to acquire woodiness and accessibility parameters and aid in generating a palatability parameter for that specific point, which can then also be extrapolated to the specific land cover units. It is hoped that the application of these correction parameters can give MAWF a realistic overview of the utilisable vegetative cover available to animals.

A land cover map was developed during January 2005 for a pilot area (Figure 4) of approximately 11 000 km^2 east of Windhoek (22–23° latitude, 17–19° longitude), in which 18 different types of land cover units were delineated. Of these 18 units, 10 were classified as vegetation cover units, based on vegetation structure and percentage canopy cover.

The surface area of each of the ten classified vegetation cover units was then considered. All those vegetation cover units contributing < 1% to the total area (Forest, Low shrub – open) in the pilot area were then discarded as insignificant. All encroached areas (Low shrub – closed, Tall shrub – closed) were discarded as well as grazing capacity in these areas is known to be very low and difficult to ground-truth. This resulted in six vegetation cover units remaining, contributing 72% to the total surface area of the pilot study area. These vegetation cover units were defined as follows:

- *Low shrub sparse*: All natural/semi-natural shrub dominated classes with bush/shrub canopy cover between 10–40% and a height of > 0.5 m but < 2 m. Either a single- or multi-canopy layered community comprised of mainly multi-stemmed woody plants branching at or near the ground.
- *Tall shrub sparse*: All natural/semi-natural shrub- and bush-dominated classes with bush/shrub canopy cover between 10–40% and a height of > 2 m. Either a single- or multi-canopy layered community comprised mainly multi-stemmed woody plants branching at or near the ground.
- *Tall shrub open*: All natural/semi-natural shrub- and bush-dominated classes with bush/shrub canopy cover between 40–70% and a height of > 2 m. Either a single-

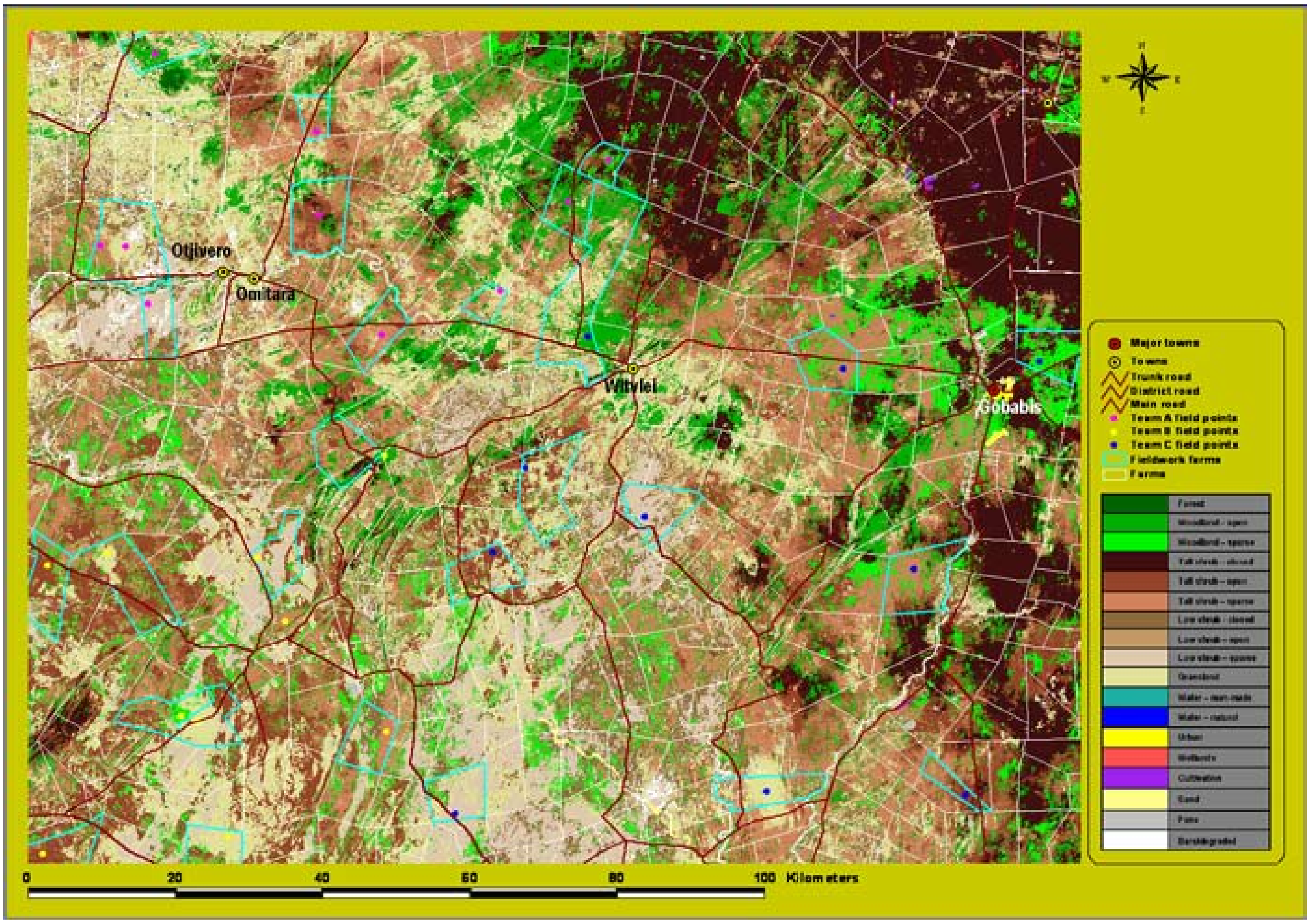


Figure 4. Fieldwork points, pilot area: 2–8 April 2005.

or multi-canopy layered community comprised mainly multi-stemmed woody plants branching at or near the ground.

- *Woodland sparse*: All natural/semi-natural tree-dominated classes with tree canopy cover between 10–40% and a height of > 5 m. Essentially a single-stemmed tree community with a low shrub or herbaceous ground cover.
- *Woodland open*: All natural/semi-natural tree-dominated classes with tree canopy cover between 40–70% and a height of > 5 m. Essentially a single-stemmed tree community with a low shrub or herbaceous ground cover.
- *Grassland*: All natural/semi-natural grass-dominated areas with < 10% tree, shrub/bush or forb canopy cover and > 1% grass cover; *grasses* defined as non-woody, rooted herbaceous plants.

Methodology to determine woody cover, accessibility and palatability parameters

Point sampling

Point sampling is one of the most common approaches to estimate cover for rangeland inventory or monitoring purposes because it is quick and relatively simple to apply. It provides a rapid, accurate, and objective method of determining the botanical composition and basal cover of herbaceous vegetation. The method provides for point readings being taken systematically along a transect across a site. The number of sampling points along a transect depends upon the vegetation, but it is usually more efficient to record more observations. According to Everson and Clarke (1987) and Hardy and Walker (1991), between 100 and 300 observations are considered to be adequate in calculating species composition. The nearest-plant approach (Foran *et al.*, 1978) is often used in conjunction with 'strike' data to determine botanical composition for a specific area. 'Strike' data are derived by determining the proportion of the points that 'hit' (intercept) vegetation. In this manner, total cover can be calculated as the percentage of hits, relative to the number of points sampled. Cover of individual species can also be estimated by recording the plant species when intercepted by a point (Figure 5a).

In the pilot area, a 500-point line intersect botanical survey was carried out at a randomly selected site in each of the six vegetation classes, as classified during the Land Cover Mapping Project. Points were spaced 1 m apart on the transect. At each point, the closest grass plant to that point, or the grass plant intersected by that point, was recorded (Figure 5a). This allowed the occurrence of species to be expressed as a percentage, which was later used in allocating a palatability factor.

Cover and accessibility

It was possible to calculate a woody cover percentage during the 500-point botanical survey. Each time a point was found to occur below the canopy of a woody species, it was duly noted. By the end of the survey, the number of points occurring below the canopy of a woody species were tallied and expressed as a percentage of the 500 points surveyed. Counting bush (its density) and relegating them to various height classes was thought to be very useful in the allocation of a woody cover and accessibility value (expressed as a percentage). Therefore, a bush count was carried out concurrently with the botanical survey along

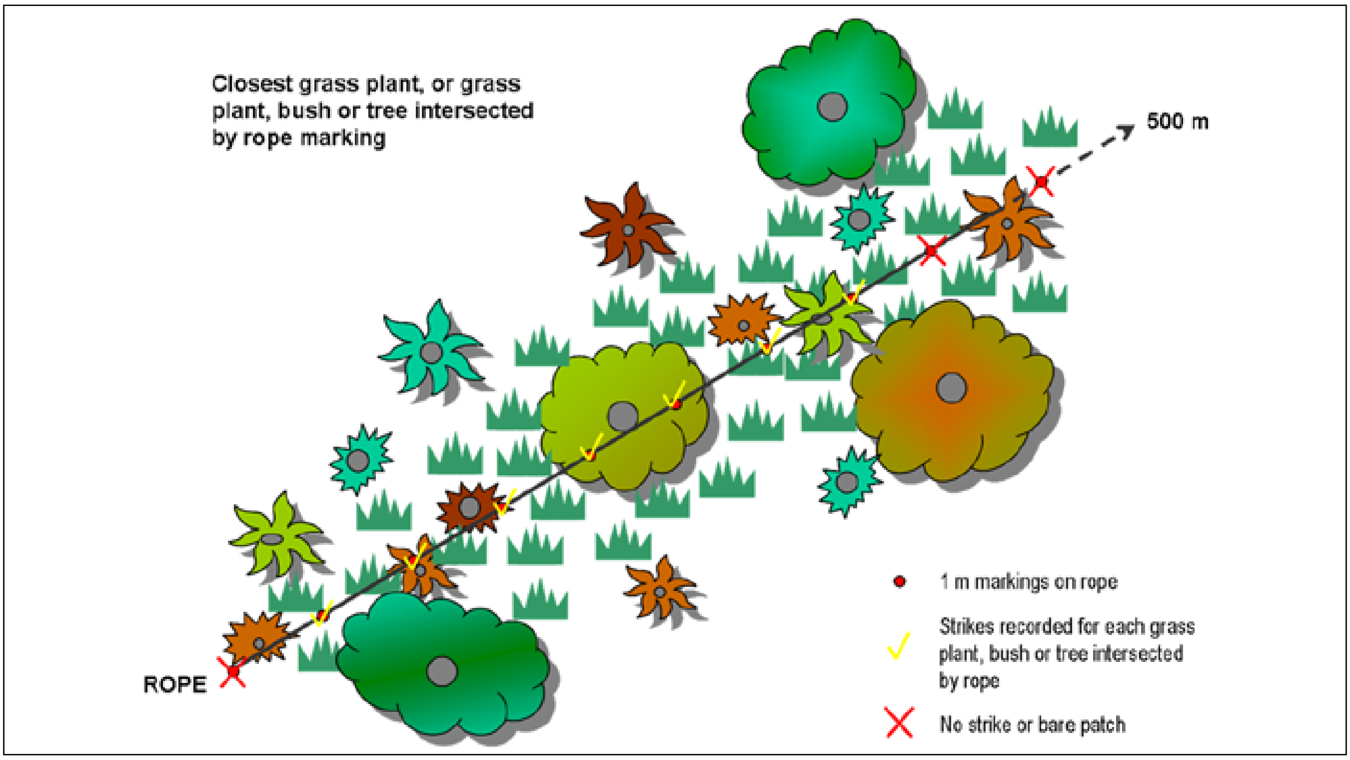


Figure 5a. Schematic representation of how the botanical survey was carried out.

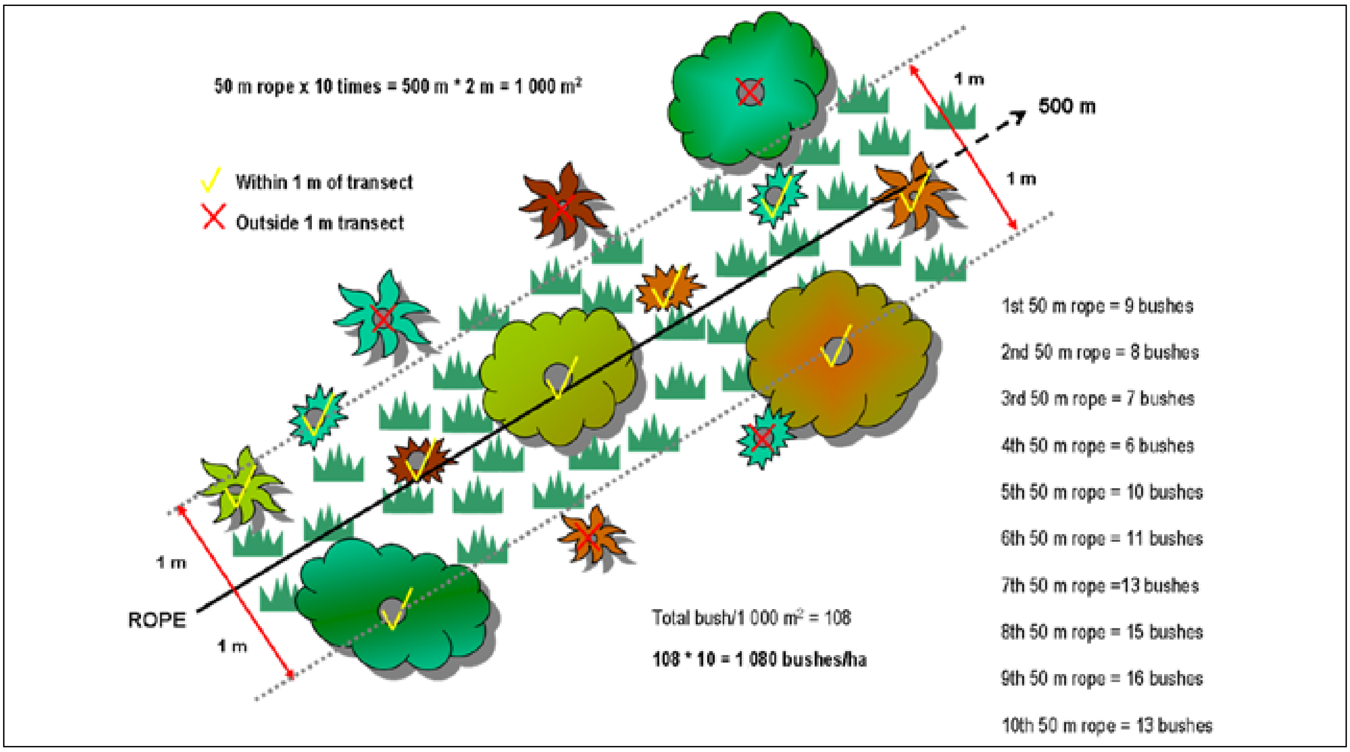


Figure 5b. Schematic representation of how the botanical survey was carried out.

the 500 m transect line (Figure 5b). All bushes within 1 m on either side of the transect line were tallied and classified according to height (≤ 50 cm, ≤ 1 m, 1–2 m, 2–4 m, and ≥ 4 m).

In order to determine accessibility, it was necessary that cut-off points be established in terms of density as well as height. These, of course, are arbitrary. For example, is an area deemed to be inaccessible (impenetrable) when the density exceeds 6 000, 7 000 or 8 000 bushes/ha of a height of ≤ 2 m?

The following density classes were used:

- Accessible (penetrable): ≤ 8 000 bushes/ha
- Inaccessible (impenetrable): > 8 001 bushes/ha

The following figures were allocated to each of the density classes:

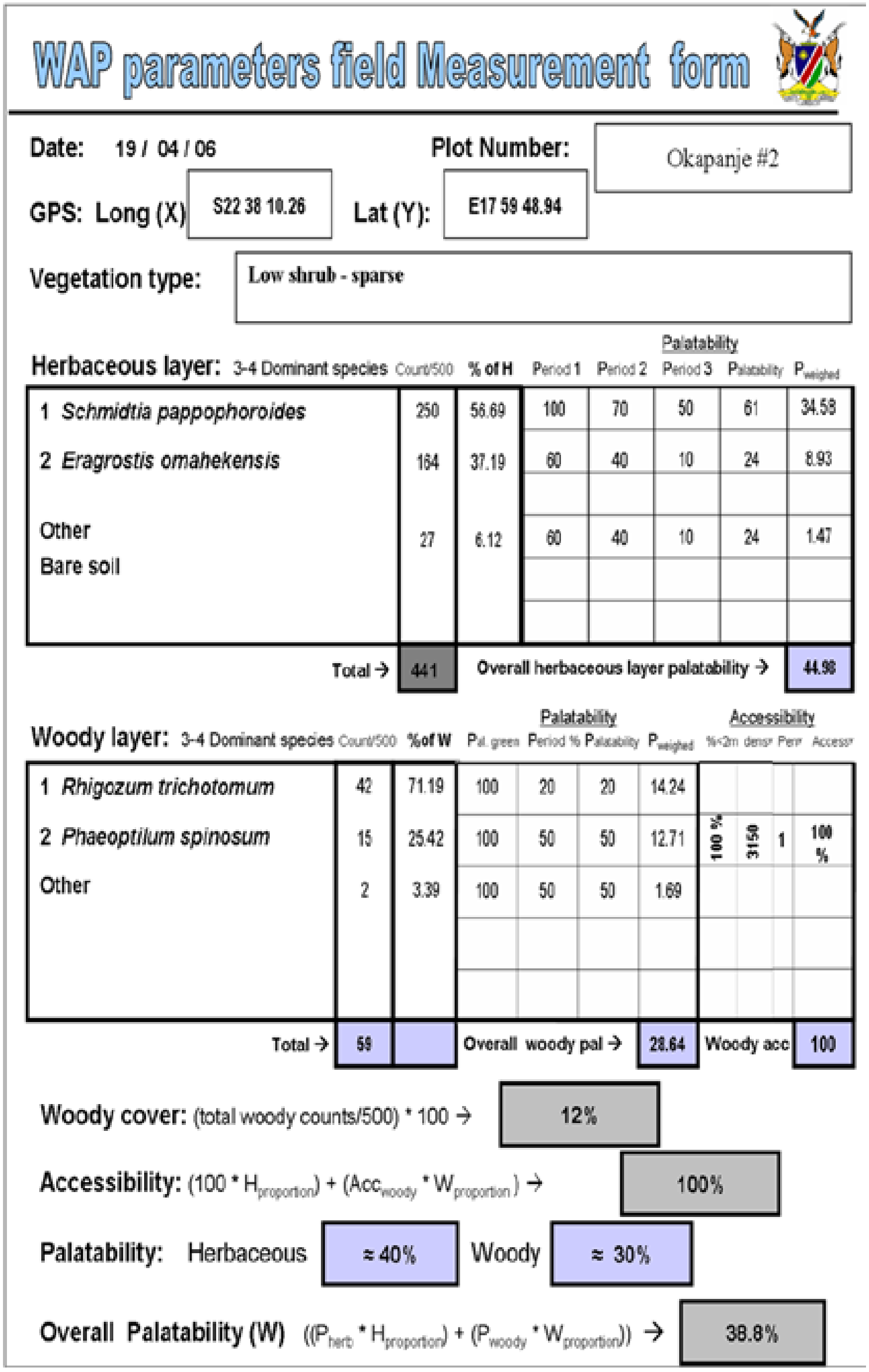
- ≤ 8 000 bushes/ha = 1
- > 8 001 bushes/ha = 0

Bushes exceeding 2 m in height was considered to be inaccessible, while those below 2 m in height were considered 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 less than 2 m in height. This percentage was then multiplied with either 0 or 1 to arrive at a final accessibility figure.

After the botanical composition and bush density surveys were completed, data for each site were summarised in the format set out in Table 1 below and then transferred to the specially designed WAP Parameter Field Measurement Form (Figure 6), which enabled workers to objectively calculate woody cover and accessibility parameters.

Table 1. Data collected from one of the sites (Okapanje) during the botanical survey and bush count

Plot (No.)	Botanical composition as per line transect				Bush density as per 1 000 m² quadrat					
	Four dominant grass species	Total No.	Four dominant bush species	Total No.	Additional bush species	Bush densities				
						≤ 50 cm	≤ 1 m	1–2 m	2–4 m	≥ 4 m
Groot Okapanje (2)	*Schmidtia pappophoroides*	250	*Rhigozum trichotomum*	42		95	170	10		
	Eragrostis spp	164			*Phaeoptilum spinosum*	3	16	13		
					Acacia erioloba	5				
					Catophractes alexandri	1				
					Acacia hebeclada		2			



WAP parameters field Measurement form

Date: 19 / 04 / 06 | Plot Number: Okapanje #2

GPS: Long (X) S22 38 10.26 | Lat (Y): E17 59 48.94

Vegetation type: Low shrub - sparse

Herbaceous layer: 3-4 Dominant species

3-4 Dominant species	Count/500	% of H	Period 1	Period 2	Period 3	Palatability	$P_{weighed}$
1 *Schmidtia pappophoroides*	250	56.69	100	70	50	61	34.58
2 *Eragrostis omahekensis*	164	37.19	60	40	10	24	8.93
Other	27	6.12	60	40	10	24	1.47
Bare soil							
Total →	441	Overall herbaceous layer palatability →					44.98

Woody layer: 3-4 Dominant species

3-4 Dominant species	Count/500	%of W	Pal. green	Period %	Palatability	$P_{weighed}$	%<2m	dens*	Pen*	Access*
1 *Rhigozum trichotomum*	42	71.19	100	20	20	14.24				
2 *Phaeoptilum spinosum*	15	25.42	100	50	50	12.71	100 %	3150	1	100 %
Other	2	3.39	100	50	50	1.69				
Total →	59		Overall woody pal →			28.64	Woody acc			100

Woody cover: (total woody counts/500) * 100 → 12%

Accessibility: (100 * $H_{proportion}$) + (Acc_{woody} * $W_{proportion}$) → 100%

Palatability: Herbaceous ≈ 40% Woody ≈ 30%

Overall Palatability (W) ((P_{herb} * $H_{proportion}$) + (P_{woody} * $W_{proportion}$)) → 38.8%

Figure 6. Completed WAP Parameter Field Measurement Form for one of the sampling sites (Okapanje) in the pilot area.

Palatability

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

- P1 = one month of the year (January), expressed as a percentage = 8% ≈ 10%
- P2 = four months of the year (February–May), expressed as a percentage = 33% ≈ 30%, and
- P3 = seven months of the year (June–December), expressed as a percentage = 58% ≈ 60%.

Each of these percentages was then multiplied by the subjectively estimated palatability of species encountered during the survey. An example is *Schmidtia pappophoroides*, which is considered to be very palatable (factor of 100) for the month of January; it was multiplied by 10%, therefore, to give 10. It was decided that palatability decreased to a factor of 70 for four months of the year (February–May), and further decreased to a factor of 50 for seven months of the year (June–December). Palatability for this species was then calculated as follows:

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

As *Schmidtia pappophoroides* had a percentage occurrence of 56.69% in the *Low shrub – sparse* survey, the factor of 61 was then multiplied with 56.69% = 34.58, which was then deemed to be the palatability factor for *S. pappophoroides*.

Different palatability factors were allocated to different grass species encountered during surveys. For example, while *S. pappophoroides* was considered to be palatable by a factor of 100 for one month of the year, *Eragrostis omahekensis* was considered to be palatable by a factor of only 60 for the corresponding period (based on expert opinion).

The palatability factors for all grass species occurring in the survey were then added together to arrive at a total palatability factor for the herbaceous component of that particular land cover unit (Figure 6).

Palatability for bushes followed a similar approach to that described for grass, with the exception that all bushes were considered to be equally palatable, but that they retained this palatability for various lengths of time during the year. For example, *Rhigozum trichotomum* was considered to be very palatable (100) for a period of about two months of the year (= 16.6% ≈ 20%). Its palatability was then weighed (100 * 20%) to give a factor of 20. This factor was then multiplied with the percentage occurrence of *R. trichotomum*, which in the case of the Okapanje site (*Low shrub – sparse* land cover unit) was 71.19%, to arrive at a palatability factor of 14.24 (Figure 6).

The palatability factors for all woody species occurring in the survey were then added together to arrive at a total palatability factor for the woody component of that particular vegetation cover unit (Figure 6).

The contribution of each component – herbaceous and woody – to palatability was then weighed by multiplying its percentage contribution to total species composition with the total palatability factor for the component concerned. The two weighed percentages were then added together to arrive at an overall palatability factor, which was the final figure for this parameter (Figure 6).

The values reflected in the WAP Parameter Field Measurement Form were used to create 'masks', which were applied to the total seasonal biomass production image (Figure 8).

Land cover map to assist in determining grazing capacity

As a result of a joint effort between the Pasture Science and Analytical Services Sections within MAWF, an exercise to determine grazing capacity was carried out to create the first set of grazing capacity data for the pilot area. The land cover map of the pilot area was used to identify six prominent 'veld types'. Within these 'veld types', 30 points were randomly selected, and the surveys were carried out at those points (Figure 7).

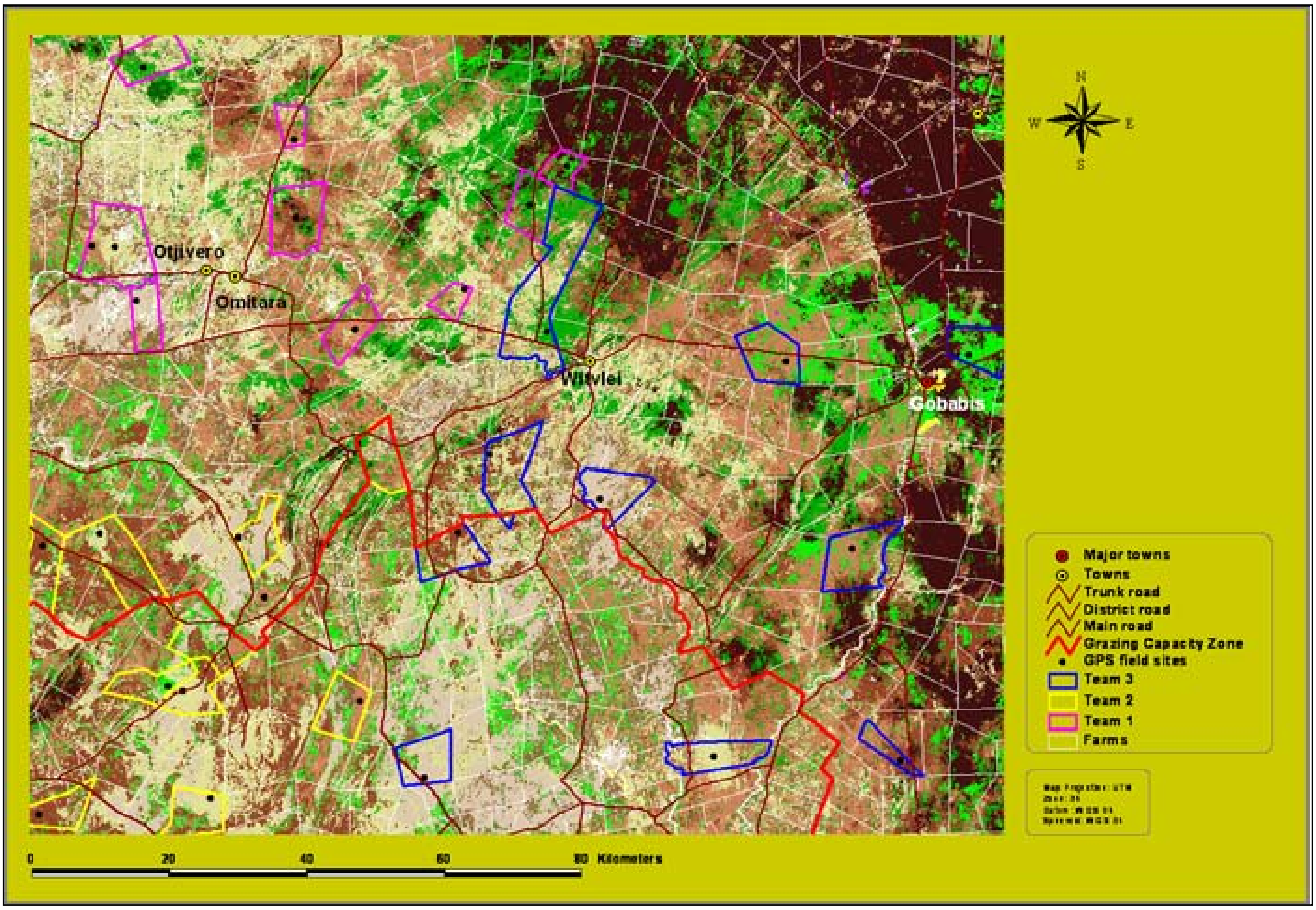


Figure 7. Land cover map of pilot area indicating the sampling sites for determining grazing capacity.

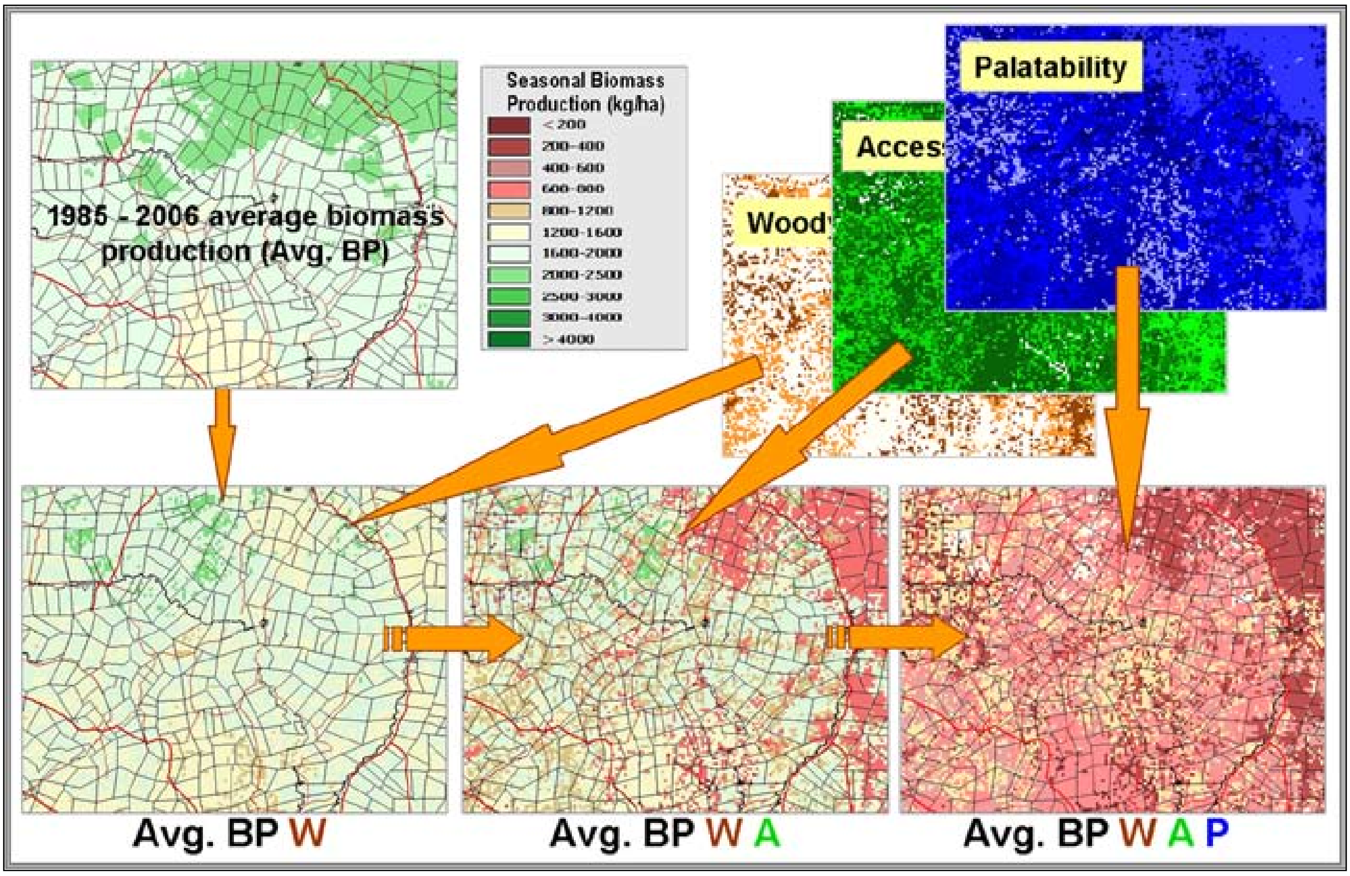


Figure 8. Application of the WAP parameters to the estimated biomass production of the pilot area for the 1985 to 2006 growing seasons.

The quantitative yield method was used for this purpose, as it is based on the objective measuring of plant biomass. The method consists of clipping 40 x 1-m^2 quadrats (using Stein's two-stage sample size equation) per site (farm) along a 1-km transect (line). All grass within these quadrats was clipped as close as possible to ground level, and then dried and weighed. Animal biomass was determined by weighing animals regularly. By setting the daily dry material (DM) intake of an animal at 3% of live weight, and matching the amount of DM needed to the amount of available grass material, the yearly grazing capacity of an area can be determined. Bester (1998) describes the complete methodology.

RESULTS AND DISCUSSION

WAP Parameter Field Measurement exercise

By following the approach described earlier, a WAP Parameter Field Measurement Form for the six sites could be completed, from which woody cover, accessibility and palatability 'masks' could be generated. These 'masks' were then applied to the total seasonal biomass production image (average of 21 years of images) of the pilot area, which generated the final seasonal biomass image (Figure 8).

If it is accepted that only 50% of the calculated biomass is available in order to maintain vigour of the sward, then a figure of 800–1 000 kg biomass/ha as per Figure 7 can be converted to grazing capacity as follows:

- The point of departure is that a kilogram of animal biomass needs 3% per day in DM to sustain itself.
- Over a one-year period, this amounts to 1 x 3% x 365 = 10.95 kg DM.
- Therefore, the 800–1 000 kg are divided by 2 (only 50% utilised to maintain vigor) = 400–500 kg plant biomass ÷ 10.95 = 36.5–45.7 kg animal biomass/ha.
- If one large stock unit (LSU) equates to 450 kg animal biomass (Trollope *et al.*, 1990), then each LSU would require between 12.32 ha (450 ÷ 36.5) and 9.84 ha (450 ÷ 45.7) to maintain itself.

To avoid overestimating grazing capacity from the corrected total seasonal biomass production image, a proper use factor needs to be introduced. A 50% utilisation level is considered proper in range science circles, as this is the accepted level of defoliation that a grass plant can undergo before it incurs physiological damage.

Table 2. Results of the grazing capacity (GC) estimated from total seasonal biomass (TSB) production corrected for WAP

Vegetation cover unit	GC as per TSB (kg animal biomass [AB]/ha, excluding proper use factor*)	GC as per TSB (kg AB/ha, including proper use factor*)	2006 calculated ha/LSU (including proper use factor*)	Vegetation cover unit	GC as per TSB (kg AB/ha, excluding proper use factor*)	GC as per TSB (kg AB/ha, including proper use factor*)	2006 calculated ha/LSU (including proper use factor*)
Alt Harte-beesvlei	73–109.6	36.5–54.8	12.3–8.2	Autabib Ost	36.5–54.8	18.3–27.4	24.6–16.4
Groot Okapanje	54.8–73	27.4–36.5	16.4–12.3	Duvenhage	9.13–18.3	4.6–9.7	97.8–46.4
Grunental	54.8–73	27.4–36.5	16.4–12.3	Eliza	73–109.6	36.5–54.8	12.3–8.2
Kanabis	73–109.6	36.5–54.8	12.3–8.2	Golden Aue	54.8–73	27.4–36.5	16.4–12.3
Kaukus (Saaleck)	73–109.6	36.5–54.8	12.3–8.2	Gross Osombahe	36.5–54.8	18.3–27.4	24.6–16.4
Merino	54.8–73	27.4–36.5	16.4–12.3	Helene	73–109.6	36.5–54.8	12.3–8.2
Olive	54.8–73	27.4–36.5	16.4–12.3	Herzwalde Section 1	54.8–73	27.4–36.5	16.4–12.3
Orumbe Nord	73–109.6	36.5–54.8	12.3–8.2	Kameel-boom		–	
Orumbu	< 18.2	< 9.1	< 49.4	Kaukurus Ost	54.8–73	27.4–36.5	16.4–12.3
Otjiwarun-mendu	73–109.6	36.5–54.8	12.3–8.2	Mountain View	54.8–73	27.4–36.5	16.4–12.3
Owiniekiro	73–109.6	36.5–54.8	12.3–8.2	Nuwe Orde	54.8–73	27.4–36.5	16.4–12.3
Spandau	54.8–73	27.4–36.5	16.4–12.3	Orumbu Nord	54.8–73	27.4–36.5	16.4–12.3
Smalhoek	54.8–73	27.4–36.5	16.4–12.3	Sandkraal	54.8–73	27.4–36.5	16.4–12.3
Volmoed Ranch	36.5–54.8	18.3–27.4	24.6–16.4	Scheidthof	36.5–54.8	18.3–27.4	24.6–16.4
Wiesesrus	54.8–73	27.4–36.5	16.4–12.3	Wendel-stein	73–109.6	36.5–54.8	12.3–8.2

* Proper use factor = 50%; only 50% of the calculated biomass taken into consideration, as this is deemed to be the level at which grass material can be utilised without detrimental effects to the plant.

Although it was possible to calculate a value for palatability at each site, the accuracy of this parameter remains questionable: allocating a value is extremely difficult, due to the influence of a number of factors, and variability within these factors. Some of the most important factors that need to be taken into account in this regard are the plant's chemical composition, the presence of volatile oils, the proportion of plant parts, its growth stage, the kind of plant involved, the availability of a species in the vegetation, or a combination of some or all of these. Proteins and carbohydrates (elements of the chemical composition of plants), which usually correlate positively with palatability, vary tremendously over time and locality. Temporal variation also applies to the growth stage of the plant, for example. Typically, grass plants are more palatable in the early growth stages, but palatability rapidly decreases as the plant matures due to an increase in its fibre content, which is negatively correlated with palatability. An attempt was made to provide for this variable by integrating three time periods in the WAP Parameter Field Measurement Form. However, the complexity of this aspect is well known, so it remains extremely difficult to allocate a realistic percentage to this parameter.

Quantitative Yield Method

The grazing capacity of 30 sites was calculated according to the Quantitative Yield Method (clipping of quadrats). The location of these sites was randomly selected within the developed Land Cover Map (Figure 8). The 30 sites extend over two of the existing grazing capacity map areas, namely the 1:10 and 1:12 areas, and include sites in the following land use cover units: *Grassland*, *Low shrub – sparse*, *Woodland – parse*, *Woodland – open*, *Tall shrub – open*, and *Tall Shrub – sparse*.

Comparison of the calculated grazing capacity figures with the old accepted norms cannot be done at this point, as the calculated figures are for the 2005/6 growing season only. Calculated figures should only be compared with the accepted norm once surveys have been carried out over a sufficiently long period of time, which should be such that rainfall variability is adequately captured (L. Lubbe, MAWF, pers. comm. 2006). Furthermore, although it is possible to start with the allocation of a grazing capacity to a specific vegetation cover unit, ground-truthing should also be carried out for a sufficiently long period before a specific land cover unit can be attached to a specific grazing capacity.

It should also be stressed that the figures generated in Table 3 cannot be compared with those generated in Table 2. The methodology used in Table 2 employed 21 years of imagery acquired every ten days, while the data in Table 3 are the first set of a five-year project, acquired after an exceptionally good rainy season.

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Table 3. Calculated grazing capacity (GC) using the Land Cover Map of the pilot project and old map grazing capacities

Vegetation cover unit	2006 calcula-tion of GC/site (kg animal biomass [AB]/ha)	2006 calcula-tion of GC (ha/LSU)	Previously estimated GC (expert opinion) (ha/LSU)	Vegetation cover unit	2006 calcula-tion of GC/site (kg AB/ha)	2006 calcula-tion of GC (ha/LSU)	Previously estimated GC (expert opinion) (ha/LSU)
Alt Hartebees-vlei	86.86	5.18	12	Golden Aue	69.17	6.51	10
Kanabis	48.85	9.21	12	Helene	50.68	8.88	12
Orumbe Nord	43.23	10.41	10	Kaukurus Ost	23.24	19.36	10
Otjiwarun-mendu	25.83	17.42	10	Nuwe Orde	55.10	8.17	10
Smalhoek	110.69	4.07	12	Orumbu Nord	20.44	22.01	10
Volmoed Ranch	77.06	5.84	10	Sandkraal	41.29	10.9	10
Wiesesrus	55.81	8.06	10	Scheidthof	24.24	18.57	10
Grunental	42.51	10.59	10	Autabib Ost	61.94	7.27	10
Merino	39.35	11.44	10	Duvenhage	50.17	8.97	10
Owiniekiro	65.81	6.84	10	Eliza	87.32	5.15	10
Spandau	44.30	10.16	10	Gross Osombahe	62.26	7.23	10
Groot Okapanje	87.18	5.16	10	Kameel-boom	49.90	9.02	10
Kaukurus (Saaleck)	86.08	5.23	10	Herzwalde Portion 1	70.70	6.37	10
Olive	94.78	4.75	12	Mountain View	92.86	4.85	12
Orumbu	54.49	8.26	10	Wendel-stein	36.07	12.47	10

Grassland
Low shrub – sparse
Woodland – sparse
Woodland – open
Tall shrub – open
Tall shrub – sparse

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