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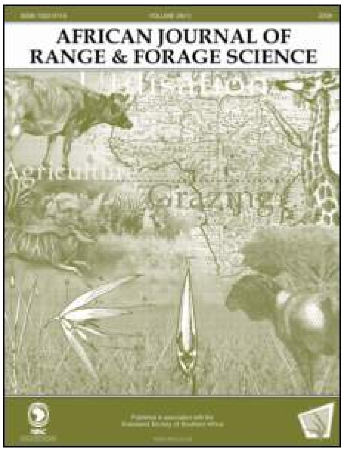

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Can brush-cutting of *Pteronia paniculata* improve the composition and productivity of veld in the Succulent Karoo, South Africa?

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Can brush-cutting of *Pteronia paniculata* improve the composition and productivity of veld in the Succulent Karoo, South Africa?

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Pteronia paniculata **is an indigenous, unpalatable shrub that invades mismanaged Karooveld, resulting in degraded rangelands with low species diversity and grazing potential. We conducted a series of trials in the Succulent Karoo Randteveld near Barrydale to determine if the uniform defoliation of *P. paniculata* dominated vegetation at two heights (0.05 m and 0.20 m above ground level) using a brush-cutter and, in one trial, application of a second cut will improve the plant species composition, productivity and grazing capacity of the veld. Brush-cutting treatments and the uncut control all resulted in a change in species composition towards greater species diversity and more palatable species and an average increase of 540 kg ha^{-1} (28%) in above-ground biomass over four years. It appears that there was a pervasive improvement in species composition associated with a general decline in the cover and abundance of *P. paniculata* over the time-scale of the present study that was not influenced by the defoliation treatments, except for the 1996-cut treatment where the cover of *P. paniculata* increased. The absence of propagules of palatable species in the soil seed bank and competition from *P. paniculata* (a long-lived, perennial shrub) are assumed to be among the main reasons for the lack of response of the vegetation community to the defoliation treatments. Brush-cutting (in the absence of reseeding), aimed at reducing the dominance of unpalatable karoo shrubs, was more costly but not significantly better than long-term resting in improving veld composition or forage production.**

Keywords: competition, defoliation, grazing capacity, palatability, rehabilitation

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Introduction

Mismanagement, for example by prolonged overgrazing by domestic livestock, is widely recognised as a direct agent of rangeland degradation in semi-arid rangeland (Milton and Dean 1995, Khresat et al. 1998, Hoffman and Ashwell 2001, IFAD 2007, Syngenta Foundation for Sustainable Agriculture 2007) and more mesic grassland (Frank et al. 1998). Holechek (2002) and Ralphs (2002) found in studies conducted in deserts, grasslands and woodlands in the USA and Mexico that poor grazing management, especially high grazing intensity, resulted in an increase of unpalatable species and a decrease in palatable species. Degradation of the arid Succulent Karoo due to overgrazing can result in an increase of unpalatable species such as *Pteronia paniculata* Thunb. (Roux and Vorster 1983, Milton and Dean 1994, Wiegand and Milton 1996, Burger 2001). Rehabilitation of overgrazed arid or semiarid shrublands cannot be achieved by the withdrawal of livestock alone (Westoby et al. 1989, Milton and Dean 1994, Stokes 1994, Wiegand et al. 1995, Wiegand and Milton 1996). According to Wiegand et al. (1995) and Wiegand and Milton (1996) the rehabilitation of overgrazed rangelands dominated by unpalatable shrubs is hindered by demographic inertia and lag-effects: once established, the unpalatable species dominate for a long time because of long life-spans, and they therefore do not necessarily facilitate succession to better alternative states (Milton and Dean 1994). The change in species composition of vegetation can possibly be explained by the 'state-and-transition' model, which suggests that unpredictable and predictable impacts such as a variable climate (natural events) and overgrazing (human activities) can change the vegetation from one state to another (Briske et al. 2008), and the movement from one state to another is not necessarily reversed by succession (Milton and Hoffman 1994).

In arid environments degradation may be rapid, but the recovery, if any, is slow because plant growth is limited by soil moisture availability owing to low, erratic rainfall and a high evaporative demand. Loss of plant cover further reduces rainfall efficiency (Milton et al. 1994, Wiegand et al. 1995). Seedling recruitment will normally take place only once competition from the established (long-lived) plants is removed and further interventions will be required as seedlings do not recruit on bare, undisturbed soils in other Karooveld types (Milton 1995, Visser et al. 2007). The removal of competition from long-lived unpalatable plants is normally due to prolonged drought, age and/or physical disturbance that results in their death. Midgley and Moll (1993) and Milton (1995) state that competition in Karoo shrublands is primarily for soil moisture, a resource that is depleted rapidly by established Karoo shrubs, such as by *P. paniculata*.

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Pteronia paniculata (Asteraceae) occurs over vast areas in the Succulent Karoo, especially in the higher-lying areas. It is an evergreen indigenous shrub that is unpalatable and poisonous to livestock (Shearing and van Heerden 1994, Esler et al. 2006). *Pteronia paniculata* increases in areas subjected to sustained mismanagement (Milton and Dean 1994, Burger 2001). Cultivation of natural veld or mismanagement of herbivores leads not only to degradation of the vegetation but also of the physical and chemical attributes of the soil (Stokes 1994). Plants that colonise degraded arid environments tend to be unpalatable, long-lived, hardy perennials and/or unpalatable plants whose abundance may be maintained by prolific seed production even if the plants do not have a strong competitive effect on, or response to, neighbouring plants (Stokes 1994).

Vegetation composition and cover influence the amount of palatable herbage available to grazing/browsing livestock. Changes in plant species composition towards unpalatable shrubs and loss of cover thus reduce the carrying capacity of rangelands and the productivity and economic potential of the rangeland to render various services, especially forage production for livestock (Milton et al. 1995).

The objectives of this paper are to test the hypothesis that the uniform defoliation of *P. paniculata* dominated vegetation using a brush-cutter would result in: (1) a reduction in the cover of *P. paniculata*, (2) improve plant species composition towards a higher proportion of more palatable and forage-productive species and less undesirable species, and (3) promote the establishment and productivity of palatable species. The purpose of the trial was to find an effective and financially viable method of restoring vegetation and carrying capacity of degraded vegetation in Succulent Karoo Randteveld, based on the results of the treatments on measurable parameters (1–3).

Methods

Study area

The study was conducted on the farm Kleinvlakte (33°50′ S, 20°40′ E) 20 km from Barrydale. It is situated in an arid vegetation type known as the Succulent Karoo Randteveld (Vlok et al. 2005) that forms part of the Succulent Karoo biome. The vegetation type is restricted to south-facing slopes on shallow, shale-derived soils. Trees and tall shrubs are absent. Sparse, short shrubs, of which *Berkheya cuneata* and *Pteronia* spp. are most abundant, dominate the vegetation while, despite being located in the Succulent Karoo, succulents are not common. Heuweltjies (mima-like mounds) are dominated by *Pteronia incana*. No endemic species occur in this vegetation type (Vlok et al. 2005).

The average annual rainfall for the area is 400 mm (%CV = 32.01; n = 19 years), with rain occurring mainly in winter and spring (data obtained from the Agricultural Research Council from a weather station located approximately 18 km south-west from the study site). The soils of the study area are sandy-loams with a very low organic carbon content of 0.67% and a pH of 5.5. The fertility of the soil is in general high with phosphorus and potassium concentrations of 41.04 mg kg^{-1} and 109.56 mg kg^{-1}, respectively, as determined by the citric acid (1%) method (Non-Affiliated Soil Analysis Work Committee 1990).

The study site is located in an area used for dry-land crop production, especially winter grains, during the late 1800s and early 1900s. Subsequently, the land lay fallow until the Second World War when the area was used to breed sheep and donkeys/mules, resulting in extensive overgrazing of the vegetation that established after the cropping lands were abandoned. Much of the shallow top-soil had been lost through sheet erosion of the cultivated fields resulting in exposure of underlying shales in patches across the landscape. The study site can thus be described as degraded old lands that, after a few decades of non-use, were severely overgrazed and became invaded by *Pteronia* spp., of which *P. paniculata* was most dominant. All livestock (mainly sheep) were withdrawn from the farm in the 1970s after which little grazing took place, except by small game that occurred naturally in the area. The farm, currently managed as a game farm with low numbers of wild game animals, is 14 000 ha in extent.

Experimental design and layout

Three separate trials in the same location were conducted to investigate the effectiveness of different timings, frequencies and intensities of brush cutting on vegetation dominated by *P. paniculata*.

Pilot trial

The study was started as a pilot project in May 1996 to determine whether brush-cutting would reduce the production and abundance of *P. paniculata* and, in particular, promote the establishment and growth of more palatable plant species to improve the grazing value of the vegetation. Plots (250 m × 20 m) were laid out in a randomised complete block design with two replications of each of three treatments. Treatments were: (1) an uncut control, (2) all vegetation cut with a brush-cutter to a height (above ground level) of 50 mm in May 1996, and (3) all vegetation cut with a brush-cutter to a height of 50 mm in May 1997. Five 10 m × 10 m exclusion plots were erected in 2001 in each of the control plots and 1997 brush-cut treatment plots to exclude grazing by wild ungulates. This trial is referred to hereafter as the Pilot trial.

New trial

A second study, situated adjacent to the Pilot trial, was initiated in 2001. The purpose of this trial was to determine the effect of different brush-cutting heights on vegetation composition and productivity. The vegetation in this (new) study had not been brush-cut at any time in the past. Plots (250 m × 20 m) were laid out in a randomised complete block design with two replications of each of three treatments. The treatments (applied in May) in this trial were: (1) a control, (2) plants brush-cut to 50 mm, and (3) plants brush-cut to 200 mm. Five 10 m × 10 m exclusion plots were erected in each of these plots in 2001 to exclude grazing by wild ungulates. This trial is referred to hereafter as the New trial.

Second-cut trial

A third component of the study was initiated in 2001 to test the hypothesis that a second cut of *Pteronia*-dominated

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vegetation would result in a reduction of the presumed competitive effect of *P. paniculata* on neighbouring plants to the extent that other, more valued plant species would have the opportunity to establish and thus increase the grazing capacity of the land. This trial was conducted on an extensive area of vegetation in the study site that had been brush-cut to 50 mm above ground level by the land owner in 1997. Plots (100 m × 20 m) were laid out in the previously brush-cut area in a randomised complete block design with three replications of each of three treatments (applied in May), namely: (1) a control, (2) plants brush-cut to 50 mm, and (3) plants brush-cut to 200 mm. This trial is referred to hereafter as the Second-cut trial.

No grazing/browzing took place at the study site for the first five to six years (1996–2001), but during the last three years (from 2002) there was light grazing/browsing by eland, springbok and grey rhebuck (except in the exclusion plots) evident by defoliation of some plants as well as animal tracks and dung in the study area.

Sampling procedure

Vegetation

Line-point surveys, recording strikes on the canopy of live plants (du Toit 1998), were done in each plot to determine percentage canopy cover of each species (Roux 1963). Five hundred points per plot, systematically located at 1 m intervals, were recorded in 1997 in the Pilot trial and in 2001, 2003, 2004 and 2005 in all the plots of all three trials. Line-point surveys of 100 points per plot were done in each of the exclusion plots (10 m × 10 m) in 2001, 2003, 2004 and 2005. The surveys were done in May of each year with the first surveys being conducted shortly before implementation of the second cutting treatment (1997-cut) in the Pilot trial, but directly after the implementation of the cutting treatments in the New and Second-cut trials. Plant species present in the different treatments were grouped according to palatability classes (grazing value; van Breda and Barnard 1991), namely highly palatable, palatable, less palatable and unpalatable.

Dry-matter accumulation of above-ground biomass was determined annually (in October) in all treatment plots in the New and Second-cut trials from 2001 to 2005. On each sampling occasion, twenty 1 m × 2 m randomly placed quadrats were sampled in the non-exclosure areas and two in each exclusion plot of the New Trial. Ten randomly placed 1 m × 2 m quadrats were sampled in each treatment plot of the Second-cut trial, avoiding previously cut areas. All living plant material within each quadrat was harvested and then divided into three groups, namely palatable species (highly palatable and palatable species combined), less palatable species and unpalatable species (note that *P. paniculata* made up 98% of the composition of the unpalatable species.) After separation, the material was dried at 60 °C for 48 h and then weighed.

Soil-stored seed banks were determined annually for all treatment plots of all three trials from 2001 to 2005. To determine the size and composition of the seed bank, five randomly located soil samples (150 mm × 230 mm in size) were collected with a spade to a maximum depth of 20 mm in each treatment plot. Sampling depth was based on Nelson and Chew (1977) and Esler (1993), who state that the seed density in the soil profile decreases greatly below a depth of 20 mm in arid environments. We sieved each sample to eliminate large stones. The soil of each sieved sample was evenly spread to a depth of 20 mm onto the surface of a prepared seed tray. The trays were placed in a nursery where they were watered three times daily. All emerging seedlings were monitored and counted weekly over a period of one year and identified, as far as possible, to family level.

The total percentage canopy cover and species composition (relative cover of each species) was used to determine the grazing capacity of each treatment on each sampling occasion (Bayer et al. 1992). This method excludes unpalatable species from the calculation of grazing capacity and uses only three palatability classes, namely highly palatable, palatable and less palatable species. The percentage cover of each of these classes are weighted by 90%, 50% and 20%, respectively, based on production utilisation, to obtain a value for the useable production (UP), which is calculated as follows:

$$\text{UP} = (\text{\% cover of highly palatable species} \times 0.9) + (\text{\% cover of palatable species} \times 0.5) + (\text{\% cover of less palatable species} \times 0.2) \quad (1)$$

Grazing capacity value is obtained using the following equations:

$$\text{Potential production (PP; kg DM ha}^{-1}\text{ y}^{-1}) = (\text{MAR} - 20) \times \text{RUE } (4.0 \pm 0.3 \text{ kg DM ha}^{-1}\text{ y}^{-1}\text{ mm rain}^{-1}) \quad (2)$$

where DM is dry matter, MAR is the mean annual rainfall (le Houérou et al. 1988) and RUE is a constant value for rain-use efficiency.

$$\text{Production (P; kg ha}^{-1}\text{ y}^{-1}) = (\text{UP}/100) \times \text{PP} \quad (3)$$

$$\text{Grazing capacity (ha LSU}^{-1}\text{ y}^{-1}) = (650/\text{P}) \times 6.67 \quad (4)$$

where 650 is equivalent to the annual DM requirement (in kg) of a 60 kg Dorper sheep based on an estimated daily intake of 3% of body weight and 6.67 is the factor used to convert small stock units (SSU) to large stock units (1 LSU = 6.67 SSU) (Meissner et al. 1983).

Data analysis

The experimental design was a split-split-split plot design. The main plot factor of the split-plot was treatment and the subplot factor was type (grazed/ungrazed)). The second subplot factor was palatability and the third subplot factor was time (year). According to Little and Hills (1972) the split-plot principle can be applied to experiments where successive observations were made on the same whole units over a period of time. Thus repeated measurements over years were analysed as a split-plot design to assess the effects of treatment × time and treatment × palatability interactions on the percentage canopy cover in each of the three trials (the Second-cut trial did not have the split on grazed/ungrazed). A Shapiro-Wilk test was performed to test for non-normality of the residuals of the data (Shapiro and Wilk 1965). Analysis of variance (ANOVA) was performed on percentage canopy spread measured in treatment plots in 2005, using SAS version 8.2 (SAS 1999), and, following significant *F*-tests in the ANOVA, Student's *t*–least significant difference were calculated at the 5% confidence level to compare treatment means (Ott 1998). The same analyses were applied to the soil-stored seed bank data and the above-ground biomass data sets. For the above-ground biomass data sets separate ANOVAs were done for each palatability class and time (year) × treatment interactions were tested.

Repeated measures ANOVA, in GenStat Release 9.1 (Lawes Agricultural Trust, Rothamsted), was used to assess the effects of treatment, time (year) and treatment × time interactions, on the percentage canopy cover (arc-sine square-root transformed for normality) of *P. paniculata* in each of the three trials.

Differences in canopy cover species composition were tested using Multi-Response Blocked Permutation Procedures (MRBPP) in PC-ORD version 4.25 (MjM Software, Gleneden Beach), with plots blocked by replication (randomised complete block design) or location for tests of changes over time. A chord transformation (Legendre and Gallagher 2001) was applied to the species' abundance data (based on proportion of canopy strikes) prior to the calculation of the Euclidean distances used in the MRBPPs and to allow appropriate projection of plots in an ordination using principal component analysis (PCA) for illustrating the main changes in species composition over time in each treatment.

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Results

Species composition and plant cover

Nine years after the area in the Pilot trial was treated, no difference in total canopy cover was evident between treatments ($F_{2,25}$ = 1.72, p = 0.3673; Table 1). No difference was found between the grazed area and the exclusion plots ($F_{1,72}$ = 0.18, p = 0.7133). The interaction between palatability class and treatment was also not significant ($F_{6,25}$ = 1.47, p = 0.2282), suggesting that species in the different palatability classes reacted similarly to the treatments (Table 1). There was, however, one exception, namely Unpalatable species (mainly *P. paniculata*), which increased in the 1996-cut treatment from 1997 to 2005 ($F_{6,9}$ = 14.5, p = 0.0004) but decreased by a similar amount in the 1997-cut and the control (Table 1).

In the New trial there were no differences in the total canopy cover, over all the palatability classes, between the treatments in 2005 ($F_{2,18}$ = 0.53, p = 0.6529), but there was a significant treatment × palatability class interaction ($F_{6,18}$ = 4.87, p = 0.0040) with a higher cover of Less Palatable species in the 50-mm-cut and 200-mm-cut plots than the other palatability classes (Table 1). No differences were found between the exclusion plots and the grazed area ($F_{1,18}$ = 0.58, p = 0.5013).

There were no treatment differences in canopy cover at the end of the Second-cut trial in 2005 ($F_{2,18}$ = 0.87, p = 0.4653) nor was the interaction between the palatability classes and treatment significant ($F_{6,18}$ = 0.40, p = 0.8705; Table 1).

In all three trials, treatment plots did not differ significantly (p > 0.05) in species composition at the start of each trial and treatment effects on composition were evident only in the Pilot trial in 2005 (p = 0.0463). There was, however, a significant general change in composition from the first to the last measurement in the Pilot trial (p = 0.0141), the New trial (p = 0.0101) and in the Second-cut trial (p = 0.0028). These temporal shifts in composition at all three trial sites were largely a result of an overall decline in the relative canopy

Table 1: The mean percentage canopy cover measured in 2005 of the different palatability classes as well as the total canopy cover (%) in the different treatments of (a) Pilot trial (two replications) (measured in 1997 and 2005), (b) New trial (two replications) (measured in 2001 and 2005) and (c) Second-cut trial (three replications) (measured in 2001 and 2005) conducted on Kleinvlakte in the Succulent Karoo. Values represent the mean ± SE

Trial	Treatment	Year	Palatability class				Total
			Highly Palatable	Palatable	Less Palatable	Unpalatable	
Pilot	Control	1997	0.1 ± 0.4	1.3 ± 0.5	9.5 ± 1.7	22.8 ± 3.2	33.7 ± 1.1
		2005	1.0 ± 0.4	2.4 ± 1.2	18.5 ± 4.7	14.6 ± 0	36.5 ± 6.3
	1997-cut	1997	0.3 ± 0.1	1.0 ± 0.2	10.6 ± 0.1	20.9 ± 0.1	32.8 ± 1.4
		2005	2.6 ± 0.0	2.6 ± 0.0	15.5 ± 1.6	13.7 ± 2.1	33.9 ± 3.7
	1996-cut	1997	1.5 ± 0.5	1.3 ± 0.3	5.7 ± 1.3	8.2 ± 1.1	16.7 ± 3.2
		2005	3.1 ± 0.7	1.6 ± 0.4	18.4 ± 1.8	17.8 ± 1.0	40.9 ± 1.9
New	Control	2001	0.3 ± 0.1	0.0 ± 0.0	8.3 ± 1.3	28.4 ± 0.6	37.0 ± 0.8
		2005	1.9 ± 0.1	1.0 ± 1.0	15.1 ± 2.5	14.6 ± 2.4	32.6 ± 1.4
	50 mm cut	2001	0.0 ± 0.0	0.0 ± 0.0	4.9 ± 1.5	12.0 ± 2.4	16.9 ± 3.9
		2005	1.0 ± 0.6	0.5 ± 0.1	20.3 ± 0.7	6.3 ± 2.1	28.1 ± 0.8
	200 mm cut	2001	0.1 ± 0.1	0.0 ± 0.0	8.2 ± 3.2	27.5 ± 0.5	35.8 ± 2.6
		2005	0.7 ± 0.5	0.3 ± 0.1	16.6 ± 0.4	12.2 ± 3.4	29.8 ± 3.1
Second-cut	Control	2001	0.5 ± 0.1	0.4 ± 0.2	8.9 ± 2.0	16.0 ± 1.1	25.8 ± 1.3
		2005	1.4 ± 0.5	0.2 ± 0.1	16.0 ± 0.6	12.9 ± 0.6	30.5 ± 1.2
	50 mm cut	2001	0.6 ± 0.3	0.5 ± 0.1	5.9 ± 0.5	12.1 ± 0.3	19.1 ± 0.9
		2005	1.6 ± 0.8	0.3 ± 0.1	15.6 ± 0.6	12.7 ± 1.2	30.3 ± 1.9
	200 mm cut	2001	1.1 ± 0.5	0.2 ± 0.2	9.3 ± 0.7	13.0 ± 1.8	23.6 ± 1.9
		2005	1.5 ± 0.9	0.4 ± 0.1	17.1 ± 2.3	14.7 ± 0.3	33.7 ± 4.2

cover of *P. paniculata*, as suggested by the general shift in the position of all control and treatment plots along the main compositional gradients extracted by PCA (Figure 1).

The mean percentage cover of *P. paniculata* in the Pilot trial did not differ among cutting treatments ($F_{2,2}$ = 2.39, p = 0.295) or between years ($F_{4,12}$ = 3.60, p = 0.152). There was, however, a significant treatment × time interaction ($F_{8,12}$ = 13.01, p = 0.031), with more *P. paniculata* in the Control plots in 1997 and 2001 than in the other years and treatments. There is a general decrease over time in the cover of *P. paniculata* in the Control and 1997-cut plots, but a steady increase in the 1996-cut plots. The mean cover of *P. paniculata* was the same in the Control and 1996- and 1997-cut plots in 2005 (Figure 2a).

In the New trial, there were no significant treatment effects ($F_{2,2}$ = 12.54, p = 0.074) on the cover of *P. paniculata* (Figure 2b) but its cover declined over time ($F_{6,9}$ = 31.61, p = 0.002) consistently across all treatments.

In the Second-cut trial the cover of *P. paniculata* changed over time, with a higher abundance in 2001 (21.4 ± 0.7%) and 2005 (21.1 ± 0.4%) than in 2003 (19.4 ± 0.8%; $F_{3,18}$ = 3.70, p = 0.05). There were no differences in the canopy cover of *P. paniculata* between treatments ($F_{2,6}$ = 2.70, p = 0.146) and a non-significant time × treatment interaction ($F_{3,18}$ = 0.99, p = 0.454; Figure 2c).

Seed bank

Twenty-four species from 10 families were present in the seed bank of the study site. These were mainly annual forb species with a low grazing value. Asteraceae was the dominant family with *Pseudognaphalium luteoalbum* the most common species in that family. In all the trials, Asteraceae overwhelmingly dominated the soil seed bank followed by Solanaceae and Poaceae (Table 2).

Above-ground biomass

New trial

The above-ground biomass of *P. paniculata* (an Unpalatable species) in the different treatments changed significantly over time (2001 to 2005; $F_{2,3}$ = 16.78, p = 0.0235) with a

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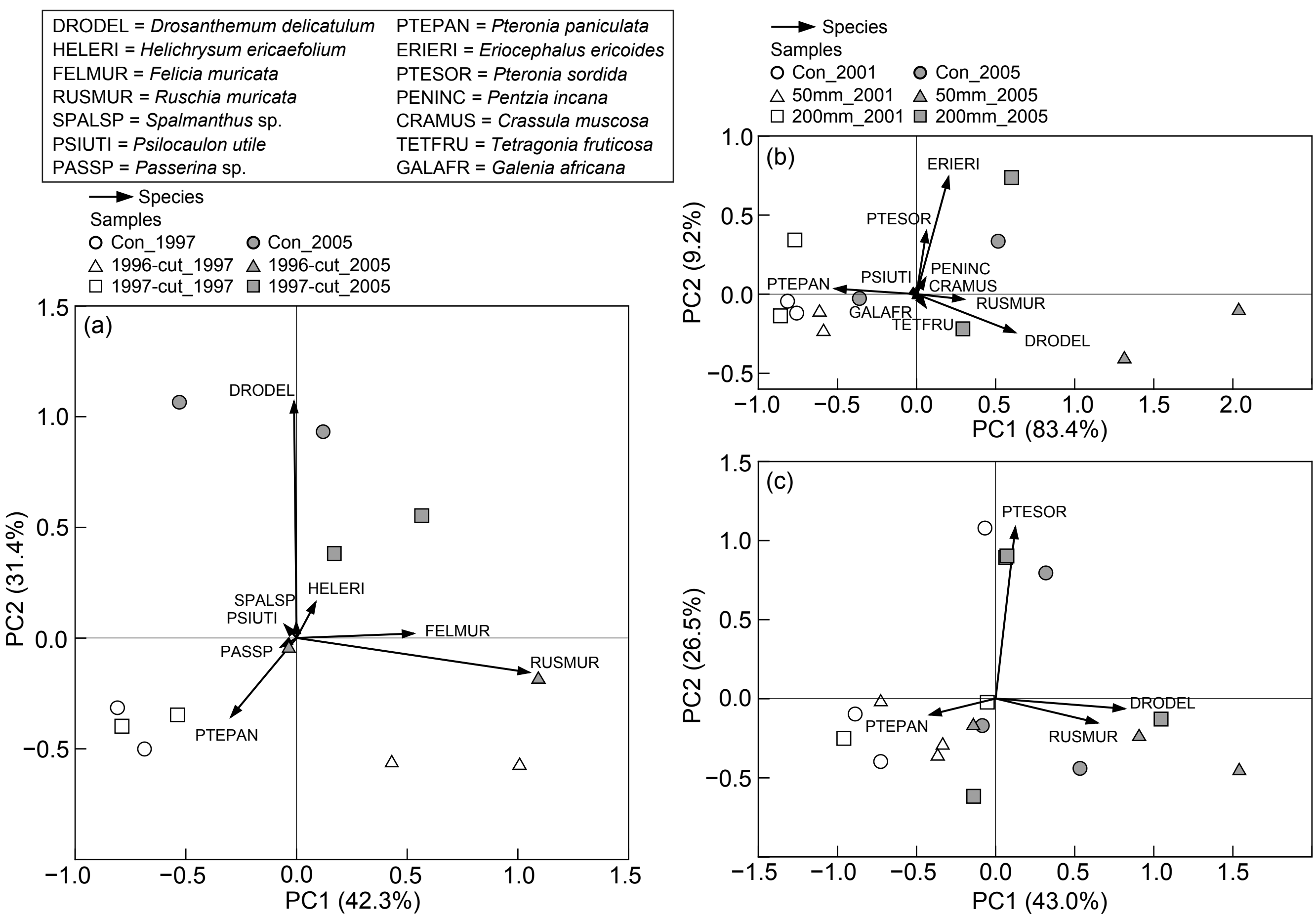

Figure 1: Principal component analysis (PCA) plot of species (those accounting for <50% of total variance not shown) and treatment plots based on canopy cover composition recorded at the start (empty symbols) and end (filled symbols) of the measuring period in the (a) Pilot trial, (b) New trial and (c) Second-cut trial. The variation accounted for by each axis is specified in brackets. Species names: DRODEL = *Drosanthemum delicatulum,* HELERI = *Helichrysum ericaefolium*, FELMUR = *Felicia muricata*, RUSMUR = *Ruschia muricata*, SPALSP = *Spalmanthus* sp., PSIUTI = *Psilocaulon utile,* PASSP = *Passerina* sp., PTEPAN = *Pteronia paniculata*, ERIERI = *Eriocephalus ericoides*, PTESOR = *Pteronia sordida*, PENINC = *Pentzia incana*, CRAMUS = *Crassula muscosa*, TETFRU = *Tetragonia fruticosa*, GALAFR = *Galenia africana*

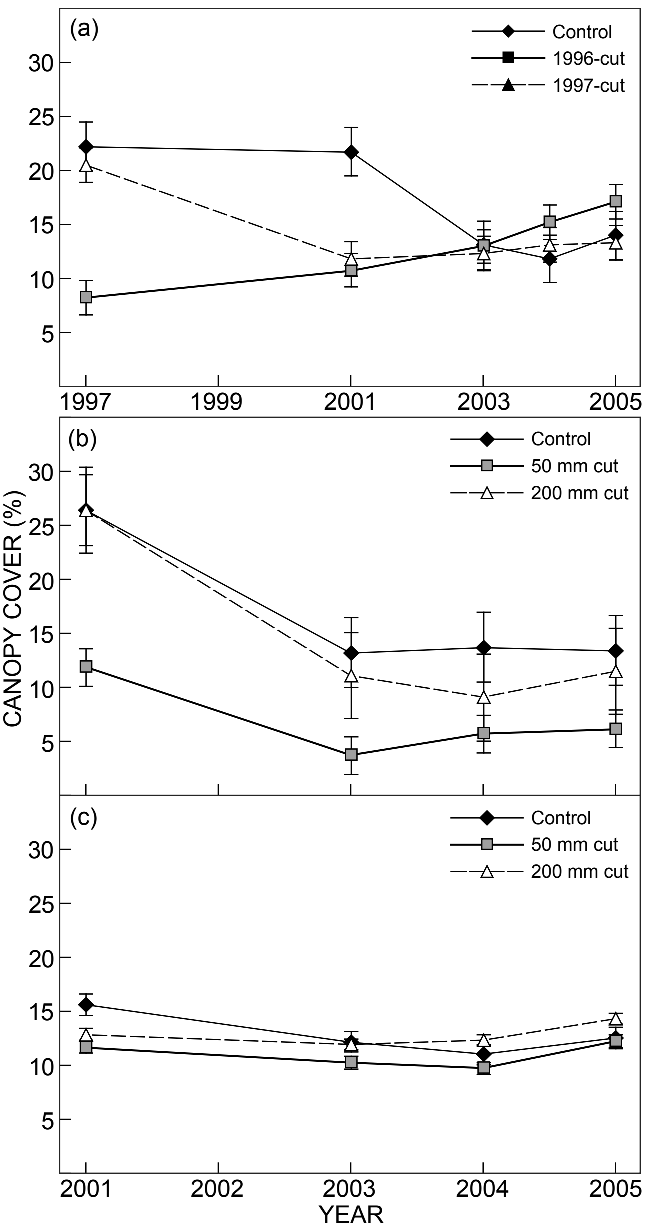

Figure 2: The mean percentage cover-abundance of *Pteronia paniculata* in each treatment over time in the (a) Pilot trial, (b) New trial and (c) Second-cut trial ($n = 2$ for a and b; $n = 3$ for c).

large reduction in the control plots and a slight increase in the 50-mm-cut and 200-mm-cut plots. The Less palatable species showed no differences over time or between treatments, while the Palatable species increased significantly in all the treatments from 2001 to 2005 ($F_{1,3} = 18.09$, $p = 0.0238$). This increase was the highest in the 50-mm-cut plots (589.9%) followed by the control (270.5%) and 200-mm-cut (158.2%) plots. The total above-ground biomass did not differ among treatments ($F_{2,3} = 2.13$, $p = 0.3192$) but increased consistently over time in all treatments ($F_{2,3} = 4.08$, $p = 0.1392$), with a significantly higher biomass in 2005 (120.41 ± 14.09g.m^{-2}) than in 2001 (66.3 ± 21.24g.m^{-2}; $F_{1,3} = 16.94$, $p = 0.0.026$; Table 3).

Second-cut trial

There were no differences in 2005 between the different treatments for total above-ground biomass ($F_{2,6} = 3.76$, $p = 0.0874$) as well as for Unpalatable ($F_{2,6} = 0.49$, $p = 0.6340$), Less Palatable ($F_{2,6} = 0.23$, $p = 0.8016$) and Palatable species ($F_{2,6} = 0.46$, $p = 0.6528$). There was a significant time × treatment interaction for Unpalatable species ($F_{8,24} = 2.82$, $p = 0.0235$). The control had significantly higher biomass of Unpalatable species (mainly *P. paniculata*) than the other treatments in 2001 and 2005. The cut treatments showed an increase in the biomass of Unpalatable species over time, while it decreased in the control (Table 3).

There was a significant increase over time (2001–2005) in the biomass of Palatable species ($F_{2,24} = 34.87$, $p < 0.0001$) as well as in the total above-ground biomass ($F_{2,24} = 19.81$, $p < 0.0001$), while Unpalatable and Less Palatable species did not show significant differences. The increase in the biomass of the palatable species occurred in all three treatments, suggesting that treatment effect was not the cause of the observed temporal change (Table 3).

Grazing capacity

The estimated grazing capacity of the vegetation in all the treatment plots in all trials improved over time (Table 4), largely because of the general decline in *P. paniculata* and a slight increase in the percentage cover of the Highly Palatable species and Less Palatable species. The improvement in the 50-mm-cut treatment was greater than in the 200-mm-cut treatment and the control. The large improvement from 2001 to 2005 in the grazing capacity of the 50-mm-cut treatment in the New and Second-cut trials can be ascribed to the timing of plant surveys of 2001, which were done after brush-cutting when the cover was very low (<10%).

Discussion

The first hypothesis that we tested was that brush-cutting would result in a reduction in the cover of *P. paniculata*. However, we observed a general decline in the relative cover of *P. paniculata* in all three trials that appeared to be unrelated to the frequency or height of brush-cutting treatment applied. In the New trial, for example, cover of *P. paniculata* declined from >12% to <7% with a 50 mm cut and dropped from >25% to <15% over the experimental period with a 200 mm cut. A similar pattern occurred in the 1997-cut treatment in the Pilot trial (>20% to <15% reduction) while changes over time were not marked under a single or double cut treatment in the Second-cut trial. An exception to this trend was the 1996-cut treatment in the Pilot trial where the cover of *P. paniculata* increased over time from <10% to >15%.

Further evidence of a general rather than a treatment-related change in all three trials came from the control (untreated) plots. The dominance of *P. paniculata* declined over time in the control plots of all three trials, with the largest reduction occurring in the Pilot (>20% to <15%) and New (>25% to <15%) trials and a smaller decline in the Second-cut trial. The biomass of *P. paniculata* also declined

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Table 2: Plant families present in the soil stored seed bank (plants m^{-2}) in the different treatments averaged across years (2001–2005) for the (a) Pilot trial (two replications), (b) New trial (two replications) and (c) Second-cut (three replications) trials conducted on Kleinvlakte in the Succulent Karoo (n = five samples per replicate; sample volume = 690 cm^3)

Family	Treatment								
	Pilot trial			New trial			Second-cut trial		
	Control	1996-cut	1997-cut	Control	50 mm cut	200 mm cut	Control	50 mm cut	200 mm cut
Asteraceae	581.31	460.73	460.73	297.54	338.70	356.81	287.83	249.66	326.76
Solanaceae	109.28	75.36	105.94	80.14	89.13	78.55	64.35	77.10	71.21
Poaceae	64.06	104.49	14.49	19.57	27.97	55.07	18.26	16.91	41.16
unknown	36.38	47.25	57.10	56.38	44.49	31.01	49.28	41.45	46.09
Oxalidaceae	6.38	4.49	4.20	9.57	7.39	8.26	28.60	32.56	41.74
Fabaceae	24.78	15.22	14.64	22.46	15.94	35.51	5.41	12.56	11.21
Polygonaceae	3.91	2.17	1.4	2.90	6.09	5.22	3.09	1.16	6.47
Cyperaceae	14.06	19.86	16.38	18.84	9.57	12.32	18.55	13.91	12.46
Mesembryanthemaceae	42.75	10.00	10.58	12.17	10.14	17.25	11.40	5.31	13.53
Crassulaceae	15.51	7.68	18.26	3.62	0.72	14.20	9.86	6.38	2.42

Table 3: The mean (± SE) above-ground biomass (g m^{-2}) measured in the (a) New trial (two replications) and (b) Second-cut (three replications) trial conducted on Kleinvlakte in the Succulent Karoo in the different treatments for 2001 and 2005

Trial	Treatment	Year	Palatability class			Total
			Palatable	Less Palatable	Unpalatable	
New trial	Control	2001	19.9 ± 0.4	5.9 ± 3.4	101.1 ± 14.2	127.9 ± 17.3
		2005	73.9 ± 15.3	1.2 ± 0.6	60.2 ± 4.9	135.1 ± 19.6
	50 mm cut	2001	12.8 ± 0.2	0.5 ± 0.2	4.3 ± 2.5	17.6 ± 2.4
		2005	88.4 ± 35.7	4.0 ± 3.9	25.4 ± 6.7	117.8 ± 32.9
	200 mm cut	2001	25.0 ± 14.8	4.9 ± 4.7	24.4 ± 3.1	54.3 ± 16.4
		2005	64.5 ± 23.7	4.8 ± 3.1	39.0 ± 7.0	108.3 ± 33.8
Second-cut trial	Control	2001	36.3 ± 6.1	11.3 ± 4.0	74.2 ± 7.5	121.8 ± 1.8
		2005	80.0 ± 17.9	11.8 ± 11.7	68.3 ± 8.2	160.0 ± 22.7
	50 mm cut	2001	22.3 ± 6.1	5.0 ± 1.7	30.6 ± 3.3	57.9 ± 9.4
		2005	61.6 ± 10.0	3.9 ± 2.7	46.0 ± 11.1	111.5 ± 6.5
	200 mm cut	2001	26.6 ± 7.9	12.2 ± 1.7	34.5 ± 5.8	73.3 ± 10.0
		2005	70.3 ± 6.4	3.5 ± 1.8	40.9 ± 7.1	114.7 ± 5.8

over time in the control plots, with a large decrease in the New trial (>100 g m^{-2} to <65 g m^{-2}) and a slight decrease in the Second-cut trial. Regardless of brush-cutting or not, there was a decrease in the cover of *P. paniculata*, other than expected.

Cover of palatable species (Highly Palatable, Palatable and Less Palatable categories) increased over time in all the treatments, including the control, in all the trials. Although the desirable species increased, it was the Less Palatable species (e.g. mesembs and *Pteronia sordida*) that increased the most (control: <10% to >15%; 50 mm cut: <6% to >15%; 200 mm cut: <10% to >15%), while the relative cover of Highly Palatable species (e.g. *Felicia muricata*) and Palatable species (e.g. *Pentzia incana*) increased by less than 2%. Consequently, there was an improvement in the species composition with more palatable and forage productive species present and less undesirable species. In most of the trials the control plots showed the same response as the treated plots, so the change in species composition and cover cannot be ascribed to brush-cutting alone.

The decrease in the above-ground biomass of *P. paniculata* in the control plots (101.1 ± 14.2 to 60.2 ± 4.9 g m^{-2} in New; 74.2 ± 7.5 g m^{-2} to 68.3 ± 8.2 g m^{-2} in Second-cut) can possibly be ascribed to mortality in these plots (NS and JCB pers.obs.), while their increase in the cut treatments could have been due to rejuvenation through defoliation (Danckwerts and Teague 1989). The above-ground biomass of Palatable (Highly Palatable and Palatable) species increased to a larger extent (>30 g m^{-2}) in all treatments of all

Table 4: Estimated grazing capacity (ha LSU^{-1}) of the vegetation in the different trials conducted on Kleinvlakte in the Succulent Karoo and treatments in 1997, 2001 and 2005, using average annual rainfall.

Trial	Treatment		
Pilot trial	**Control**	**1996-cut**	**1997-cut**
1997	161.61	135.87	147.67
2001	156.28	127.4	132.93
2005	73.57	58.70	63.30
New trial	**Control**	**50 mm cut**	**200 mm cut**
2001	221.11	435.42	246.66
2005	81.57	81.91	104.05
Second-cut trial	**Control**	**50 mm cut**	**200 mm cut**
2001	175.62	216.64	144.67
2005	93.58	90.58	85.84

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three trials than the Less Palatable species (<5 g m^{-2}), which decreased in the cut treatments of the Second-cut trial and control of the New trial. This is in contrast to the observed changes in relative canopy cover, where Highly Palatable and Palatable species showed a little increase and Less Palatable species a large increase. A possible explanation for the differences between the little increase in cover and large increase in biomass of the Palatable and Unpalatable species is that these species are mostly woody plants (e.g. *P. paniculata, Felicia muricata, Eriocephalus ericoides* and *Pentzia incana*), having a higher biomass after they were dried, in comparison to the Less Palatable species that consist mainly of succulents, including the mat-forming *Ruschia muricata* that covers a large area, but when dried have low biomass. Soil moisture, water infiltration, soil organic carbon content and the chemical properties of the soil did not differ between the treatments over time (data not shown) and could not have contributed to the observed changes in the cover and biomass of various components of the vegetation.

The general increase in the above-ground biomass in all the treatments implies an improvement of the veld with more forage available for grazing. Increased forage availability is also reflected in the estimated grazing capacities of the various treatments and the control. The overall improvement in the grazing capacity of all treatments was due mainly to an increase in the cover of Less Palatable species, and a decrease in the cover of *P. paniculata*. Although the improvement of biomass and cover in the cut treatments was greater than in the control, the difference between these in each of the trials was minimal, thus indicating that brush-cutting alone does not necessarily improve the grazing value of *P. paniculata*-dominated veld. The low abundance of Palatable and Highly Palatable species and an absence of their seed in the soil seed bank are considered to be among the main factors limiting recruitment and establishment of these plants (Jones and Esler 2004) in both the uncut control and cut treatments. The absence of *P. paniculata* and Highly Palatable and Palatable species in the seed bank can be ascribed to the fact that their seed is not long-lived and therefore does not survive in the seed bank (Milton and Dean 1994, Milton et al. 1995, Wiegand et al. 1995, Bakker et al. 1996, Wiegand and Milton 1996). By contrast seeds of small-seeded species, such as *Galenia fruticosa*, annuals and pioneer species, can survive for more than two years in the soil seed bank (Esler 1993, Wiegand et al. 1995) as was found in this study. Milton (1995) found that regeneration after disturbance depends on the recent years' seed production and not a long-dormant seed bank. Bakker et al. (1996) concluded that only those species with seeds that persist in the soil for at least five years are likely to contribute to the regeneration of degraded vegetation. Snyman (2004) found that it is not the density of seeds that is most important, but that the composition of the seed bank may be more critical in dictating which species can participate in the recovery of degraded veld (Jones and Esler 2004). This emphasises the fact that the recovery of degraded veld depends on the number of plants of desirable, seed-producing perennial species within or adjacent to the degraded area (Milton and Dean 1994, 1995, Milton et al. 1995, Snyman 2004). Therefore, it is important that any grazing in the area should be at a low stocking rate and timed to allow for flowering and seed set of the desirable species. Grazing should take place for the first time in the second summer following the brush-cutting (CG du Plessis, Department of Agriculture: Western Cape, 2009, pers. comm.), after which the veld should rest until late winter to allow seedlings to establish (Milton 1994). Stocking should be scheduled to avoid grazing the vegetation in a particular area in the same season every year and allow periods of rest for plants to build up reserves, set seed and for seedlings to establish.

Plant cover and species composition influence the vegetation productivity, grazing capacity and the economic potential of livestock systems utilising Karooveld (Milton et al. 1995). An improvement in the grazing capacity over a period of 4–9 years as a result of brush-cutting, light grazing and/or resting leads to an increased gross margin between R6 ha^{-1} and R13 ha^{-1} ( ). With a cost of R230 ha^{-1} (in 2004) for brush-cutting that only resulted in an increase in gross margin of R6–R13 ha^{-1} after 4–9 years, brush-cutting is definitely not an economically viable option. The increase in the gross margin after a second cut is even lower than after only one cut, while the cost of application is almost double. It would also not be a viable option to buy additional land (at an average cost of R1 500 ha^{-1}) with a better grazing capacity, because the long-term grazing capacity for veld in optimal condition in the area is 72 ha LSU^{-1} or 11 ha SSU^{-1} (as indicated in regulation 10 of the Conservation of Agricultural Resources Act, Act no. 43 of 1983; RSA 1984). Herling et al. (in press) found that the rehabilitation cost of reseeding is high compared to the resultant benefits accrued from small stock farming because of the low recommended grazing capacity for the Succulent Karoo.

Milton (1994), Milton and Dean (1995) and Milton et al. (1995) found that some disturbance of the vegetation is necessary to facilitate seedling establishment and thereby an improvement of the veld. This disturbance could be caused by climatic events (e.g. hailstorm or drought), by fire or through grazing/browsing or mechanical defoliation of the plants, such as by brush-cutting. Milton (1995) warned against extensive removal of vegetation because run-off and sediment loss increase when vegetation cover is removed. With brush-cutting, the plant litter is left in the cut area to help prevent run-off.

Vegetation recovery could possibly have been accelerated by reseeding the area with desirable species, such as *Tripteris sinuata, Hirpicium integrifolium, Chaetobromus dregeanus* and *Ehrharta calycina*, though this was not tested in the current study. Milton (1994) found that germination and establishment of sown-in seed is not always successful. The time of reseeding in relation to environmental factors such as temperature and rainfall, and disturbance events that may reduce the competitive effect of extant plants is critical for successful rehabilitation. Germination is most successful after autumn rain and survival is highest if there is follow-up rain during spring (Milton 1994).

With reseeding, the cost of rehabilitation increases (Milton and Dean 1994), but may not produce the desired composition state, except perhaps after many decades (Milton 1995), but Visser et al. (2007) found that recovery was much faster (within five years) with certain interventions, such as

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Table 5: Change in gross margins (R SSU^{-1} ha^{-1}) from the control in 1997 for the Pilot trial and control in 2001 for the New and Second-cut trials to 2005 in the control and cut-treatments conducted on Kleinvlakte in the Succulent Karoo

Trial	Treatment		
Pilot trial	**Control**	**1996-cut**	**1997-cut**
2005	9.88	14.47	12.51
New trial	**Control**	**50 mm cut**	**200 mm cut**
2005	10.32	10.25	6.79
Second-cut trial	**Control**	**50 mm cut**	**200 mm cut**
2005	6.66	7.13	7.94

Information: 1 LSU = 6.67 ssu; gross margin for dorper sheep = R200 SSU^{-1}. Assumption: 8-month-old Dorper sheep with 17 kg of meat/sheep at a price of R19 kg^{-1} (2006 price)

reseeding, tilling and brush-packing. Herling et al. (in press) found that the cost-recovery of restoration interventions that include reseeding could be longer than 20 years because of low seedling survival rates.

Conclusion

Brush-cutting did not have a more positive effect than resting (with some light grazing by wild ungulates) over a long period. Sheep were removed from the farm more than 40 years ago after which the veld was rested until the late 1990s when a small number of game were introduced. In other words, active intervention by cutting aimed at reducing the competitive dominance of *P. paniculata* has the same positive effect as passive restoration (no intervention with light grazing). Therefore there are no obvious circumstances for which brush-cutting without seeding can be recommended as a viable rehabilitation intervention.

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