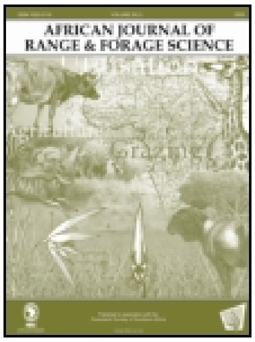

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Carrying capacity of the succulent valley bushveld of the eastern Cape

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Carrying capacity of the succulent valley bushveld of the eastern Cape

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Abstract

This experiment evaluated the relationship between carrying capacity and veld condition. Goat browsing days were used as a measure of shrub productivity and cattle grazing days as a measure of the sward. Twigs on two shrub species were monitored to quantify utilization and recovery of the woody layer and a pasture disc meter was used to monitor grazing of the grass layer. Dense bushveld (high ecological status) had higher overall carrying capacity than open bushveld (low ecological status). Carrying capacity changed considerably depending on annual rainfall and this was complicated because the more degraded the veld the greater the variation. Maximum long-term grass production occurred at intermediate tree densities. This was, however, extremely unreliable between years and a permanent grazer enterprise cannot be recommended. For total forage production and constant fodder supply, dense bushveld is optimum. Optimum, however, changes from season to season and with operator objectives. In wet seasons it will pay to have veld in the lower range of ecological status (i.e. open bushveld) whereas in other seasons veld with high ecological status (dense bushveld) will be more productive. Farmers with only cattle may aim to have veld in the mid-range of ecological status but this conflicts with farmers who have browsers (e.g. goats and kudu) and with the conservation ideal, because bushveld, once thinned, does not regenerate, thereby limiting future management alternatives.

Introduction

The succulent valley bushveld, also known as Kaffrarian Succulent Thicket (Cowling 1984), occurs on the eastern seaboard of South Africa in hot, dry (rainfall 225 to 500 mm a^{-1}), frost-free areas at low altitudes (usually below 500 m but never above 1 000 m) (Acocks 1975; Cowling 1984; Everard 1987; Agmet. records, Döhne Research Station, Private Bag X15, Stutterheim, 4930 Republic of South Africa). It is a dense, semi-succulent, thorny thicket approximately 2 to 3 m high where succulents contribute in excess of 20 to 30% relative cover (Cowling 1984). Grasses are present, but sparse (10 000–30 000 plants ha^{-1}) and mostly non-perennial (Acocks 1975). In a pristine state this vegetation is dominated by the tree-succulent *Portulacaria afra* (nomenclature follows Gibbs Russell *et al.* 1987), representing over half of the total phytomass (data from Aucamp 1979). It is considered to be the most important plant from a goat forage production viewpoint (Aucamp 1979).

This vegetation is currently farmed with goats and supports a large proportion of the mohair industry of South Africa. It is sensitive to utilization and is rapidly being eliminated under current pastoral systems (Hoffman & Everard 1987; Hoffman 1989; Hoffman & Cowling 1990). This is serious as it represents an irreversible loss of a unique vegetation type, and the community which replaces it is unstable, prone to soil erosion, and alleged to support fewer stock. There has been considerable controversy over the years regarding the carrying capacity of succulent valley bushveld, with some farmers claiming that the vegetation can carry large numbers of animals without becoming degraded. The objective of this study was to evaluate the carrying capacity of succulent valley bushveld in various conditions (states).

Numerous authors have attempted to define carrying capacity (Booysen 1967; Caughley 1979; Collinson & Goodman 1982; Danckwerts 1982; Turner 1988; Trollope & Trollope 1990) but these definitions are not consistent. Carrying capacity is a rather nebulous notion of sustainable productivity and, as a consequence, is an aspect frequently avoided by purist scientists. Despite the academic demerits of determining carrying capacity it is possibly the information most frequently requested by land managers, and applied scientists are, therefore, obliged to provide such guidelines. Invariably, carrying capacity attempts to describe the productivity of the vegetation in terms of the number of animals that can be maintained in a productive state on an area of land without deterioration of vegetation or soil (Danckwerts 1989).

In this study, carrying capacity was determined by using an experimental approach similar to that devised by Danckwerts (1982) for sweet grassveld. The carrying capacity estimates determined in this study are intended to be used as initial guidelines which land managers can immediately implement, and later adapt.

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Procedure

The experimental approach was to use animals to harvest seasonal production with a simulated rotational grazing/browsing system, similar to that devised by Danckwerts (1982). Forage is produced by a host of herbaceous, succulent and woody species, the relative contributions changing from site to site. We viewed this productivity as two sources of forage: herbage for grazers and browse for browsers. The idea was to use goat browsing days to measure shrub productivity and cattle grazing days for the grass. The number of grazing/browsing days obtained per unit area was considered to be an index of the forage productivity and, therefore, carrying capacity.

Five 2-ha camps were visually selected in the Kirkwood district so that (1) they represented a range in possible vegetation conditions or states; (2) the vegetation within a single camp was relatively homogeneous; and (3) they were in close proximity to each other (<1 km) to reduce the influence of differential rainfall events between sites. The sites were surveyed using a modified point-centred-quarter method and the principal components analysis (described in Stuart-Hill *et al.* 1986). Vegetation scores were obtained for each camp and these were later modified by Stuart-Hill (1989) to be independent of value judgement (see also Stuart-Hill & Hobson 1991). Each site received a score which ranged between 100 and −10 (Table 1), although in practice the range in scores is open ended. High scores represent very dense thicket vegetation dominated by *P. afra* (pristine succulent valley bushveld) and low scores represent an ephemeral herbaceous community with a woody layer consisting of a few scattered umbrella-shaped *Pappea capensis* trees interspersed with unpalatable shrubs such as *Lycium oxycarpum* and *Zygophyllum morgsana*.

All wild ungulates (kudu, bushbuck, duiker, and grysbok) were excluded from the experimental camps with a 4 m high game fence and the camps were rested for 10 months before the first grazing in February 1986. Seasons were assumed to start in May and end in April. The experiment continued until the end of April 1988.

Determination of browsing capacity

Portulacaria afra and *Grewia robusta* were selected as the browse indicator plants because both are important forage producers (Aucamp 1979), and *P. afra* in particular is one of the first plants to be eliminated with heavy browsing.

Portulacaria afra and *G. robusta* plants were selected in a stratified random manner and marked. The number of plants per camp varied according to the density of shrubs in each camp (see Table 1 for numbers of plants per camp). Six twigs were permanently marked (Figure 1) on each plant. Twig length and leaf number were monitored before, during, and after each browsing period to ensure that browse utilization was the same between camps.

Goats were placed in each camp and allowed to browse until 50% of leaves of either *P. afra* or *G. robusta* had been removed, or 25% of twig length of either species had been removed, or the animals were losing weight. The weights of 15 goats camp^{-1} were monitored before, during, and at the end of each browsing period. The rest of the animals in each camp (filler animals) were not weighed individually.

During the non-browsing (recovery) periods, the marked twigs were measured at approximately monthly intervals. When twig length and leaf number had recovered to pre-defoliation levels, plants were assumed to have recovered and the next grazing period was started.

Over a period of three years, the total number of kg livemass browsing days for each camp was determined, the idea being that this represented sustainable browse (goat) productivity for that camp. These values were converted to LSU per hectare and hectares per LSU. Throughout the experimental period, it was attempted to keep game out of the camps, but when this was not possible the number and type of animals and the period which they occupied the camps was recorded at weekly intervals. These were all browsers (Smithers 1983) and kilogram livemass browsing days for these animals were added to the browser totals.

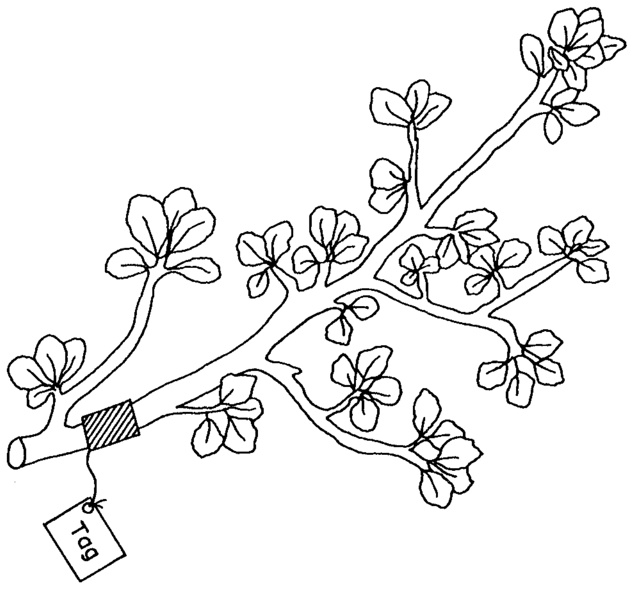

Figure 1 Detail of twig showing marking procedure. All leaves on the marked twig were counted and the lengths of all the subsidiary twigs were measured and added to give total twig length.

Table 1 Number of plants monitored in each of the five experimental camps

Camp number	Vegetation score	*Portulacaria afra* plants	*Grewia robusta* plants
1	100	10	10
2	84	8	8
3	46	6	6
4	20	6	6
5	−9	–	6

There were insufficient *P. afra* plants in camp 5

Determination of grazing capacity

When sufficient grass was present (only following exceptional rainfall events) dry dairy cattle were introduced into each camp. Sward height was monitored with 100 placements of a pasture disc meter (Bransby & Tainton 1977) and the cattle were removed once average disc height was within 5 mm of 30 mm, the height at which animals would be on restricted intake (using the logic argued by Danckwerts 1982). Cattle were weighed before, during, and at the end of each period of occupation, and if they started to consistently lose weight, the experimental rule was to terminate the period of occupation. In addition to monitoring sward height, 50 square quadrats (1 m × 1 m) were cut just prior to and immediately following the period of occupation. Owing to the clumped nature of the woody layer, the sward was discontinuous over the area. Sward sampling was confined to those areas where the sward was dominant and a consequence is that the measurements for the sward do not reflect herbage availability in each camp. Rather, these data were merely used to monitor herbage disappearance to ensure even utilization between camps.

Over a period of three years, the total number of kilogram livemass grazing days for each camp was determined, the idea being that this represented sustainable grazing (cattle) productivity for that camp. These values were converted to LSU per hectare and hectares per LSU. Naturally there was some dietary overlap between the goats and cattle, but as the latter are not a permanent component of farming systems in this vegetation, this problem was overcome by letting the goats be the primary enterprise with the cattle following. It follows that browsing capacity might be slightly inflated at the expense of grazing capacity. This, however, is likely to be insignificant as the goats were never subjected to nutritional stress and were, therefore, primarily browsers (Aucamp 1979).

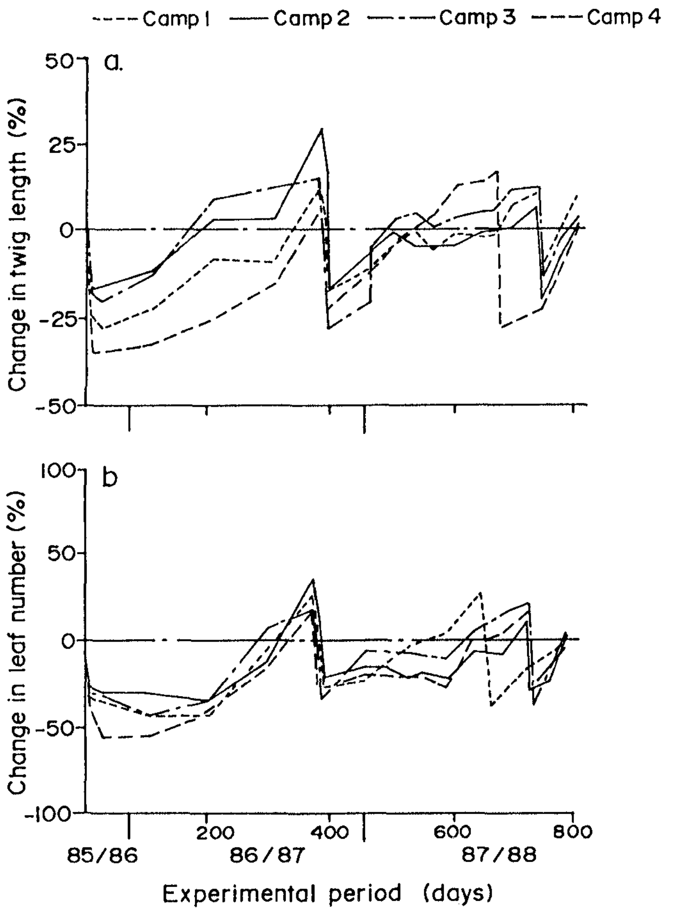

Figure 2 Change over the experimental period of twig length (a) and leaf number (b) of permanently marked *Portulacaria afra* twigs in four 2-ha camps representing differing states of Succulent Valley Bushveld. Camps were rested for 10 months before the first grazing; six twigs were marked on each plant (see Table 1 for number of plants marked per camp); statistics are contained in Table 2.

Productivity of animals

As described, animal mass was monitored during each period of occupation, but as these were inevitably short (less than one month), these data could not be used to reliably quantify animal productivity. They were nevertheless used to ensure that the animals did not lose weight as one of the experimental rules was that the animals were to be removed from the camp as soon as they started to consistently lose weight.

Data analysis

The mean change in twig length and leaf number against that originally present was determined at each sampling date for both shrub species in all five camps. These were relativized (expressed as a percentage change) and plotted against time to give a graphical display of the relative utilization or recovery of the twigs or leaf number (Figures 2 and 3). Confidence limits for each mean are not displayed as they confuse the trends and are not necessary as the repeatability of this technique is being reported in a separate study (Stuart-Hill unpubl.). However, least significant differences ($P = 0.05$) for each parameter on both species in each camp are summarized in Table 2. It will be noted that the technique was more repeatable for *G. robusta* than for *P. afra*.

Results

Browsing capacity

Twig monitoring

The change in twig length and leaf number of *P. afra* and *G. robusta* over the experimental period is shown in Figures 2 and 3, respectively. There was a severe dry spell (1986/87) after the first period of occupation and the plants were slow to recover. In some cases defoliation continued through desiccation (Figures 2b and 3b). During the latter part of the 1987/88 season, growing conditions were more favourable and recovery was rapid.

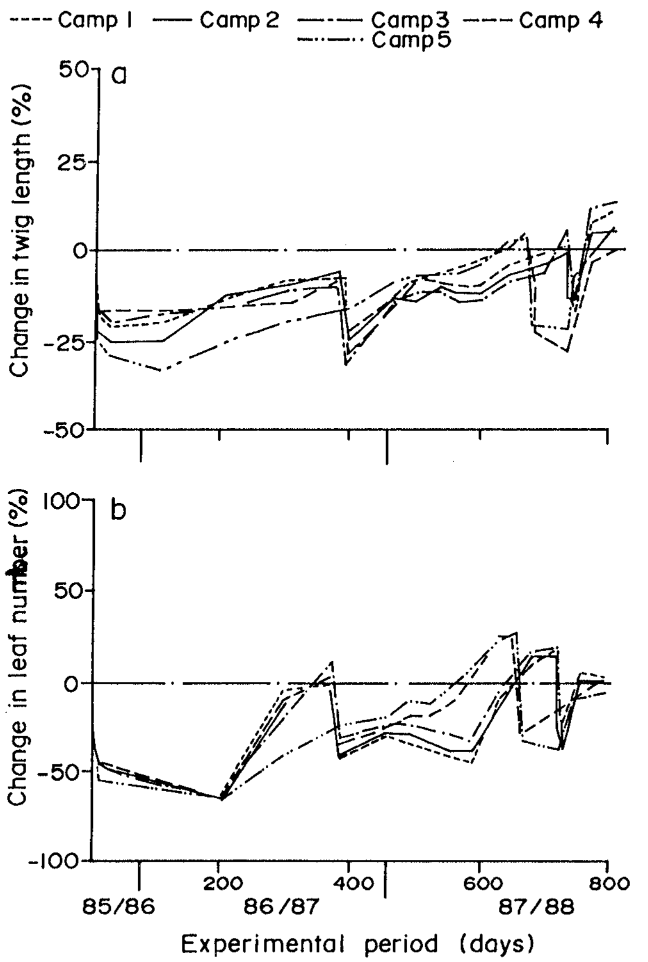

Figure 3 Change over the experimental period of twig length (a) and leaf number (b) of permanently marked *Grewia robusta* twigs in five 2-ha camps representing differing states of Succulent Valley Bushveld. Camps were rested for 10 months before the first grazing; six twigs were marked on each plant (see Table 1 for number of plants marked per camp); statistics are contained in Table 2.

Table 2 Number of samples (N) and least significant differences (P = 0.05) for each parameter measured in this study

	Portulacaria afra			*Grewia robusta*		
		Change in			Change in	
Camp number	N	Twig length (%)	Leaf number (%)	N	Twig length (%)	Leaf number (%)
1	60	20	25	60	12	6
2	48	22	28	48	15	7
3	36	25	35	36	18	8
4	36	25	35	36	18	8
5	0[1]	–	–	36	18	8

[1]There were insufficient *P. afra* plants in this camp

Prior to the second period of occupation, *G. robusta* twig length in all camps had not recovered to pre-defoliation levels, but it was nevertheless decided to browse camps 1 to 4 as *P. afra* had regrown to well beyond its pre-defoliation levels and *G. robusta* leaves in these four camps had recovered. Camp 5 was not utilized during the second period of occupation (1986/87) as neither the twigs nor leaves of *G. robusta* had recovered to pre-defoliation levels.

Table 3 Mean masses (kg) of goats monitored on each treatment during the various periods of occupation. Standard errors ranged between 6.51 and 7.92 kg

Date	Camp 1	Camp 2	Camp 3	Camp 4	Camp 5
Feb. 1986					
20.2	38	38	40	38	38
25.2	39	39	39	41	39
27.2	42	40	39	39	39
30.2	42	41	40	41	40
2.3	42	42	41	41	39
5.3	42	41	41	41	40
Feb. 1987					
24.2	42	40	42	40	
27.2	42	39	44	39	
3.3	42	40	43	39	
5.3	41	39	42	40	
9.3	41	41	43	39	
11.3	42	40	43	40	
13.3	43	41	43	41	
Dec. 1987					
4.12				50	54
7.12				48	52
9.12				48	53
11.12				50	52
13.12				50	51
16.12				51	54
20.12				52	55
Feb. 1988					
9.2	50	47	51		
10.2	50	50	53		
12.2	52	51	53		
15.2	53	51	53		
17.2	53	51	53		
19.2	52	52	54		

Table 4 Kilogram livemass browsing days obtained from each of five 2-ha camps representing a range in ecological statuses. Browsing contributed by game (kudu, duiker, bushbuck, and grysbok) which had found their way into the camps has not been included

	Camp				
Season	1	2	3	4	5
1985/86	36 833	32 629	13 839	14 205	8 840
1986/87	26 143	26 565	12 200	5 004	0
1987/88	43 063	40 420	16 631	6 961	1 575
Mean	35 346	33 204	14 223	8 723	3 472

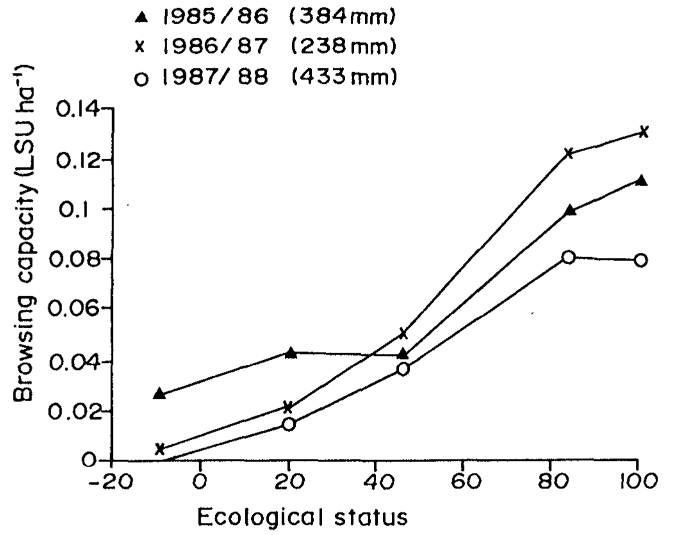

Figure 4 Relation between ecological status of Succulent Valley Bushveld and browsing capacity measured for the three experimental seasons with differing annual rainfall.

Only camps 4 and 5 were browsed during the first period of occupation in 1987/88. In retrospect, camps 1 to 3 were probably also ready to be browsed at this time and camps 4 and 5 should actually have been browsed approximately one to two months earlier. This was partly due to an operational delay of about a month between determining that the plants had recovered and the start of the period of occupation. We believe that this will not greatly influence the results given that the rest of the camps were browsed only two months later and within the same experimental season (1987/88).

The twig length and leaf number of both species had recovered to at least their pre-defoliation levels when the experiment was terminated. Indeed, some twigs had recovered slightly beyond (non-significant) the pre-defoliation levels but this (if meaningful) would emphasize the conclusions drawn in this investigation.

Goat mass

Average goat mass did not consistently decline during any of the periods of occupation (Table 3) and it follows that, from an animal performance viewpoint, none of the camps was over-utilized.

Browsing capacity

The number of browsing days obtained during each season from each camp are displayed in Table 4. Included in these values are the contribution made by game (kudu, duiker, bushbuck, and grysbok) which had found their way into the camps. Their kilogram grazing days were determined as the estimated number of days they occupied the camp multiplied by 0.75 of mean female mass (Smithers 1983).

In all three seasons high ecological status had a higher browsing capacity than low ecological status. Increasing rainfall generally increased browsing capacity but did not markedly affect the shape of the relation (Figure 4). It will be noted, however, that the browsing capacity estimations for the lower two ecological statuses during the 1985/86 season were inconsistent with the rest of the results (higher than expected) and this was possibly due to camps 4 and 5 being more heavily utilized during the first period of occupation. This is evident for camp 4 in the *P. afra* data (Figure 2) and for camp 5 in the *G. robusta* twig length

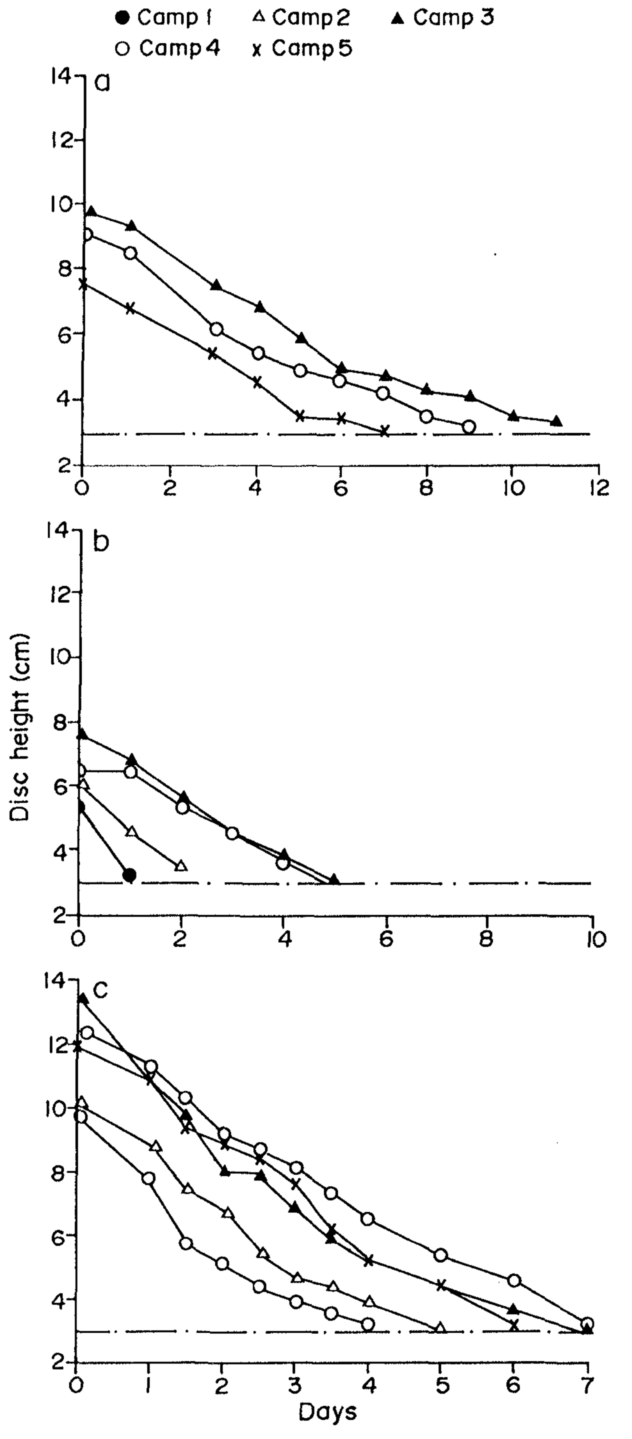

Figure 5 Change in sward height, measured with 100 placements of a pasture disc meter (Bransby & Tainton 1977), during the April 1986 (a), November 1987 (b), and April 1988 (c) periods of occupation. Cattle numbers and average weights are described in Table 6.

Table 5 Sward dry matter measurements (kg ha^{-1}) determined by cutting 50 m^{-2} quadrats before and after each period of occupation for each of five 2-ha experimental camps

Date	Camp 1	Camp 2	Camp 3	Camp 4	Camp 5
April 1986					
Before	–	–	1 630	1 505	1 118
After	–	–	554	521	588
Nov. 1987					
Before	897	983	1 169	964	–
After	529	503	572	527	
April 1988					
Before	1 670	1 580	2 450	2 160	2 130
After	544	554	498	550	560

Although the units are kg ha^{-1}, this is not a true reflection of herbage on offer as grass occurred only in patches in the camps. Sampling was concentrated in these areas as the intention was to monitor herbage disappearance, not to determine herbage on offer.

Table 6 Number of days each camp was occupied, number of cattle and average cattle weight (kg) before and after each period of occupation. The before and after masses were compared with paired *t* tests and were not different ($P \leq 0.05$)

Date	Camp 1	Camp 2	Camp 3	Camp 4	Camp 5
April 1986					
No. days	–	–	11	9	7
No. cattle	–	–	5	5	5
Wt. before	–	–	378	415	434
Wt. after	–	–	369	424	439
Nov. 1987					
No. days	1	2	5	5	–
No. cattle	2	2	4	4	–
Wt. before	310	305	336	391	–
Wt. after	295	300	338	398	–
April 1988					
No. days	4	5	7	7	6
No. cattle	2	2	12	12	8
Wt. before	288	328	379	381	451
Wt. after	285	321	388	384	444

Table 7 Kilogram livemass grazing days obtained from each of five 2-ha camps representing a range in ecological statuses

	Camp				
Season	1	2	3	4	5
1985/86	0	0	20 543	18 878	15 278
1986/87	0	0	0	0	0
1987/88	2 897	4 455	38 954	40 020	21 480
Mean	966	1 485	19 832	19 633	12 252

data (Figure 3a), but there was no evidence of excessive utilization of *G. robusta* in camp 4 compared to the other camps (Figure 3). Furthermore, as *P. afra* was absent in camp 5, and therefore not monitored, we cannot be sure of this interpretation.

Grazing capacity

Sward monitoring

The decline in sward height in each camp during the three periods of occupation is illustrated in Figure 5. Measurements of sward mass before and after each period of occupation are contained in Table 5. There was insufficient grass in camps 1 and 2 and in camp 5 during the April 1986 and November 1987 periods of occupation, respectively, to warrant grazing (Table 5, Figure 5).

Cattle mass

Cattle mass did not decline during any of the periods of occupation (Table 6) and it can be assumed, therefore, that the animals were not under nutritional stress.

Grazing capacity

The number of grazing days obtained during each season from each camp are displayed in Table 7. During the 1986/87 season rainfall was low (238 mm) and no grazing days were obtained from any of the camps and grazing capacity, therefore, was zero (Figure 6). In reality, some grass was produced but this was almost entirely utilized by the goats during their period of occupation. Grazing

Table 8 The differences between measured carrying capacity (grazing plus browsing capacity) and predicted carrying capacity derived from a response surface mathematical model using 12 monthly rainfall figures and vegetation condition (ecological status) as input variables

Season	Veld score	Rain (mm)	Measured (LSU ha^{-1})	Predicted (LSU ha^{-1})	Difference (LSU ha^{-1})
1985/86	100	384	0.112	0.106	0.006
	84	384	0.099	0.108	0.009
	46	384	0.105	0.105	0
	20	384	0.101	0.095	0.006
	–9	384	0.073	0.076	0.003
1986/87	100	238	0.080	0.086	0.006
	84	238	0.081	0.071	0.010
	46	238	0.037	0.039	0.002
	20	238	0.015	0.019	0.004
	–9	238	0	–0.002	0.002
1987/88	100	433	0.136	0.124	0.012
	84	433	0.130	0.149	0.019
	46	433	0.169	0.164	0.005
	20	433	0.143	0.138	0.005
	–9	433	0.070	0.074	0.004
Mean difference					0.006

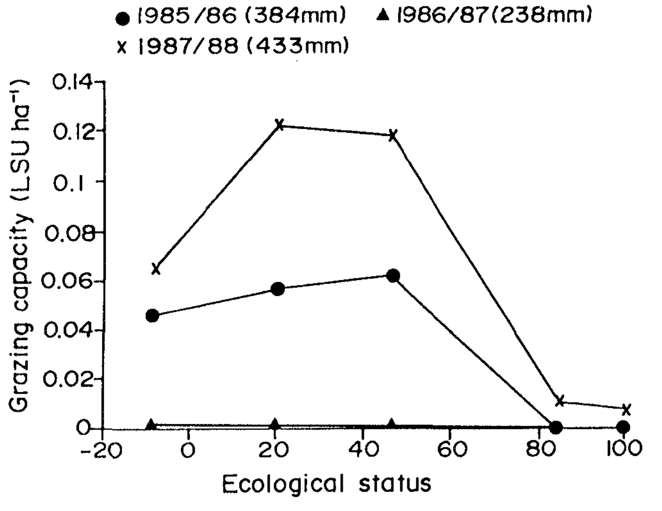

Figure 6 Relation between ecological status of Succulent Valley Bushveld and grazing capacity measured for the three experimental seasons with differing annual rainfall.

capacity in the other two seasons was highest at intermediate ecological status and decreased considerably at high ecological status. Increasing rainfall had the effect of increasing grazing capacity at intermediate ecological status but had little effect at high or low ecological statuses (Figure 6).

Carrying capacity

Carrying capacity was assumed to be the sum of grazing capacity and browsing capacity. Dense bushveld had a higher overall carrying capacity than open bushveld with a requirement of 9 ha of dense bush LSU^{-1} (i.e. 0.1111 LSU ha^{-1}) down to 21 ha of severely degraded bush LSU^{-1} (i.e. 0.0476 LSU ha^{-1}) (Figure 7). Averaged over all seasons, there was little increase in carrying capacity with ecological status above *c.* 50% (Figure 7). Possibly this represents a measure of the system's potential, which at higher ecological status remains constant, even with rather marked changes in vegetation composition and structure; i.e. the resources (rain, nutrients, etc.) are merely partitioned differently but overall productivity remains the same. However, at lower ecological status, it seems that system breakdown has occurred (e.g. soil erosion) and potential productivity has declined. However, it is evident that between seasons, carrying capacity would vary markedly with ecological statuses of less than *c.* 80% (Figure 8).

Carrying capacity changed considerably depending on rainfall (Figure 8). This was complicated because the more degraded the veld the greater was the variation. Carrying capacity varied by approximately 26% above and below average carrying capacity for pristine bushveld, whereas for degraded bushveld carrying capacity varied by 52% above or 100% below the average.

Discussion

In the long run and with a combination of grazers and browsers it will pay to have dense bushveld (Figure 7).

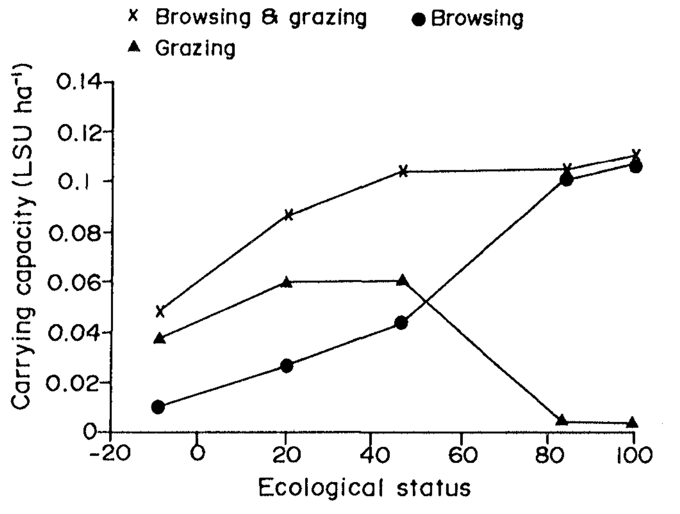

Figure 7 Relation between ecological status of Succulent Valley Bushveld, and average grazing, browsing, and grazing plus browsing capacity measured over the experimental period.

However, it is important to note that optimum veld condition changes from season to season and with management objectives.

In wet seasons, total forage production is highest at intermediate ecological status (i.e. more open bushveld), whereas in other seasons veld with high ecological status (dense bushveld) was more productive (Figure 8). This was due to the sward which, at intermediate tree densities (Figure 6), is extremely productive during wet seasons. Two points, however, must be made regarding this forage source. Firstly, it is extremely unreliable between years (Figure 6) and secondly, in the long term, food from the shrubs at high ecological status will exceed forage from the grass at lower ecological status (Figure 7). For a constant fodder flow, therefore, dense bushveld is preferable to open bushveld (Figure 8). Nevertheless, the considerable amounts of forage produced by degraded bushveld

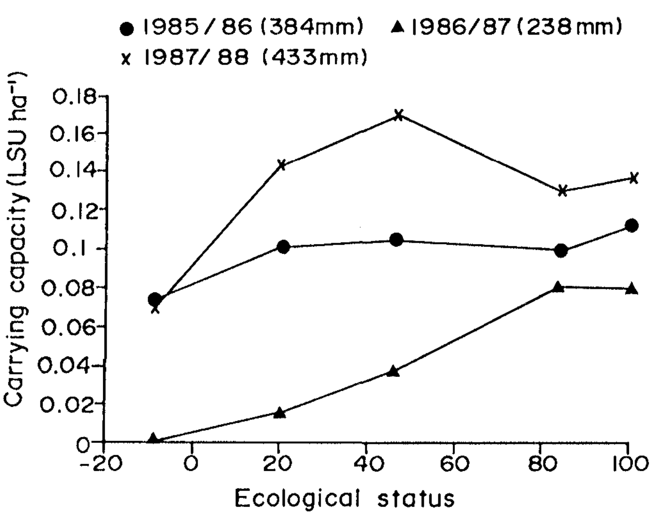

Figure 8 Relation between ecological status of Succulent Valley Bushveld and average grazing plus browsing capacity measured for three seasons with differing annual rainfall.

during exceptional rainfall years is extremely valuable, especially as it remains relatively sweet even when it dries off. Grazers could be bought in on a speculation basis to use this forage but these should never form a permanent enterprise as droughts with zero sward production (Figure 6) are common. Another use of this forage in browser systems is to utilize it during the wet seasons thereby relieving pressure on the areas with dense bush so they get a chance to recover.

Optimum veld condition will also change with operator objectives. For overall productivity, farmers with only cattle (grazers) would aim to have veld in the mid-range of ecological status (Figure 7) but this would conflict with farmers (and conservationists ?) who have browsers (e.g. goats and kudu). Their optimum would be vegetation with high ecological status (Figure 7).

The results appear to comply with the theory of stability and resilience as advocated by Walker (1980). Pristine bushveld (high ecological status) is stable from a forage production point of view (Figure 8) but lacks resilience as once degraded it will not recover (within a human lifespan at least). Veld with lower ecological status is unstable from a forage production viewpoint (Figure 8) but is resilient in that it rapidly reverts to its desert-like character following disturbance.

It is perhaps noteworthy that the carrying capacity result for the wet year (Figure 8) is similar to that found for the more mesic neighbouring False Thornveld of the eastern Cape (Aucamp *et al.* 1983; Stuart-Hill 1987) where total forage productivity was found to be highest at intermediate tree densities. This leads us to question whether there is not a continuum between False Thornveld and succulent valley bushveld.

The results of this investigation enabled a model to be developed, where carrying capacity (C) can be predicted from rainfall and vegetation condition (ecological status). This was done mathematically by developing the following equation which uses 12-monthly rainfall (R) and ecological status (V) as input variables.

$$C = A_1 + A_2V + A_3V^2 + A_4R + A_5R^2 + A_6VR + A_7V^2R + A_8VR^2 + A_9V^2R^2$$

where: C in LSU ha^{-1}; R in mm;

$A_1 = -2.35955432$
$A_2 = 1.73322191$
$A_3 = -1.32997188$
$A_4 = 1.29914587$
$A_5 = -1.22172784$
$A_6 = -1.13147013$
$A_7 = 9.38097966$
$A_8 = 1.81879951$
$A_9 = -1.57320123$

Table 8 shows the difference between the observed and predicted carrying capacities. Other less complex but less accurate equations are available from the senior author. A second model was also developed by employing Kriging (Clark 1982) to interpolate between the measured carrying capacities. This is represented as a three dimensional plot (Figure 9a) for descriptive purposes, and as both a contour plot (Figure 9b) and a read-up table (Table 9) for non-mathematical prediction. The latter, we propose, will be useful for field predictions of carrying capacity. The difference between observed and carrying capacities predicted from the read-up table are presented in Table 10 and it would appear that the table method is more accurate than the mathematical method.

It is important to stress that although the predictions are presented as numeric values, these should be treated with caution, especially when extrapolating beyond the limits of the input variables or, especially, to other areas. In addition, users of these models should be aware that

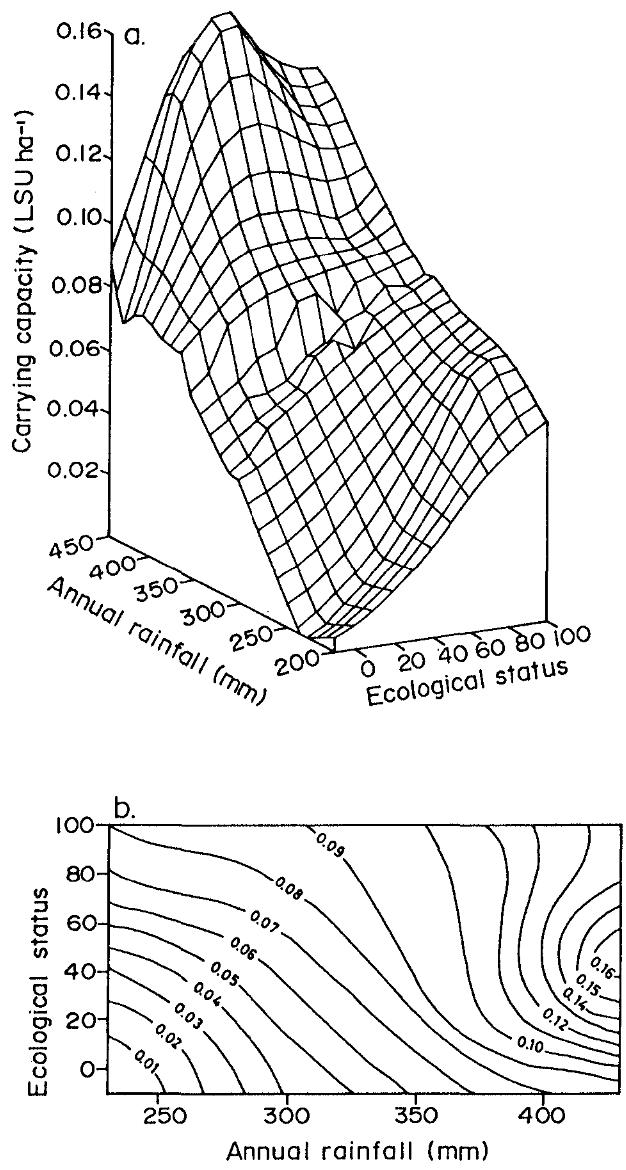

Figure 9 Carrying capacity (browsing capacity plus grazing capacity) of Succulent Valley Bushveld as predicted from Kriging where the independent variables are rainfall and vegetation condition (ecological status). The predicted relation is shown in three-dimensions (a) and as a contour plot (b).

Table 9 Combined predicted carrying capacity (LSU 1000 ha^{-1}) of grazers and browsers in succulent valley bushveld for different ecological statuses and for various rainfall seasons. Predictions were derived from interpolation using linear Kriging (see Clark 1982)

Rain	Ecological status (%)											
(mm)	–10	0	10	20	30	40	50	60	70	80	90	100
240	1	4	9	15	23	31	41	52	63	73	78	79
250	2	6	11	17	25	33	43	54	66	77	81	81
260	8	11	16	22	29	38	47	57	67	76	81	83
270	15	18	22	28	35	43	51	60	68	75	81	84
280	21	25	29	35	41	48	55	63	70	76	81	85
290	28	31	36	41	47	53	60	66	72	78	83	86
300	35	38	42	47	52	58	64	70	75	80	84	87
310	41	44	48	53	58	63	69	74	78	83	87	89
320	42	46	54	59	64	69	73	78	82	86	87	90
330	45	51	56	59	64	74	78	74	83	87	90	93
340	51	55	61	61	65	72	75	81	84	90	89	92
350	56	60	65	71	74	87	89	81	91	92	94	96
360	61	67	81	85	89	91	92	93	94	96	97	99
370	73	78	85	90	93	95	96	96	96	97	100	104
380	73	80	89	96	99	101	101	101	100	99	102	108
390	74	83	93	103	107	108	109	108	106	103	106	113
400	76	87	98	109	116	119	120	118	116	113	114	117
410	78	90	104	117	127	132	133	130	126	122	121	122
420	76	91	110	127	139	146	147	142	134	129	127	128
430	72	92	116	139	150	160	161	151	141	132	131	134
440	77	96	119	140	153	162	163	155	146	138	135	137
450	88	102	120	136	148	156	157	154	148	143	140	139

Table 10 The differences between measured carrying capacity (grazing plus browsing capacity) and predicted carrying capacity derived from Table 9 which uses 12 monthly rainfall figures and vegetation condition (ecological status) as input variables

Season	Veld score	Rain (mm)	Measured (LSU ha^{-1})	Predicted (LSU ha^{-1})	Difference (LSU ha^{-1})
1985/86	100	384	0.112	0.110	0.002
	84	384	0.099	0.101	0.002
	46	384	0.105	0.104	0.001
	20	384	0.101	0.100	0.001
	–9	384	0.073	0.073	0
1986/87	100	238	0.080	0.080	0
	84	238	0.081	0.079	0.002
	46	238	0.037	0.038	0.001
	20	238	0.015	0.012	0.003
	–9	238	0	0.002	0.002
1987/88	100	433	0.136	0.134	0.002
	84	433	0.130	0.133	0.003
	46	433	0.169	0.162	0.007
	20	433	0.143	0.139	0.004
	–9	433	0.070	0.074	0.004
Mean difference					0.002

there are generally high densities of kudu (*c*. 58 per 1 000 ha) and bushbuck (*c*. 13 per 1 000 ha) in this vegetation and these must be taken into account when determining stocking rates. Neglecting to do this could result in overstocking by between 25 and 45 %.

It should also be stated that this experiment was designed around ensuring that *P. afra* and *G. robusta* were utilized in a sustainable manner. While these species are the most preferred common species there are rarer species which (from observation) are more heavily utilized. It follows that these species may eventually be lost even while *P. afra* and *G. robusta* are maintained. There may be other issues of sustainability which this study was not able to address. If so, then the long-term sustainable carrying capacity could be even lower than these data suggest.

Conclusion

Optimum vegetation condition changes from season to season and with management objectives. However, despite the possibility that for some enterprises veld with intermediate ecological statuses may be preferable to dense bushveld, our recommendation is that existing remnants of pristine bushveld should never be harmed. This is because:

1. It cannot regenerate once destroyed and this limits future management alternatives;
2. it provides a relatively consistent fodder flow between seasons (indeed, farmers in the succulent valley bushveld should never have to rely on drought subsidies);
3. it is more productive than open bush; and
4. most farms already have considerable areas of veld with low ecological status.

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