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Selective herbicides extirpate forbs more effectively than alien plants, facilitating dominance of aggressive low grazing value grasses

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ABSTRACT

Between 2005 and 2008, eight selective herbicides were applied as broadcast foliar sprays at two grassland communities, a dry site and a wetland, infested with *Campuloclinium macrocephalum* in Gauteng. The study found that native forbs were highly susceptible to these selective herbicides. While treatment effects for both forbs and graminoids were not significant, significant changes occurred within treatments over time, leading to a notable decline in forb richness and abundance. At the dry site, 89 of 105 species (66 % forbs) were extirpated in some plots, with 36 species (80 % forbs) locally extinct. However, one year post-treatment, 52 new species (52 % forbs) were recorded. At the mesic site, 66 % of the 49 species also faced extirpation, and only 12 new records were found in the final year. The herbicide treatments primarily affected less common forb species, while more abundant ones persisted, indicating that this was due to large initial population sizes rather than herbicide tolerance. Graminoids increased overtime at the dry site reflecting an herbicide release effect from broadleaf species competition. However, the temporary nature of the herbicide's effects on species diversity suggests that rare species losses could be lasting. Herbicide drift emerged as a key contamination source, exacerbated by atmospheric factors, and soil moisture stress further influenced plant survival. Ultimately the emergence of a highly competitive native grass with low palatability capitalizing on suppressed forb communities at both sites raised concerns about the role of herbicides in improving veld condition.

1. Introduction

Herbicide effects on native species have largely been overlooked in studies evaluating the chemical control of alien weeds in natural ecosystems (Rice et al., 1997; Crone et al., 2009; Reid et al., 2009; Kettenring and Adams, 2011); making it difficult to determine acceptable trade-offs in the loss of indigenous species from alien plant control activities. The extensive use of broadleaf herbicides in natural pastures provides insights on effects that benefit land use such as increased grass production through the release from broadleaf plant competition (Thilenius et al., 1975; Koger et al., 2002; Shelly and Denny, 2006). Selective broadleaf herbicides are harmful to all dicotyledonous species, hence the control of broadleaf weeds may promote grass production but also will damage non-target forbs. Grassland forbs in general have a modest seed dispersal and short-lived seedbanks (Lunt, 1995; Soons and Heil, 2002; Soons et al., 2005) making them vulnerable to both alien plant invasions and clearing operations that utilise herbicides.

The classification of species into groups based on physiognomy, e.g. forbs and graminoids, is used in veld condition assessments to determine carrying capacity and changes in condition over time in response to defoliation from grazing pressure and/or fire (Tainton, 1981). The problem with this classification is that all forb species are grouped in the same category with the lowest "grazing value" even though many are palatable and constitute a diverse component in grassland (Morris and Scott-Shaw, 2019; Siebert et al., 2024), whereas grasses are rated according to their palatability and competitiveness in response to defoliation frequency. Grasses have been categorised as being either Decreaser or Increaser species. Decreaser grass species are palatable and decline in abundance when veld is under or over utilized. Less palatable Increaser grasses dominate under varying frequencies and intensities of defoliation. An upsurge in Increaser I species occurs under infrequent grazing and fire, Increaser II species become dominant in disturbed veld or/with sustained heavy grazing and Increaser III grasses are dominant in veld that is selectively over-grazed.

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Native forbs are collectively grouped as Increaser species in veld assessments despite the fact that the responses of the vast majority to disturbance and defoliation are not well documented (Siebert and Dreber, 2019; Siebert et al., 2024). Morris and Scott-Shaw (2019) categorized certain forb species in KwaZulu-Natal as Decreaser or Increaser species according to grazing intensity with the aim of refining the method as a rapid assessment tool in combination with other veld evaluation methods. Currently however, forbs are still lumped together in veld assessments for animal production because their relative contribution to bulk forage in comparison with grasses is very small. Secondly, it may take many years to categorise grassland forbs as either Decreaser or Increaser species, including forb identification and the recognition and implementation of forb condition scores (FCS) in veld condition assessments.

The importance and functions of grassland forbs in nature was recently published by Siebert et al. (2024). An important highlight of this research relevant to this article is the ability of forbs to coexist with grasses and prevail when grass cover is depleted through grazing intensity and/or drought. Forb diversity can also be substantial in grasslands invaded by herbaceous alien plants (Goodall et al., 2011, 2022). Forbs and grasses can also share equal dominance when nutrients and soil moisture are not limiting. Plant on plant interactions between forbs and grasses could also be competitive, facilitative and even amelioratory depending on the underlying drivers that determine coexistence and the direction of change (Siebert and Dreber, 2019). Grassland forbs respond favourably to various disturbances including variable grazing pressure and drought, but what happens to the ecological resilience of grassland communities if in addition to these disturbances, the forb component is destroyed? Does forb diversity mitigate the chances of highly competitive species gaining dominance if Decreaser species have been selected out through grazing for example? An applied scenario would be when selective herbicides are used to control broadleaf rangeland weeds in disturbed grassland that result in the elimination of forbs; are the gaps in the kill zones colonized by similar desirable functional species or do selective herbicides facilitate the densification of existing, highly invasive species?

We report on the effects of sequential herbicide applications, to control the noxious weed *Campuloclinium macrocephalum* (Less.) DC. (Asteraceae) (pompom weed), on native species in grassland. *Campuloclinium macrocephalum* is an alien perennial forb that is rapidly spreading in the savanna and grassland biomes of South Africa that receive ≥600 mm annual rainfall (Henderson, 2020). Highveld grasslands with dense stands of *C. macrocephalum* still retain many native species and growth forms (Goodall et al., 2011). Research into the chemical control of *C. macrocephalum* was conducted between 2005 and 2010 (Goodall and Witkowski, 2014, 2022).

The forb communities in this study have three main clades, namely monocots, dicots and ferns and the species within these clades will not have the same degree of tolerance or susceptibility to herbicide active ingredient's selectivity spectrum. Do life and growth forms play a role in their survival? For example, cryptic species such as geophytes and prostrate trailing species theoretically can avoid contact if the herbicide-tolerant grass layer is dominant and intercepts most of the pesticide spray. Annual species might be better adapted to persist in the form of seed in grasslands under frequent chemical control. Perennial species might also persist in areas under treatment as long as their seed constitutes a viable component of the residual seedbank.

In grasslands densely infested with *C. macrocephalum* it is not practical to spot-spray, as it will likely result in many of the plants being missed and increase the volume and costs of herbicide per treated hectare; so the most effective option is to initially apply herbicides as broadcast applications. Although vegetation assessments were conducted annually during the study period the only non-target species effects reported on was *Thesium utile* A.W.Hill (Santalaceae, a parasitic plant), which was extirpated by herbicides and hoeing but increased in the untreated control group (Goodall et al., 2022). Sequential applications of herbicide once a year provide a "worse-case" scenario for assessing herbicide damage on native species. Here we disclose the effects of treatments targeting *C. macrocephalum* on native forb and graminoid species at two contrasting grassland sites in Gauteng. The key question was whether chemical control can influence grassland community ecology by promoting species that are highly competitive and minimally impacted by herbicide exposure, considering the existing factors that determine species composition.

2. Materials and methods

2.1. Trial design

The study was conducted in two distinctly different vegetation communities, each receiving identical treatments. Design specifications were for 28 randomized treatments, replicated in three randomized blocks at each site, i.e. a total of 84 plots per site. Eight herbicides (Table 1), five at two levels and three at a single level each, were applied at two times of year in separate plots, viz. summer (January) and autumn (April) and repeated annually for three consecutive years. Manual weeding by hoe and an untreated control group were also included in the design. The design can be summarised as follows: herbicides applied in summer (n = 13) and autumn (n = 13), hoeing in summer and autumn in the same plot (n = 1) and the control group

Table 1
Treatments (n = 28) applied to veld in summer (January) and autumn (April) in separate 5 x 5 m plots with three replicates per treatment. Herbicide (n = 26) was applied as full cover sprays at a rate of 300 L water ha^{-1}. Hoeing and the untreated control did not have separate summer and autumn plots. Five herbicides were applied at two levels; three herbicides were at a single level each, two of which are registered (*) on *Campuloclinium macrocephalum* and were applied at label rates. Herbicides were applied once per annum over three years, i.e. "1 (3)" (see Frequency column below), in summer and autumn. Hoeing was done in summer and autumn in the same plot, i.e. twice per annum "2 (3)".

Treatment	Levels (N)	Fq.	Product dose (ℓ / kg ha^{-1})	A.I. dose (g ha^{-1})	Code	Target group on label
2,4-D (dimethylamine salt) 480 g L^{-1} †	2	1 (3)	3–6 ℓ	1440–2880	24D	herbaceous broadleaf species and certain grasses
2,4-D/dicamba/MCPA 180/120/158 g L^{-1} †	2	1 (3)	3–6 ℓ	540/360/474–1080/720/948	Tw	herbaceous broadleaf species
dicamba 480 g L^{-1}	2	1 (3)	0.5–1 ℓ	240–480	Ba	herbaceous broadleaf species
diuron 800 g L^{-1} ‡	2	1 (3)	3–6 ℓ	2400–4800	Di	annual dicot and monocot species
MCPA (potassium salt) 400 g L^{-1} †	2	1 (3)	3–6 ℓ	1200–2400	MCPA	herbaceous broadleaf species
metsulfuron-methyl 600 g kg^{-1} *	1	1 (3)	0.075 kg	45	MM	woody, herbaceous broadleaf and certain grass species
picloram (potassium salt) 240 g L^{-1} *	1	1 (3)	1.05 ℓ	252	P	woody and certain herbaceous broadleaf species
triclopyr (butoxy ethyl ester) 480 g L^{-1}	1	1 (3)	1.5 ℓ	720	T	woody species
hoeing	1	2 (3)	–	–	H	n/a, only *C. macrocephalum* removed
untreated control	1	–	–	–	C.	–

* registered and † unregistered herbicides found to control *Campuloclinium macrocephalum*, ‡ only diuron residues detected in soil up to 56 days after application (Goodall and Witkowski, 2022).

(n = 1) make up the 28 treatments in each replicate. Each plot measured 5 × 5 m in size. Because most plots received herbicide, 78 out of 84 plots (93 %), a 3 m buffer strip was imposed between plots and a 5 m buffer strip between blocks to mitigate the effects of herbicide drift.

The herbicides picloram 240 g ℓ^{-1} and metsulfuron methyl 600 g kg^{-1} were already registered on *C. macrocephalum* at inception and were included at label rates (Table 1) as standards against 5 unregistered herbicides at two levels each, viz. 2,4-D amine 480 ℓ^{-1}, 2,4-D/dicamba/MCPA 180/120/158 ℓ^{-1}, dicamba 480 ℓ^{-1}, diuron 800 ℓ^{-1} and MCPA 400 ℓ^{-1}. Triclopyr 480 ℓ^{-1} was included out of interest at single level of 0.5 ℓ formulated product per 100 ℓ water which is a common label concentration for foliar spraying.

2.2. Study sites

The experiment was carried out in two grassland communities 16 km apart, one at Swartkops Air Force Base (25°48′25″ S, 28°09′52″ E) Valhalla and the other at Rietvlei Nature Reserve (25°53′49″ S, 28° 17′38″ E) near Irene. Soils at Swartkops are well drained Clovelly and tillite conglomerate (MacVicar et al., 1977). It has a slight north-facing slope of 1°, altitude of 1460 m and an average annual rainfall of 678 mm. The vegetation type is classified as Carletonville Dolomite Grassland (Mucina and Rutherford, 2006). At the start of the study the grassland was described as having a sparse sward with a high forb component and dense stands of *C. macrocephalum*, indicative of a highly disturbed site. The most abundant grass and forb species at the start were *Setaria sphacelata* (Schumach.) Moss var. *torta* (Stapf) Clayton (Increaser II) and *Indigofera oxytropis* Benth. ex Harv. with plot frequencies of 93 and 62 % respectively.

The Rietvlei site is a wetland in the Carletonville Dolomite Grassland subdivision with a Rensburg soil form and a poorly drained, deep vertic A horizon (MacVicar et al., 1977). The site is flat with an elevation of 1500 m above sea level and an average annual rainfall of 724 mm. Vegetation at the site has been subjected to soil moisture stress over many years in the form of several boreholes that extract groundwater for municipal water supply (Marais, 2004). This has lowered the water table and caused a shift away from wetland vegetation to increasing invasions of native terrestrial grasses. The wetland is also traversed by drainage channels which indicate sections of the wetland were reclaimed for agricultural production prior to its status as a nature reserve. At the start the site was not as rich in native plant species as Swartkops and had been invaded and dominated by the grass *Hyparrhenia hirta (L.) Stapf* (Increaser II), which does not naturally grow in areas that are frequently waterlogged, and *C. macrocephalum* with plot frequencies of 100 %, whilst the most abundant native forb was *Diclis reptans Benth.* with frequency of 33 %.

2.3. Application of treatments

The hoe treatment selectively targeted and removed *C. macrocephalum* rootstocks (25 cm deep) and most of its fleshy, non-regenerative roots, while minimising disturbing native species above ground. Severing of underground roots of desirable species near the target weed could not be avoided. Hoe treatments occurred in February and April in the same plots for three consecutive years. Herbicides were applied as full cover sprays in plots, also known as blanket or broadcast applications, in early to mid-February (summer) and April (autumn) in 2005, 2006 and 2007, after each vegetation assessment had been concluded. Precision 10 ℓ sprayers (Holder, Germany) were fitted with even flat-fan spray nozzles and were calibrated to apply mixtures at a rate of 300 ℓ ha^{-1} at an operating pressure of 200 kPa. Plots were sprayed in 0.5 m swaths at a walking speed of 1 m sec^{-1} ensuring an even application of tank mix to the vegetation in the plot. Application rates were verified by measuring back residual volumes in the tank after spraying each plot.

Additional plots were laid out adjacent to the trial area at each site where the same herbicides (Table 1) were applied for monitoring herbicide persistence in the soil. Gas chromatography determined that only diuron exhibited residual activity in weekly soil sampling over a two month period after the applications were made (Goodall and Witkowski, 2022). The other herbicides tested were not detected in the soil at any sampling interval.

Herbicides can move in the atmosphere out of the treated zone in the form of particles and vapour. This mobility is independent from the application and is largely effected by pesticide chemical properties and weather conditions such as wind speed, wind direction, warm temperatures and low relative humidity. Weather conditions during spraying intervals in February and April (2005–2007) were sunny with light to gentle gusts of wind that ranged from four to 10 m s^{-1}. Temperatures ranged from 23 to 29 °C and relative humidity from 38 to 55 %. Herbicide spraying is not advisable if the wind speed exceeds 15 km/h so on some application days wind specifications were exceeded. To mitigate drift the operator only sprayed in lulls between gusts. No rain fell within 24 h after application.

The atmospheric model AgDISP version 8.26 (USDA Forest Service, 2015) was used to estimate minimum spray drift distance from the treated area using the application and meteorological data described above. The picloram 240 g ℓ^{-1} formulation at the registered rate of 1.05 ℓ product per 300 ℓ ha^{-1} (Table 1) or 0.35 % tank mix was used in this simulation. The model estimated that drift depositions at trace amounts of 1 mg ha^{-1} of picloram ranged from 70 to 125 m downwind from treated plots based on meteorological variation on the day of treatment. Based on the model outputs and that 93 % of the trial area was allocated for herbicide treatments, herbicide cross contamination in plots was definitive.

2.4. Climate

In the southern hemisphere the growing season is from September to March. For this reason we used winter to following winter (1 July to 30 June) to correlate rainfall and veld growth in the same period. Rainfall and temperature data for the study period were obtained from a weather station located between the two trial sites near Irene (Fig. 1). The long term average (LTA) rainfall for the district was 692 mm per annum. Rainfall over the study period was characterised by two years of below average rainfall, 2004/05 recorded 523 mm and 2006/07 recorded 243 mm, and two years above average rainfall, 2005/06 with 867 mm and 2007/08 with 987 mm (Fig. 1A). Two out of the three treatment years (2005–2007) occurred during dry years. The drought of 2006/07 received 449 mm less rainfall than the long term average and was also the hottest year (Fig. 1B). Vegetation had become severely water stressed and dusty at the time of the summer and autumn herbicide treatments which may have impeded herbicide translocation and perhaps elevated the risk of herbicide volatilization and drift.

2.5. Vegetation assessments

Vegetation assessments were carried out annually in January and April prior to the application of treatments, starting in January 2005 and ending April 2008, a year after the last treatments were applied. The hoe treatment and the untreated control group were the only treatments that were enumerated in summer and autumn in the same plots, i.e. herbicide treatments were measured once a year in either summer or autumn. The line intercept method (Canfield, 1941) was used to record relative species composition along 5 parallel 5 m long permanent transects spaced 0.75 m apart in each plot. Each transect had a metal peg at opposite ends of the plot that were used to attach a measuring tape during veld assessments. Plants that intercepted the tape were identified for species richness (S) and the length of each intercept was measured in centimetres. Graminoid

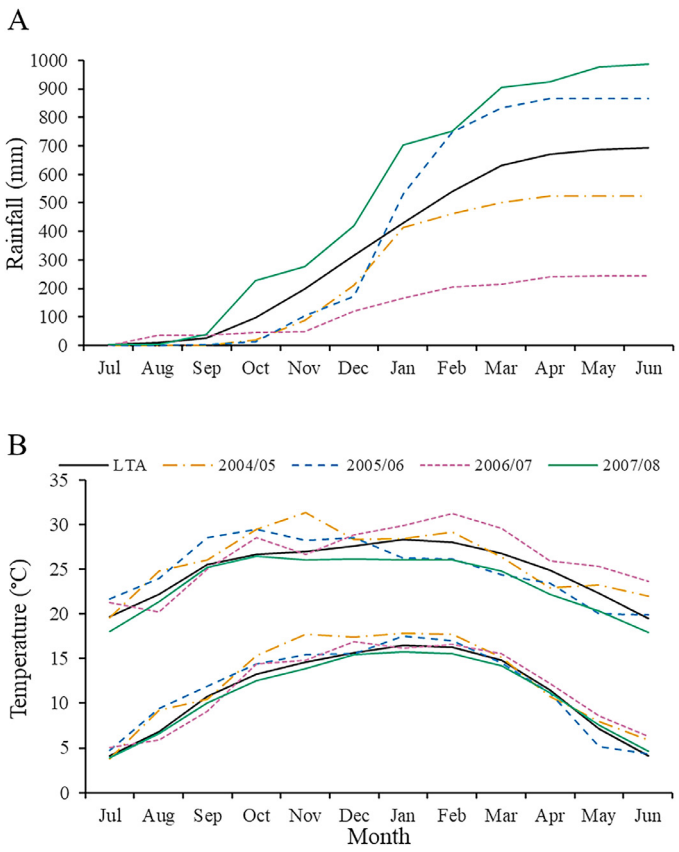

Fig. 1. Accumulated monthly rainfall (A) and average monthly maximum and minimum temperatures (B) obtained from a weather station between the two trial sites for the period July 2004 to June 2008, LTA = long term average.

intercepts were measured at ground level (basal cover) and forb species were measured as aerial cover at the maximum canopy intercept width. Enumerations always started at the zero end of the tape and the total transect length per plot was 2500 cm or 25 m, thus every 25 cm of intercept distance constituted 1 % basal or canopy cover.

2.6. Data capture and analysis

Species nomenclature followed Germishuizen and Meyer (2003) with authorities listed in Appendix A. Grass response groups, namely Decreaser and Increaser I to III grasses (Appendix A) are according to Van Oudtshoorn (2012). Herbicide mode of action and target group (Table 1) necessitated the separation of species into two groups based on physiognomy and herbicide susceptibility, namely graminoids (grasses and sedges) and forbs (ferns, dicots and non-graminoid monocots). This division is also used in veld condition assessments for livestock grazing management where grasses are the primary focus and other growth forms are lumped together as forbs. Data obtained from vegetation assessments in each plot included species richness (S), number of intercepts per species, intercept distance (cm) per species, total number of intercepts for forbs and graminoids and total intercept distance for forbs and graminoids.

Other characteristics/traits were also ascribed to species (Appendix A), viz.: physiognomy (forb, graminoid), clade (monocot, dicot, pteridophyte), life form (chamaephyte, geophyte, hemicryptophyte, therophyte), growth form (herb, grass, lily, sedge, succulent, suffrutex, vine), life span (annual, biennial, perennial) and lastly, habit (climbing/creeping/trailing, decumbent, erect, prostrate, stoloniferous, tufted). Some traits could provide insight as to how some species might avoid direct contact with herbicide sprays and improve their chances of survival. It is expected that selective herbicides affect monocot species to a lesser extent than dicots but size, habit and position of regenerating buds may also play a critical role in the survival of susceptible species. For example, interception of herbicide spray by herbicide-tolerant grass tufts might offer some protection to prostrate trailing forbs under the grass canopy but less so to exposed erect forb species.

Over the study period three patterns of response were observed; viz. extirpation, persistence and migration, which included species already present in the area but absent in plots and new species. Relative change in forb and grass richness was calculated for each plot to limit the influence of serial dependency between measurements to determine which treatments had the greatest impact on richness and when these changes occurred. The formula for relative change is S_{ij}-TS_i; where S=richness, TS=total richness (2005–2008), i=ith plot, j=jth year for forb and graminoid groups respectively and TS in each plot is constant. The Jaccard Similarity Index (J) was used to measure the degree of similarity in species composition in each plot between two vegetation assessments, viz. start (2005) vs. final assessment (2008) and between successive years (e.g. 2006–2007). The formula is simply the number of shared species divided by the total number of species in two sets of data, where values of 1=identical species compositions, and values of <1= degrees of similarity. The J index was used as a response variable to measure treatment effects on vegetation composition over the study period. Data were analysed on Statistica version 13.5.0.17 (TIBCO Software Inc., 2018) using Analysis of Variance methods including GLM, repeated measures, one and two-way factorial ANOVAs and descriptive statistics.

3. Results

The distribution of species and their respective population sizes were highly variable (Appendices B and C), plot compositions were quite heterogeneous and it was not possible to compare treatment effects on individual species with sample sizes insufficient for the planned statistical comparisons. Graminoids and forbs were analysed separately, not just because the latter are more susceptible to selective herbicides than grasses, but because they were measured differently; basal intercepts for graminoids and canopy intercepts for forbs.

A total of 105 plant species were recorded at Swartkops over the study period, 66 species were forbs (19 unidentified) and 39 species were graminoids (Appendix B). Monocot forbs (8 species) were from the families Amaryllidaceae, Asparagaceae, Asphodelaceae, Commelinaceae, Hypoxidaceae and Hyacinthaceae (Appendix A). A total of 49 species were recorded at Rietvlei over the study period (Appendix C), 33 species were forbs (9 unidentified) and 16 species were graminoids (3 unidentifiable sedges). Monocot forbs (4 species) were from the families Asparagaceae, Commelinaceae and Hyacinthaceae (Appendix A).

Generalized linear model (GLM) repeated measures ANOVAs of richness (S), number of intercepts (abundance) and intercept distance (cover) on forbs and graminoids at both sites revealed that treatments (Table 1) did not contribute to sources of variation in any significant manner (Appendix D). The most likely cause of this homogenisation is herbicide drift, which could have taken place on numerous occasions during application days in January and April 2005 to 2007. The drought of 2006/2007 is also a factor that might have affected survival, especially when coupled with pesticide exposure. The tables of species outcomes (Appendices B and C) show the wide ranges in extirpation, persistence and new records at both species and treatment levels at Swartkops and Rietvlei. Although not significant, picloram and metsulfuron methyl were ranked the most lethal herbicides on forbs at Swartkops and Rietvlei respectively (summary sections of Appendices B and C). Hoeing twice a year was ranked the least harmful treatment to both forbs and graminoids at both sites. The most harmful herbicides on graminoids at Swartkops

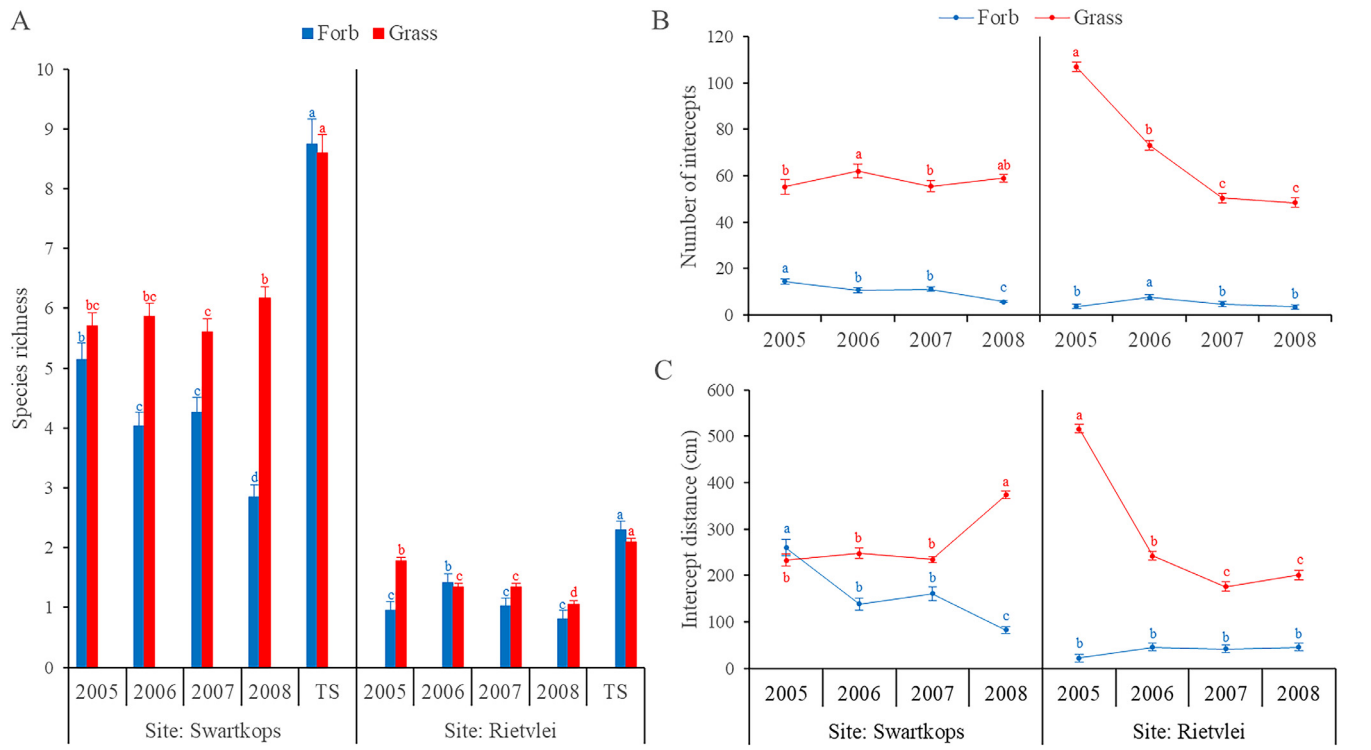

Fig. 2. Mean ± SE forb and grass richness (A), abundance (B) and cover (C) over time at Swartkops and Rietvlei. Forb and grass groups were analysed separately, as were sites. On the x-axis of chart A "TS" indicates the total number of species encountered over the study period, y-axes indicate mean values of data captured along 25 m transects in each plot. Forbs and grass groups were recorded separately as canopy and basal intercepts respectively, hence comparisons (Tukey α = 0.05) are only valid within these groups (same colour) at each site (Appendix D).

were 2, 4-D amine and diuron, the latter persisting in the soil longer than the 56 day monitoring period; both are indicated for the control of certain monocot species (Table 1). Dicamba and metsulfuron methyl were ranked highest for graminoid extirpation at Rietvlei, although untested, it was believed that sustained water stress was the main cause of species losses at the site. The most significant effect on richness, abundance and cover (Appendix D) was the within subjects change over time (years) and occasionally its interaction with season of treatment (summer vs. autumn).

An account of the within subjects changes (interaction = years) in forbs and grasses follows for each site. Forb richness (Fig. 2A), abundance (Fig. 2B) and cover (Fig. 2C) declined in plots over time at Swartkops whereas grass measurements remained stable (Appendix D). At Rietvlei forb and grass richness was much lower than at Swartkops, but initial grass abundance and cover was higher. Forb richness, abundance and cover remained relatively stable over the study period at Rietvlei (Fig. 2, Appendix D). The initial (2005) high grass cover (Fig. 2B and C) at Rietvlei may had provided adequate protection for understorey species from herbicide contact that was lacking in the more exposed and more diverse forb community at Swartkops. Grass richness, abundance and cover at Rietvlei declined significantly over time, in sharp contrast to grass responses at Swartkops. The differences in grass trends between the two sites cannot be explained as treatment effects as these were minimal (Appendix D), and in general terms the herbicides tested (Table 1) are well tolerated by graminoid species. Confounding factors, particularly limiting soil moisture emanating from drought could be regarded as being more critical on the mortality of graminoid species than the effects of selective herbicides and which was amplified by groundwater extraction at Rietvlei.

Changes in relative richness, defined as the difference between a plot's existing richness and its total richness over the study period, were only significant for forbs and graminoids at Swartkops and Rietvlei in the repeated measures effect, i.e. only changes over time were significant and all interactions involving treatments were not significant. At Swartkops changes in relative richness in the forb group was most significant in 2006 (Fig. 3A), a year after the first phase of treatments and 2008 ($F_{(3,180)}$=33.482, $P < 0.001$), a year after the third phase of treatments and coupled with drought and high temperatures (Fig. 1). In contrast changes in relative richness in the graminoid group were more restrained with a slight but significant increase in 2008 ($F_{(3,180)}$=4.124, P = 0.007), demonstrating a competitive relationship existed between forbs and grasses over the study period in spite of periods when soil moisture was limiting. At Rietvlei subtle yet significant reductions in the relative richness occurred in forb ($F_{(3,180)}$=9.681, $P < 0.001$) and graminoid groups ($F_{(3,180)}$=30.242, $P < 0.001$) (Fig. 3A). Rietvlei had much fewer species per plot than Swartkops (Fig. 2A), with an average of one to two forb and grass species per plot, half the grasses being terrestrial species. Plots therefore became relatively monospecific in terms of native species as wetland forbs and grasses declined. The mean number of forbs extirpated per plot at Swartkops was more than double that of persisting forbs, whereas graminoids experienced the exact opposite with persistence more than double that of extirpation (Fig. 3B). The rate of colonisation by existing and new species was roughly equal between forb and graminoid species. At Rietvlei both forbs and graminoids experienced significant extirpations, with rates of colonization by both groups much lower than at Swartkops. At the end of the study the typical composition of native species per plot at Rietvlei consisted of a single forb species with low abundance with a dominant terrestrial graminoid. Treatments intended to alleviate the effects of alien plant competition appear to have done more harm than had both sites been left untreated.

The Jaccard index (J) was used to compare similarity in species composition between vegetation assessments, viz. start-end (2005–2008) and between consecutive years (2005–2006, 2006–2007 and 2007–2008), and whether or not differences occurred between treatments. Treatment effects did not result in significant variation in J at both Swartkops ($P > 0.2$) and Rietvlei

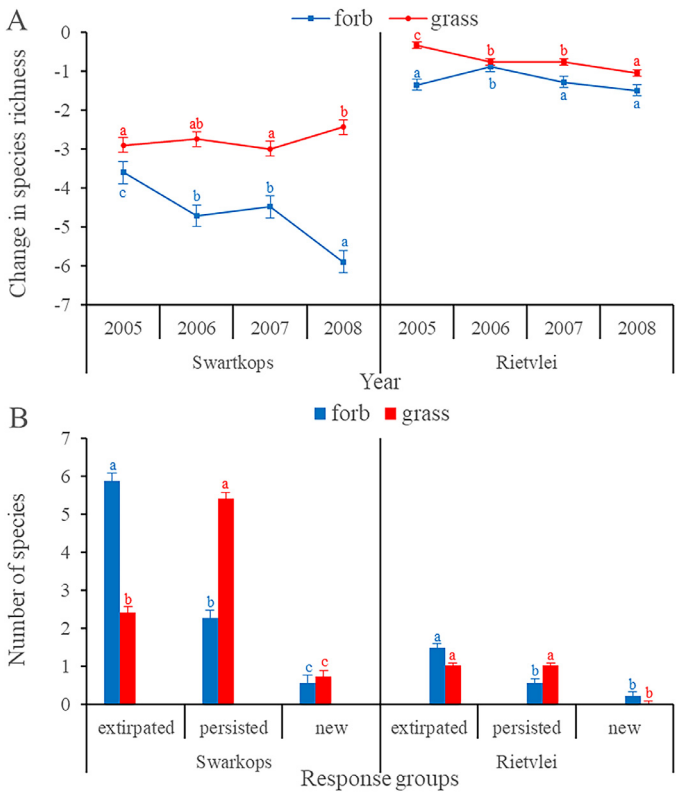

Fig. 3. Change in mean richness of forbs and grasses at Swartkops and Rietvlei sites relative to the total number of species observed over the study period (A), and (B) mean number of forb and grass species extirpated, persisted and new records at both sites. Forb and grass groups were analysed separately, as were sites. Hence comparisons (Tukey $\alpha = 0.05$) are only valid within these groups (same colour) at each site.

($P > 0.4$). However, changes in composition over the study period were highly significant (Fig. 4) with start-end comparisons (2005–2008) having the least degree of similarity at both Swartkops ($F_{(3,180)}$=30.266, $P < 0.001$) and Rietvlei ($F_{(3,180)}$=5.942, $P = 0.001$). There were also large differences in plot compositions between 2005 and 2006 at Swartkops a year after the first treatments were applied. In fact, significant differences in similarity over time did not matter as much as the indexes themselves, which showed substantial compositional changes took place on an annual basis across all treatments. In general plot compositions changed by 40 to 50 % year to year and these changes could be explained by the extirpation of forb species in plots. This also implies that changes in species composition in the untreated controls over the study period were of equal

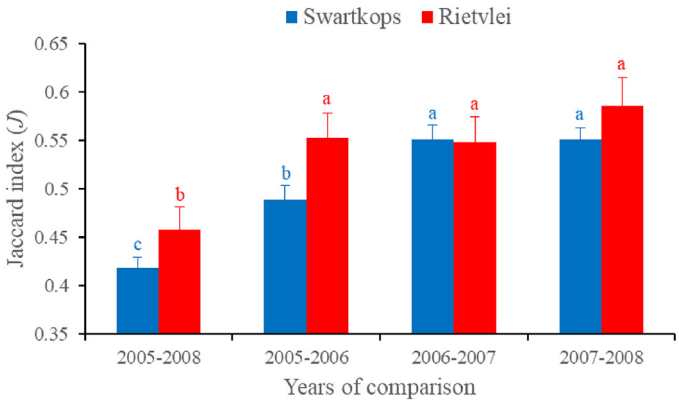

Fig. 4. Similarity in species composition (Jaccard index *J*) between vegetation assessments at Swartkops and Rietvlei. Sites were analysed separately, different letters depict significant differences within sites across years (Tukey $\alpha = 0.05$).

magnitude to herbicide and manual weeding treatments. The drought of 2006/07 did not appear to have a negative effect as strong as herbicide toxicity on compositional similarity. The largest dissimilarity between 2005 and 2006 under significantly less moisture stress indicates most of the damage occurred after the first treatments were applied.

The relation between the total number of intercepts (=abundance) and the total number of plots each species occurred in (plot frequency) were definitive for both forb and grass groups at each site (Fig. 5). Abundance was positively correlated to plot frequency in baseline assessments (2005). At Swartkops changes in abundance and frequency between 2005 and 2008 were severe in the forb group (Fig. 5A) as indicated by the abrupt decline in the indicated dominant species and the local extinction of *Hebenstretia comosa*. In contrast, graminoid species (Fig. 5B) generally showed slight increases, with *Hyparrhenia hirta* being the most notable exception with an increase in abundance of 268 %. Dominant species with the exception of *H. comosa* retained their status in 2008, notwithstanding significant reductions in individual populations in the forb group. Changes in the forb group at Rietvlei (Fig. 5C) were more subtle than at Swartkops. The common wetland forb *Diclis reptans* declined while the shrubby encroacher *Asparagus laricinus* increased. The few grass species at Rietvlei (Fig. 5D) declined from 2005 to 2008 with the loss of the true wetland grasses *Imperata cylindrica* and *Leersia hexandra*, as well as the Decreaser grass *Themeda triandra. Hyparrhenia hirta* abundance declined by 52 % but maintained its presence in every plot, resulting in a near monotypic graminoid stand at the end of the study.

Population size in most cases was influential for survival, i.e. species with higher abundance and frequency had better rates of survival than species that only occurred in one or a few plots. Commonness and rarity were a strong basis for persistence and extirpation respectively for both forb and graminoid species, as shown in Frequency attribute of Table 2. At Swartkops rare to occasional forbs (1 to 5 plots) had an extirpation rate of 88 % compared to 29 % in the 6–20 plot frequency and 17 % in the 21–84 plot frequency. Graminoids on the other hand had a 57 % extirpation rate at the lowest frequency, 9 % in the intermediate frequency and 0 % in the 21–84 plot frequency band. This also revealed the greater tolerance of graminoids to selective herbicides than forbs. Rietvlei had much fewer species than Swartkops but extirpation rates across population sizes was much higher in graminoids than forbs. Forb extirpation rates from lowest to highest frequency bands was 67 %, 20 % and 0 % respectively. Graminoids extirpations went from 91 %, 50 % and 0 % from lowest to highest frequency. Cognisance is taken of the greater probability for experimental error in repeated measures of species with low frequency, e.g. not consistently touching the tape or missed in subsequent surveys. There were cases where more abundant species were eliminated, for example *Hebenstretia comosa*, was a common perennial forb with a plot frequency of 52 % but was extirpated in all treatments (Appendix B, Fig. 5A), making it a good indicator species for herbicide intolerance.

The higher graminoid mortality at Rietvlei was not attributed to herbicide intolerance, rather sustained drawdown of the water table combined with drought. The demise of the stoloniferous wetland grasses *I. cylindrica, Ischaemum fasciculatum* and *L. hexandra*, cannot be attributed to a transient phase under chemical control because they declined in non-herbicide treatments; the untreated control was ranked third most lethal (Summary section of Appendix C), and most of the herbicides tested have minimal activity against grasses (Table 1). Other biological characteristics may have also played a role in the fates of species (Table 2). Geophytic forbs displayed higher levels of survival than life forms with perennating buds at or above the soil surface such as hemicryptophytes and chamaephytes, encompassing herbs and sub-shrubs. Low growing, creeping species also had higher rates of persistence than extirpation, which indicate

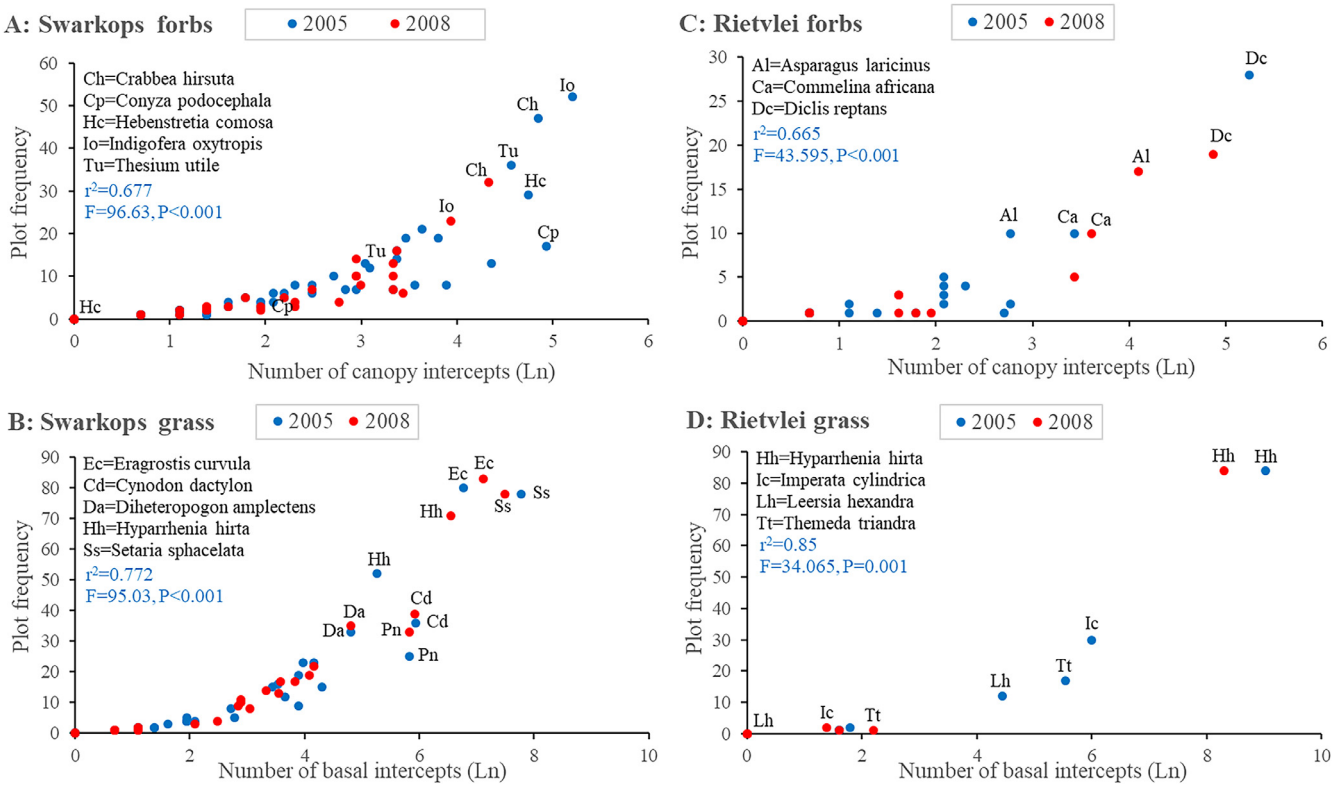

Fig. 5. Relation between the total number of intercepts (=abundance) and the total number of plots (plot frequency) that forb (A, C) and grass species (B, D) occurred in at Swartkops (A, B) and Rietvlei (C, D) trial sites at the beginning (2005) and the end (2008) of the study. The goodness of fit and level of significance of baseline data (2005) are expressed as r^2, F and P values in each chart. Changes in the most abundant species between 2005 and 2008 are indicated by genus-species abbreviations at corresponding data points and equivalent taxon in each chart.

cryptic species may have been partially protected by neighbouring taller plants which intercept most of the herbicide spray and therefore have less herbicide exposure. Most annual and biennial forbs were susceptible to treatments (Appendices A to C) and declined or were extirpated. The annual grasses *Aristida congesta* (Increaser II) and *Melinis repens* (Increaser II) persisted and were recorded as coloniser species at the end of the study.

Rates of colonization were highest in the hoe treatments for forbs and graminoids at both sites (Summary section of Appendices B and C), followed by the untreated control at Swartkops. Species with the highest number of new records in 2008 at Swartkops were *Trachypogon spicatus* (Increaser I), *H. hirta* (Increaser II), *Oxygonum dregeanum* and *Schizachyrium sanguineum* (Increaser I). At Rietvlei rates of colonization were low due to water stress with forbs being more prevalent than graminoids.

4. Discussion

The chemical control of broadleaf alien species has been shown to yield benefits in grass production within heavily invaded grasslands (Thilenius et al., 1975; Rice et al., 1997; Koger et al., 2002; Shelly and Denny, 2006). This effect was also quantified as an herbicide release impact on grasses, resulting from the reduction of *C. macrocephalum* (Goodall and Witkowski, 2014, 2022) and various forb species at Swartkops (see Fig. 3A). Following the implementation of chemical weed control, there was an observed increase in grass production; however, this improvement only marginally enhanced the veld condition (Fuhlendorf et al., 2002; Rinella et al., 2009). Similarly, at Swartkops palatable Decreaser grasses did not effectively exploit the niche space that became available due to the attrition of weeds and forbs following herbicide application. Grass abundance increased from 4574 to 4862 intercepts between 2005 and 2008. Throughout this period, the proportions of increaser and decreaser species remained relatively stable at approximately 88.7 % and 11.3 %, respectively. *Hyparrhenia hirta* (Increaser II) demonstrated exceptional competitiveness among the grass species. Over a span of three years, which notably included a year marked by drought conditions, this species exhibited an impressive growth increase of 268 %. This remarkable resilience highlights its adaptability and potential for thriving in challenging environmental conditions which is not a positive outcome because it is not very palatable and is only utilized by herbivores in the early growing season.

Stocking rates are reliant on palatable species that decrease under grazing pressure as well as soil fertility and bioclimatic influences (Fynn and O'Connor, 2001; Fensham et al., 2005). Generally heavily invaded rangelands do not revert back to quality pasturage through chemical control alone (Papanastasis, 2009) and this view is supported in this study. If not coupled with restoration/rehabilitation activities (Kirkman, 2024), herbicide release effects on their own will likely benefit the most aggressive Increaser grass already established, as was noted at both Swartkops and Rietvlei.

These observations lead to the following premises. Poor veld management characterised by under-grazing, over-grazing, and selective grazing practices is a significant factor contributing to poor veld condition and the spread of native and alien weeds. Selective herbicides control broadleaf species but the gaps left by dead plants are not necessarily colonized by desirable species. Reliance solely on chemical control has the potential to modify veld to whichever increaser species is most competitive under the prevailing management paradigm where Decreaser grasses have been exploited. For example *Cymbopogon nardus* (Increaser I) could become dominant following herbicide applications in underutilized grassland (moribund), *H. hirta* has been verified as becoming invasive following chemical control in disturbed and overgrazed grassland and *Elionurus muticus* (Increaser III) could

Table 2
Outcomes of forb and graminoid species expressed as extirpation (Ext.), persistence (Per.) and new records (New) at Swartkops and Rietvlei over a four year study period, arranged according to population and biological attributes. Population attributes places the number of individual species into three plot frequency classes, viz. rare-occasional (present in 1–5 plots), frequent (6–20 plots) and common (21–84 plots). Attributes have the same number of species per column.

Attribute	Range/Scope	Site: Swartkops						Site: Rietvlei					
		Forbs			Graminoids			Forbs			Graminoids		
		Ext.	Per.	New	Ext.	Per.	New	Ext.	Per.	New	Ext.	Per.	New
Frequency	1–5	23	3	7	8	6	6	16	8	3	10	1	1
	6–20	6	15		1	10		1	4		1	1	
	21–84	2	10			8			1			2	
Clade	monocotyledon	1	6	1	9	24	6		4		11	4	1
	dicotyledon	30	21	6				17	9	3			
	pteridophyte		1										
Lifespan	annual	1	2		3	3	1		1	1	1		1
	biennial	1			1	1		1			1		
	perennial	15	26	2	5	20	5	9	12		6	4	
	unknown	14		5				7		2	3		
Growth form	grass				9	23	6				8	4	1
	fern		1										
	herb	10	13	1				7	9	1			
	lily		4	1					1				
	sedge					1					3		
	succulent	1	1										
	suffrutex	5	7					2	2				
	vine	1	2					1	1				
	unknown	14		5				7		2			
Life form	chamaephyte	8	11					4	5				
	geophyte	1	5	1		1		2	5				
	hemicryptophyte	7	10	1	6	20	5	4	2		7	4	
	therophyte	1	2		3	3	1		1	1	1		1
	unknown	14		5				7		2	3		
Habit	climbing	2	1						3				
	decumbent	2											
	erect	10	18	1				5	8	1			
	prostrate/trailing	3	9	1				5	2				
	stoloniferous					1					2	1	
	tufted				9	23	6				9	3	1
	unknown	14		5				7		2			
Total		31	28	7	9	24	6	17	13	3	11	4	1

become problematic under selective grazing (Nel, 1983). This indicates various stages in a continuum of weed invasion and grassland degradation when herbicides can be effective on their own, when they should be integrated with veld restoration efforts, and when their use should be completely avoided.

All the herbicides tested in this study (Table 1) were unsuccessful at eliminating *C. macrocephalum* in plots after three annual broadcast applications (Goodall and Witkowski, 2022). The weed's density increased after cessation of treatments through seedling recruitment and it was estimated that at least 5 years of follow-up treatments would be required to bring the weed under complete control at the plot level (Goodall and Witkowski, 2014). From an economic perspective this effectively makes chemical control unfeasible for the control of medium to dense infestations of *C. macrocephalum*, where the veld condition is likely to be low, and will likely remain low if less desirable invasive grasses establish in spaces opened up by the extirpation of broadleaf species. It also serves as a warning not to allow invasions to advance to a level where consequential reduction in carrying capacity and escalation in control costs could end in bankruptcy (Evans, 2004). The densification of *C. macrocephalum* to levels of more than one plant per square metre, where only blanket herbicide sprays were feasible to combat the weed, also resulted in unacceptably high losses in native plant species, particularly in the forb physiognomic group. As our results indicate, weed density not only affects economic viability of grassland, but herbicide interventions to reduce weed density have disastrous consequences for plant species diversity (Figs. 3 and 5).

Hoeing twice a year was completely ineffective as a control measure against *C. macrocephalum* (Goodall and Witkowski, 2022) and facilitated the establishment of annual weeds such as *Bidens pilosa* L. and *Tagetes minuta L.* Although hoeing was the least damaging treatment (Appendices A and B) it extirpated the parasitic plant *Thesium utile* (Santalaceae), a species which declined in all treatments (Fig. 5A) except the untreated control group (Goodall et al., 2022). The role of hoeing in weed management in grassland is most suited to small scale situations and for the control of species that do not produce copious quantities of seed, especially not against achene-producing species with long distance seed dispersal and phytochrome mediated germination.

The effects of groundwater pumping in wetlands has the potential to shift vegetation away from species adapted to hydrophytic conditions to favour species that have little tolerance to saturated soils (Cooper et al., 2015). This happened at the Rietvlei trial site where sustained drawdown resulted in the extirpation of aquatic graminoids such as *I. cylindrica, I. fasciculatum* and *L. hexandra. Imperata cylindrica* is a troublesome weed in other parts of the world and difficult to control (Enloe et al., 2018), but it is native to Africa and plays an important role in wetland function. Grass abundance went from 9036 to 4017 intercepts from 2005 to 2008, with wetland graminoids declining from 741 (8.2 %) to 11 (0.3 %) intercepts. The loss of wetland grasses and the increase in the terrestrial grass *H. hirta* cannot be rationalised as susceptibility to selective herbicides. The 2007 application was to desiccated vegetation and not to active growth. Herbicide application onto drought stressed vegetation would be less effective than on healthy vegetation because of stomatal closure, dust and the diminished capacity for absorption and translocation. Hence sustained water stress through groundwater pumping was as damaging to vegetation as herbicide exposure, both of which harmed many species but also altered structure of the vegetation thought

sequential plant succession. *Hyparrhenia hirta* was identified as a species capable of exerting dominance in grasslands under chemical weed control in both dryland and hydric conditions, the latter when the water table is constantly lowered by drawdown. The effects of periodic drought on grassland species composition and productivity appear to be short lived (Wilcox, 2020), which supports the trends in grass richness, abundance and cover at Swartkops. However, when severe drought coincides with pumping groundwater, the recovery time is extended and in this study the wetland vegetation at Rietvlei had collapsed. The absence of significant treatment differences under soil moisture stress at Rietvlei, already elevated by sustained water extraction and compounded by drought, is seen as the leading cause of population declines in aquatic graminoid species (Appendix B). Closing up the drainage canals and preserving periods of inundation may be an effective strategy to curb invasions of *H. hirta* and *C. macrocephalum* in the Rietvlei wetland system.

The lack of treatment differences for richness, abundance and cover of forb and grass species over three years at Swartkops and Rietvlei sites indicates that herbicide drift, either as primary particles or secondary vapour, could not be contained. Herbicide depositions of trace amounts of active ingredient up to 125 m from the edge of the plot, as deduced from the AgDISP simulations, would have affected all plots and had a homogenising effect that was most lethal to the forb component. These findings are in line with other studies where drift from ground applications affected non-target species >300 m downwind (Moore et al., 2021). In our study the acute toxicity of forbs to herbicides was to a greater extent attributed to airborne contact rather than the persistence of herbicide residues in the soil. Our understanding of herbicide mobility in the atmosphere was woefully inadequate in hindsight or else we would have implemented a design with fewer treatments and larger buffer zones between plots. Nevertheless, this does not detract from the fact that many large scale programmes on alien plant control are unaware of the hazards of herbicide drift on susceptible species, particularly in open grasslands.

In this study the persistence of susceptible species after repeated herbicide exposures does not infer tolerance, which is the ability of a species to maintain its population and reproduce after multiple treatments (Leon, 2024). Susceptible species like forbs that persisted were usually common at the start and were still present at the end of the study in spite of substantial reductions in populations even with augmentation from the soil-seed reserve. For example, at Swartkops *Crabbea hirsuta* had an Extirpation – Persistence - New Records (E-P-N) of 28-31-1 (Appendix B) and at Rietvlei *Diclis reptans* had an E-P-N record 30-19-2 (Appendix C). The 5 years of herbicide treatments required to eradicate dense stands of *C. macrocephalum* will undoubtable decimate forb species in the zones being treated. Many of the susceptible species encountered were rare and were lost after the first herbicide treatment, which raises concerns about conserving the diversity of rare forbs in rangelands earmarked for chemical control (Fuhlendorf et al., 2002).

In light of these findings careful consideration needs to be given to best practises for herbicide usage in grassland. Invasive species are generally more problematic in grazing-related disturbed grasslands (Keeley, 2003; Goodall et al., 2011) and the benefits of chemical control are unlikely to result in increased sward palatability if the ratio of Increaser to Decreaser species favours the former. This is because palatable grasses may have been reduced through grazing pressure, many of which have low seed production potential and poorly adapted long-distance dispersal mechanisms (O'Connor, 1991), thereby facilitating the establishment of both alien and native invasive species and increased competition from less palatable grass species. The main purpose for applying herbicides in grasslands should be to reduce invasive species and curb their spread and should never be viewed as a remedy for poor pasture management. Knowledge of herbicides and application techniques, e.g. target specific spot sprays versus broadcast sprays and use of spray nozzles that produce coarser droplet sizes that are less prone to drift, is very important to prevent damage to susceptible native plants as our results have shown. Additional methods including restoration/rehabilitation, sound management practises such as frequent veld assessments, veld resting, correct timing and frequency of burning, adjusting stocking rates and animal ratios according to limitations of the resource base are essential to facilitate the process towards improving pasture condition and species diversity. Before embarking on a chemical control programme for herbaceous veld invaders it would be prudent to first conduct veld condition assessments to ascertain the proportions of weeds and Decreaser to Increaser grass species. In the event that Decreaser grasses are not a common in the grassland it may be wiser to place the asset under biological control, if applicable, along with revised veld management that includes minimal grazing, resting, triennial burning and monitoring. The use of herbicides for the control of weeds in grassland is most effective and least damaging when it applied to the target weed only (e.g. spot spray) when weed densities are low as soon as they appear in response to grazing.

In 2021 the *C. macrocephalum* infestation at the Rietvlei trial site was very dense (Natalie Vos pers. comm.), implying past progress in its control had been lost and that the purging of forbs may have rendered the site even more susceptible to invasion. Broadcast applications of herbicide using a boom sprayer in 2021 and application by a drone in December 2024, with a wildfire in the winter of 2024, reduced the infestation significantly. However, recruitment by seed continues to present a significant source of reinfestation and the continued reliance on chemical control. This observation supports the question laid out in the introduction that forb diversity may play an important functional role in ecological resilience and ameliorating competition amongst highly competitive species, especially alien plants and Increaser grasses. If this is the case then selective herbicides could be a double edged sword leading to unintentional vegetation change in grasslands affected by invasive plants, with implications for large scale clearing operations in the grassland and savanna biomes of South Africa.

Conflict of interest statement

The authors declare there is no conflict interest in this research or in the submission of this article to the SAJB.

CRediT authorship contribution statement

J.M. Goodall: Writing – review & editing, Writing – original draft, Validation, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **E.T.F. Witkowski:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization.

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Appendix A. List of native species and authorities in alphabetical order with physiognomy, family, clade, lifespan, growth form, life form and habit included

Genus	Physiognomy	Family	Clade	Life span	Growth form	Life form	Habit
Aloe zebrina Baker	forb	ASPHODELACEAE	monocotyledon	perennial	succulent	chamaephyte	erect
Andropogon schirensis A.Rich.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, d[1]
Aristida bipartita (Nees) Trin. & Rupr.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2[1]
Aristida congesta Roem. & Schult.	graminoid	POACEAE	monocotyledon	biennial	graminoid	hemicryptophyte	tufted, i2
Aristida stipitata Hack.	graminoid	POACEAE	monocotyledon	annual	graminoid	therophyte	tufted, i2
Asparagus laricinus Burch.	forb	ASPARAGACEAE	monocotyledon	perennial	suffrutex	geophyte	climbing
Asparagus setaceus (Kunth) Jessop	forb	ASPARAGACEAE	monocotyledon	perennial	suffrutex	geophyte	climbing
Becium obovatum (E.Mey. ex Benth.) N.E.Br.	forb	LAMIACEAE	dicotyledon	perennial	herb	hemicryptophyte	prostrate/trailing
Berkheya radula (Harv.) De Wild.	forb	ASTERACEAE	dicotyledon	perennial	herb	hemicryptophyte	erect
Bewsia biflora (Hack.) Gooss.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, ?[1]
Boophone disticha (L.f.) Herb.	forb	AMARYLLIDACEAE	monocotyledon	perennial	lily	geophyte	erect
Brachiaria serrata (Thunb.) Stapf	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted
Chamaecrista comosa E.Mey.	forb	FABACEAE	dicotyledon	perennial	herb	hemicryptophyte	erect
Cheilanthes involuta (Sw.) Schelpe & N.C.Anthony	forb	PTERIDOPHYTA	pteridophyte	perennial	fern	geophyte	erect
Clematis brachiata Thunb.	forb	RANUNCULACEAE	dicotyledon	perennial	vine	chamaephyte	climbing
Commelina africana L.	forb	COMMELINACEAE	monocotyledon	perennial	herb	chamaephyte	prostrate/trailing
Convolvulus sagittatus Thunb.	forb	CONVOLVULACEAE	dicotyledon	perennial	vine	hemicryptophyte	prostrate/trailing
Conyza podocephala DC.	forb	ASTERACEAE	dicotyledon	perennial	herb	chamaephyte	erect
Crabbea angustifolia Nees	forb	ACANTHACEAE	dicotyledon	perennial	herb	hemicryptophyte	prostrate/trailing
Crabbea hirsuta Harv.	forb	ACANTHACEAE	dicotyledon	perennial	herb	hemicryptophyte	prostrate/trailing
Crassula capitella Thunb.	forb	CRASSULACEAE	dicotyledon	biennial	succulent	chamaephyte	decumbent
Cymbopogon excavatus (Hochst.) Stapf ex Burtt Davy	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i1[1]
Cymbopogon nardus (L.) Rendle	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i1
Cymbopogon pospischilii (K.Schum.) C.E. Hubb.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i1
Cynodon dactylon (L.) Pers.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	stoloniferous, i2
Cynoglossum hispidum Thunb.	forb	BORAGINACEAE	dicotyledon	biennial	herb	chamaephyte	erect
Cyperus esculentus L.	graminoid	CYPERACEAE	monocotyledon	biennial	graminoid	geophyte	tufted, i2
Dichapetalum cymosum (Hook.) Engl.	forb	DICHAPETALACEAE	dicotyledon	perennial	suffrutex	geophyte	prostrate/trailing
Diclis reptans Benth.	forb	SCROPHULARIACEAE	dicotyledon	perennial	herb	chamaephyte	prostrate/trailing
Digitaria eriantha Steud.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, d
Digitaria monodactyla (Nees) Stapf	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Diheteropogon amplectens (Nees) Clayton	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, d
Elephantorrhiza elephantina (Burch.) Skeels	forb	FABACEAE	dicotyledon	perennial	suffrutex	hemicryptophyte	erect
Elionurus muticus (Spreng.) Kuntze	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i3[1]
Eragrostis capensis (Thunb.) Trin.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Eragrostis chloromelas Steud.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Eragrostis curvula (Schrad.) Nees	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Eragrostis gummiflua Nees	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Eragrostis inamoena K.Schum.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Eragrostis micrantha Hack.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Eragrostis plana Nees	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Eragrostis racemosa (Thunb.) Steud.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Eriosema cordatum E.Mey.	forb	FABACEAE	dicotyledon	perennial	herb	hemicryptophyte	prostrate/trailing
Eucomis autumnalis (Mill.) Chitt.	forb	HYACINTHACEAE	monocotyledon	perennial	lily	geophyte	erect
Galium capense Thunb.	forb	RUBIACEAE	dicotyledon	perennial	herb	chamaephyte	prostrate/trailing
Gomphocarpus glaucophyllus Schltr.	forb	APOCYNACEAE	dicotyledon	perennial	herb	geophyte	erect
Hebenstretia comosa Hochst.	forb	SCROPHULARIACEAE	dicotyledon	perennial	herb	hemicryptophyte	erect
Helichrysum dasymallum Hilliard	forb	ASTERACEAE	dicotyledon	perennial	herb	hemicryptophyte	erect
Helichrysum kraussii Sch.Bip.	forb	ASTERACEAE	dicotyledon	perennial	suffrutex	chamaephyte	erect
Helichrysum nudifolium (L.) Less.	forb	ASTERACEAE	dicotyledon	perennial	herb	hemicryptophyte	erect
Helichrysum rugulosum Less.	forb	ASTERACEAE	dicotyledon	perennial	herb	hemicryptophyte	erect
Hermannia cordata (E.Mey. ex E.Phillips) De Winter	forb	STERCULIACEAE	dicotyledon	annual	herb	therophyte	erect
Heteropogon contortus (L.) Roem. & Schult.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Hibiscus microcarpus Garcke	forb	MALVACEAE	dicotyledon	annual	herb	therophyte	prostrate/trailing
Hibiscus trionum L.	forb	MALVACEAE	dicotyledon	annual	herb	therophyte	erect
Hyparrhenia hirta (L.) Stapf	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Hyparrhenia tamba (Steud.) Stapf	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i1
Hypoxis iridifolia Baker	forb	HYPOXIDACEAE	monocotyledon	perennial	lily	geophyte	erect
Hypoxis rigidula Baker	forb	HYPOXIDACEAE	monocotyledon	perennial	lily	geophyte	erect
Imperata cylindrica (L.) Raeusch.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	stoloniferous
Indigofera oxytropis Benth. ex Harv.	forb	FABACEAE	dicotyledon	perennial	herb	chamaephyte	erect
Ipomoea ommaneyi Rendle	forb	CONVOLVULACEAE	dicotyledon	perennial	vine	hemicryptophyte	prostrate/trailing
Ischaemum fasciculatum Brongn.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	stoloniferous
Justicia anagalloides (Nees) T.Anderson	forb	ACANTHACEAE	dicotyledon	perennial	herb	hemicryptophyte	erect
Lantana rugosa Thunb.	forb	VERBENACEAE	dicotyledon	perennial	suffrutex	chamaephyte	erect
Ledebouria ovatifolia (Baker) Jessop	forb	HYACINTHACEAE	monocotyledon	perennial	lily	geophyte	prostrate/trailing
Ledebouria revoluta (L.f.) Jessop	forb	HYACINTHACEAE	monocotyledon	perennial	lily	geophyte	prostrate/trailing
Leersia hexandra Sw.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	stoloniferous
Lotononis calycina (E.Mey.) Benth.	forb	FABACEAE	dicotyledon	perennial	herb	hemicryptophyte	prostrate/trailing
Melinis nerviglumis (Franch.) Zizka	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, d
Melinis repens (Willd.) Zizka	graminoid	POACEAE	monocotyledon	annual	graminoid	therophyte	tufted, i2
Oxygonum dregeanum Meisn.	forb	POLYGONACEAE	dicotyledon	perennial	herb	hemicryptophyte	erect
Panicum natalense Hochst.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, d
Parinari capensis Harv.	forb	CHRYSOBALANACEAE	dicotyledon	perennial	suffrutex	chamaephyte	prostrate/trailing
Pogonarthria squarrosa (Roem. & Schult.) Pilg.	graminoid	POACEAE	monocotyledon	biennial	graminoid	hemicryptophyte	tufted, i2
Pollichia campestris Aiton	forb	CARYOPHYLLACEAE	dicotyledon	perennial	herb	chamaephyte	erect
Polygala hottentotta C.Presl	forb	POLYGALACEAE	dicotyledon	perennial	suffrutex	chamaephyte	erect
Pygmaeothamnus zeyheri (Sond.) Robyns	forb	RUBIACEAE	dicotyledon	perennial	suffrutex	chamaephyte	prostrate/trailing
Rhoicissus tridentata (L.f.) Wild & R.B.Drumm.	forb	VITACEAE	dicotyledon	perennial	vine	chamaephyte	climbing
Rhynchosia totta (Thunb.) DC.	forb	FABACEAE	dicotyledon	perennial	herb	hemicryptophyte	prostrate/trailing
Rumex sagittatus Thunb.	forb	POLYGONACEAE	dicotyledon	perennial	vine	geophyte	climbing

(*continued*)

(*Continued*)

Genus	Physiognomy	Family	Clade	Life span	Growth form	Life form	Habit
Schizachyrium sanguineum (Retz.) Alston	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i1
Selago densiflora Rolfe	forb	SCROPHULARIACEAE	dicotyledon	perennial	suffrutex	chamaephyte	erect
Senecio affinis DC.	forb	ASTERACEAE	dicotyledon	perennial	herb	chamaephyte	erect
Senecio erubescens Aiton var. *crepidifolius* DC.	forb	ASTERACEAE	dicotyledon	perennial	herb	chamaephyte	erect
Senecio isatideus DC.	forb	ASTERACEAE	dicotyledon	perennial	herb	chamaephyte	erect
Senecio venosus Harv.	forb	ASTERACEAE	dicotyledon	perennial	herb	hemicryptophyte	erect
Seriphium plumosum L.	forb	ASTERACEAE	dicotyledon	perennial	suffrutex	chamaephyte	erect
Setaria pumila (Poir.) Roem. & Schult.	graminoid	POACEAE	monocotyledon	annual	graminoid	therophyte	tufted, i2
Setaria sphacelata (Schumach.) Moss var. *torta* (Stapf) Clayton	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Solanum panduriforme E.Mey.	forb	SOLANACEAE	dicotyledon	perennial	suffrutex	chamaephyte	erect
Sonchus dregeanus DC.	forb	ASTERACEAE	dicotyledon	annual	herb	therophyte	erect
Tephrosia semiglabra Sond.	forb	FABACEAE	dicotyledon	perennial	herb	chamaephyte	decumbent
Themeda triandra Forssk.	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, d
Thesium utile A.W.Hill	forb	SANTALACEAE	dicotyledon	perennial	suffrutex	hemicryptophyte	erect
Trachypogon spicatus (L.f.) Kuntze	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i1
Trichoneura eleusinoides (Rendle) Ekman	graminoid	POACEAE	monocotyledon	annual	graminoid	therophyte	tufted, i2
Trichoneura grandiglumis (Nees) Ekman	graminoid	POACEAE	monocotyledon	annual	graminoid	therophyte	tufted, i2
Tristachya leucothrix Nees	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i1
Urochloa brachyura (Hack.) Stapf	graminoid	POACEAE	monocotyledon	perennial	graminoid	hemicryptophyte	tufted, i2
Urochloa panicoides P.Beauv.	graminoid	POACEAE	monocotyledon	annual	graminoid	therophyte	tufted, i2
Vernonia oligocephala (DC.) Sch.Bip. ex Walp.	forb	ASTERACEAE	dicotyledon	perennial	herb	hemicryptophyte	erect
Withania somnifera (L.) Dunal	forb	SOLANACEAE	dicotyledon	perennial	suffrutex	chamaephyte	erect
Xysmalobium undulatum (L.) Aiton f.	forb	APOCYNACEAE	dicotyledon	perennial	herb	geophyte	erect

[1] grass response groups: *d*=Decreaser, i1=Increaser I, i2=Increaser II, i3=Increaser III, ?=unknown.

Appendix B. Swartkops

Table of species outcomes by treatment code ([1],Table 1) showing the number of plots extirpated "E" (plain text), persisted "P" (underlined) and new records "N" (bold), numbers in brackets in the header row indicate total number of plots, sum of numbers per cell cannot exceed numbers in brackets (extirpated values are subtracted). Species with an asterisk * became locally extinct.

Genus	Physiognomy	C	H	24D	Tw	MCPA	Di	Ba	P	M	T	Total E	Rank E	Total P	**Total N**
	plots (n)	(3)	(3)	(12)	(12)	(12)	(12)	(12)	(6)	(6)	(6)	(84)		(84)	**(84)**
Aloe zebrine	forb				1				**1**					1	**1**
Andropogon schirensis	graminoid				1		2				1	3	24	1	
Aristida bipartita	graminoid								**1**						**1**
Aristida congesta	graminoid	**1**		1 1	3	1 1	1 2	1 1	1 **1**	1	1	7	20	8	**2**
Aristida stipitata	graminoid						1	1						2	
*Asparagus laricinus**	forb			1	2	1		1				5	22		
Becium obovatum	forb	1 2 **1**		2 1	2 1	2 2	3 1	1 2 **1**	1	1	1 **1**	13	14	10	**3**
Bewsia biflora	graminoid			1			1					1	25	1	
Boophone disticha	forb				**1**										**1**
Brachiaria serrata	graminoid	2 1	1	2 2	2 2 **1**	2 1	3	1 3 **1**	1 1		1 1	11	16	15	**2**
Chamaecrista comosa	forb	3	1 1	3	3	4 1	3	3	1	2	1 **1**	24	**5**	2	**1**
Cheilanthes involute	forb	2		2		1	1	2	2 1		1	7	20	5	
Clematis brachiata	forb			**2**	1			**2**		1 **1**		2	25		**5**
Commelina africana	forb						1			**1**		1	25		**1**
Conyza podocephala	forb	1 1		1 2	1 1 **1**	3	3	2 1	1	3	2	17	10	5	**1**
*Crabbea angustifolia**	forb	2		4	7	1	2	3		1	4	24	**5**		
Crabbea hirsuta	forb	1	1 2	2 5	3 5	6 3	5 5 **1**	4 5	2 3	4	1 2	28	**4**	31	**1**
*Crassula capitella**	forb	1	1	1			1	1		1		6	21		
Cymbopogon excavatus	graminoid		**1**							**1**					**2**
Cymbopogon nardus	graminoid		1 1	1	1		**1**				1	2	25	3	**1**
Cynodon dactylon	graminoid	3	2 2	4 5	2 7	3 4	3 3 **1**	1 5 **1**	3 2 **1**	1 4	1 2	20	7	35	**5**
Cyperus esculentus	graminoid	2	1	2	1	3	2	1	1	1		13	14	1	
Digitaria eriantha	graminoid		1 1	1		1	1	2 1	1			5	22	4	
Digitaria monodactyla	graminoid						**1**								**1**
Diheteropogon amplectens	graminoid	1 1	1 **1**	1 3 **2**	1 6	1 3	4	6	1 4	2 1	3	7	20	32	**3**
Elephantorrhiza elephantine	forb				1 1	2	1 1	2 2				6	21	4	
Elionurus muticus	graminoid	1 1	1	2 1	1	4 1	1 4	2 2 **1**	2	2		15	12	10	**1**
Eragrostis capensis	graminoid			1 1		2	2	1		1	1	7	20	1	**1**
Eragrostis chloromelas	graminoid							**1**							**1**
Eragrostis curvula	graminoid	3	3	12	12	12	12	1 11	6	6	6	1	25	83	
Eragrostis gummiflua	graminoid	1		1 1	5	1 2	1 1	2	1		1 2	4	23	14	**1**
*Eragrostis inamoena**	graminoid			1		2	1					4	23		
Eragrostis micrantha	graminoid							**1**							**1**
*Eragrostis plana**	graminoid			1							1	2	25		
Eragrostis racemosa	graminoid			1			**1**	1				1	25	1	**1**
*Eriosema cordatum**	forb	1			1	1	2	2		1	1	9	18		
*Hebenstretia comosa**	forb	2	1	9	8	6	7	3	5		3	44	**1**		
*Helichrysum dasymallum**	forb			1	1		1	1				4	23		
*Helichrysum kraussi**	forb						1			1		2	25		
Helichrysum nudifolium	forb	2 1	1 **1**	2 3 **1**	2	1 3	5 **1**	3 1		**1**	2	14	13	12	**4**
Helichrysum rugulosum	forb			2	4	1 **1**	3 1	3		3 1	1 1	17	10	3	**1**
Hermannia cordata	forb			1		2	1	2		1	1	5	22	3	
Heteropogon contortus	graminoid	1 1	2 1	6 1	2 2 **1**	4 2 **1**	3 3	1 1 **1**	2 1	1 **1**	3 2	24	**5**	15	**4**
Hibiscus microcarpus	forb	1	1	2	2 1 **1**	1 2	2 1	2 1	**1**		2	13	14	5	**2**
Hyparrhenia hirta	graminoid	1 2	3	11	8 2	1 10 **1**	1 9	1 9 **2**	5	5	5 **1**	4	23	67	**6**
*Hyparrhenia tamba**	graminoid		1	1	1	1	3	1				8	19		
Hypoxis iridifolia	forb		1 **1**	1 1	2 **1**		2 1	1				6	21	3	**2**
Hypoxis rigidula	forb		1	1	3	2 3	4 2	4	3	2	2	20	7	7	
Indigofera oxytropis	forb	1 2	2 **1**	3 4 **2**	5 5	5 4	6	7	3 1	2 2	6	38	**2**	20	**3**

(*continued*)

(*Continued*)

Genus	Physiognomy plots (n)	C (3)	H (3)	24D (12)	Tw (12)	MCPA (12)	Di (12)	Ba (12)	P (6)	M (6)	T (6)	Total E (84)	Rank E	Total P (84)	**Total N (84)**
Ipomoea ommaneyi	forb	1 2	1	1	3	2	1	1 1	1	1	1 1	10	17	7	
*Justicia anagalloides**	forb				1							1	25		
Lantana rugose	forb			1	1 **1**	2		2 1		2 1	1	5	22	6	**1**
Ledebouria ovatifolia	forb	2	1	3 1	3 1	5	1 2	1 **1**				16	11	4	**1**
Ledebouria revoluta	forb	1		1 1	2 1 **1**	1	1	1	2		1	8	19	4	**1**
Lotononis calycina	forb							**1**							**1**
Melinis nerviglumis	graminoid	1 **1**		4	2 1	3 1	5	2 2	3 1			20	7	5	**1**
Melinis repens	graminoid	3	1 **1**	2 3	1 4	4 1 **1**	3 3	6 1	1 1	1 **1**	1 **1**	23	6	13	**4**
Oxygonum dregeanum	forb	1 **1**	1 **1**	3 **1**	3 1	4 **1**	3 **2**	1 1	1	1	1	19	8	2	**6**
Panicum natalense	graminoid	2	2	2	2 5	1 6	4 **1**	4	1 1 **1**	1 2	1 3	6	21	31	**2**
Parinari capensis	forb	1	1	1	1 **1**	1	2	1 3	1		1	3	24	9	**1**
*Pogonarthria squarrosa**	graminoid	1							1			2	25		
Pollichia campestris	forb	1	1	1 1		2 2	2 1	2	1	2 1	3	12	15	8	
*Polygala hottentotta**	forb				1							1	25		
Pygmaeothamnus zeyheri	forb	1		4	1 1	3	1 2	1 4		1	1	10	17	10	
*Rhoicissus tridentata**	forb	1										1	25		
Rhynchosia totta	forb				2	3	3 1	1 1	1		1	11	16	2	
Schizachyrium sanguineum	graminoid	1	1 **1**	1 3	1 **1**	3	2 3 **1**	2 **2**	1	1 **1**	2	3	24	18	**6**
*Selago densiflora**	forb				1	1		1				3	24		
Senecio erubescens	forb			1 **1**	1		**1**	1		**1**		3	24		**3**
*Senecio venosus**	forb							1				1	25		
Seriphium plumosum	forb				1 1	1 1	1				1	3	24	3	
*Setaria pumila**	graminoid				1							1	25		
Setaria sphacelata	graminoid	3	2	12	12	1 11	1 11	2 10	1 5	6	6	5	22	78	
Solanum panduriforme	forb			2	1	1 1	1	1		1	1	7	20	2	
*Sonchus dregeanus**	forb	1		4		1	1	2			1	10	17		
*Tephrosia semiglabra**	forb			1	4	4		2			1	12	15		
Themeda triandra	graminoid	1 **1**		1	3 **1**	1 **1**	1	1 **1**	**1**			1	25	7	**5**
Thesium utile	forb	2	1	4 3	4	3 2	5 3	6 2 **1**	3	2	3	31	**3**	12	**1**
Trachypogon spicatus	graminoid		**1**	2	3 **1**	2 **3**	1 3	3 2	2 **1**	**1**		4	23	14	**7**
*Trichoneura eleusinoides**	graminoid			1			2					4	23		
Trichoneura grandiglumis	graminoid							1 **1**			1	1	25	1	**1**
*Tristachya leucothrix**	graminoid			1		1	2					4	23		
Urochloa brachyuran	graminoid		**1**						**1**		**1**				**3**
Urochloa panicoides	graminoid					**1**	**1**								**2**
Vernonia oligocephala	forb	1 **1**	1 **1**	2 1	3 **1**	2 2 **1**	5 4	2 2 **1**	1	1 1	2	18	9	12	**5**
*Withania somnifera**	forb		1		2	1		2		2		8	19		
unknown unique species	forb		1	2	2	2	**2**	1 **2**	2	1 **1**	3	14			**5**
Summary															
Total species=105	forb=66 graminoid=39											89		52	**52**
Total extinctions=36	forb											29			
	graminoid											7			
Means per plot	forb	6 3 **1**	4.7 2 **1.7**	2.8 0.9 **0.4**	2.8 1.3 **0.7**	2.6 1.3 **0.3**	2.5 1.3 **0.5**	2.8 1.5 **0.7**	2.7 0.8 **0.3**	3.5 1.2 **0.8**	4 1.8 **0.3**				
	graminoid	3 4 **1**	2.3 3.7 **2.3**	1.5 1.5 **0.2**	1.1 1.3 **0.5**	1.5 1.4 **0.5**	1.6 1.3 **0.7**	1.3 1.7 **0.8**	2.3 2 **1.2**	1.5 1.3 **0.8**	1.5 2.2 **0.5**				
Extirpation rate (E/E+P+N)	forb	0.6	0.56	0.683	0.583	0.619	0.581	0.56	0.711	0.636	0.656				
	graminoid	0.375	0.277	0.469	0.379	0.441	0.444	0.342	0.418	0.417	0.357				
Extirpation rank order	forb	6	9	**2**	7	**5**	8	9	**1**	**4**	**3**				
	graminoid	7	10	**1**	6	**3**	**2**	9	**4**	**5**	8				

1 Untreated control (C), hoe (H), 24D (2,4-D (dimethylamine salt)), Tw(2,4-D/dicamba/MCPA), MCPA (MCPA (potassium salt)), Di (diuron), Ba (dicamba), P (picloram (potassium salt)), M(metsulfuron-methyl), T (triclopyr (butoxy ethyl ester))

Appendix C. Rietvlei

Table of species outcomes by treatment code ([1], Table 1) showing the number of plots extirpated "E" (plain text), persisted "P" (underlined) and new records "N" (bold), numbers in brackets in the header row indicate total number of plots, sum of numbers per cell cannot exceed numbers in brackets (extirpated values are subtracted). Species with an asterisk * became locally extinct.

Genus	Physiognomy plots (n)	C (3)	H (3)	24D (12)	Tw (12)	MCPA (12)	Di (12)	Ba (12)	P (6)	M (6)	T (6)	total E (84)	rank E	total P (84)	**total N (84)**
*Aristida congesta**	graminoid	1		2		1						4	8		
Asparagus laricinus	forb			2	1 4 **1**	3	2	2	1	1 1	2	3	9	16	**1**
Asparagus setaceus	forb			1	1		2	1				4	8	1	
*Becium obovatum**	forb						2	1		1		4	8		
Berkheya radula	forb			2	2	1			1			5	7	1	
Commelina africana	forb	1 1	1 1 **1**	2 2	2 1	4	4	2 1 **1**	1 1	1	1 1	19	**3**	8	**2**
*Convolvulus sagittatus**	forb					1						1	11		
Conyza podocephala	forb	1 1	**1**		1	2 **1**	1	1	1		**1**	6	6	2	**3**
*Cymbopogon pospischilii**	graminoid									1		1	11		
*Cynoglossum hispidum**	forb	1			1							2	10		
*Dichapetalum cymosum**	forb			1								1	11		
Diclis reptans	forb	1 2	2 2	4 2 **1**	6 1 **1**	7	4 3	2 1	3	3 2	1 3	30	**2**	19	**2**
*Elionurus muticus**	graminoid			1				1				2	10		
*Eriosema cordatum**	forb			1								1	11		
Eucomis autumnalis	forb					1			**1**	1		2	10		**1**
*Galium capense**	forb			1			1	1		1		4	8		
*Gomphocarpus glaucophyllus**	forb			1		2				1	1	5	7		
*Helichrysum nudifolium**	forb				1	2						3	9		
Helichrysum rugulosum	forb	1 1			1							2	10	1	
*Heteropogon contortus**	graminoid						1	1				2	10		

(*continued*)

(*Continued*)

Genus	Physiognomy plots (n)	C (3)	H (3)	24D (12)	Tw (12)	MCPA (12)	Di (12)	Ba (12)	P (6)	M (6)	T (6)	total E (84)	rank E	total P (84)	**total N (84)**
Hibiscus trionum	forb	**1**			**1**	**1**				**1**	**1**				**5**
Hyparrhenia hirta	graminoid	3	3	12	12	12	12	12	6	6	6			84	
*Hyparrhenia tamba**	graminoid									1		1	11		
Imperata cylindrica	graminoid	3	2	5	5 **1**	3	5	3	3 1	3	3	35	**1**	1	**1**
*Ischaemum fasciculatum**	graminoid								1	1		2	10		
*Lantana rugosa**	forb	1										1	11		
*Leersia hexandra**	graminoid	1		2	3	1	2	2	1	3		15	**5**		
Melinis repens	graminoid		**1**												**1**
Rumex sagittatus	forb								1					1	
Senecio affinis	forb			1		1		1				2	10	1	
*Senecio erubescens**	forb	1	1	2	1	2	3	2		2	2	16	**4**		
Senecio isatideus	forb			1		1	3	1			1	6	6	1	
*Setaria pumila**	graminoid								1			1	11		
Setaria sphacelata	graminoid			1		1	1	1	1		1	5	7	1	
Sonchus dregeanus	forb				1			**1**	1			2	10		**1**
Themeda triandra	graminoid			2 1	3		3	2	2	2	2	16	4	1	
Xysmalobium undulatum	forb		**1**	1	1	**2**		1 **1**	1	1	1	5	7	1	**4**
unknown unique species*	forb		1	2 **1**	1 **1**		2			1		7			**2**
unknown unique species*	graminoid	1			1			1				3			
Summary															
Total species=49												43		15	**12**
Total extinctions=28	forb											17			
	graminoid											11			
Means per plot	forb	2.3 1.3 **0.3**	1.3 0.7 **1**	1 0.4 **0.2**	1.1 0.3 **0.3**	0.8 0.3 **0.3**	0.8 0.3	0.8 0.3 **0.3**	1 0.5 **0.2**	1.7 0.3 **0.2**	1 0.5 **0.3**				
	gram	1.3 0.3	0.3 0.3 **0.3**	0.5 0.2	0.3 0.1 **0.1**	0.3 0.1	0.4 0.1	0.6 0.1	0.8 0.5	1 0.2	0.5 0.2				
Extirpation rate (E/E+P+N)	forb	0.59	0.433	0.625	0.647	0.571	0.727	0.571	0.588	0.773	0.556				
	graminoid	0.813	0.333	0.714	0.6	0.75	0.8	0.857	0.615	0.833	0.714				
Extirpation rank order	forb	**5**	10	**4**	**3**	7	**2**	7	6	**1**	9				
	graminoid	**3**	10	6	9	**5**	**4**	**1**	8	**2**	6				

1 Untreated control (C), hoe (H), 24D (2,4-D (dimethylamine salt)), Tw(2,4-D/dicamba/MCPA), MCPA (MCPA (potassium salt)), Di (diuron), Ba (dicamba), P (picloram (potassium salt)), M(metsulfuron-methyl), T (triclopyr (butoxy ethyl ester))

Appendix D. Summaries of GLM repeated measures ANOVAs of species richness, number of intercepts=abundance and intercept distance=cover for forbs and grasses at Swartkops and Rietvlei study sites over a four year sampling period; forb cover = canopy/aerial cover and grass cover = basal cover. Bold text signifies significant effects ($P < 0.05$)

SITE	EFFECT	DF	F	P	η_p^2	F	P	η_p^2	F	P	η_p^2
			Forb species richness (n)			Forb number of intercepts (n) = abundance			Forb intercept distance (cm) = canopy cover		
Swartkops	Treatment (T)	14	0.977	0.487	0.186	1.367	0.198	0.242	**1.976**	**0.035**	**0.316**
	Season (S)	1	0.017	0.898	0.000	0.009	0.927	0.000	0.132	0.718	0.002
	T*S	14	0.581	0.870	0.119	0.525	0.909	0.109	0.605	0.850	0.124
	Error	60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
(Fig. 2)	Year (Y)	3	**33.482**	**0.000**	**0.358**	**31.123**	**0.000**	**0.342**	**54.871**	**0.000**	**0.478**
	Y*T	42	1.053	0.395	0.197	0.853	0.723	0.166	1.058	0.388	0.198
	Y*S	3	**4.037**	**0.008**	**0.063**	1.957	0.122	0.032	0.316	0.814	0.005
	Y*T*S	42	0.739	0.876	0.147	0.745	0.869	0.148	0.953	0.558	0.182
	Error	180	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
			Grass species richness (n)			Grass number of intercepts (n) = abundance			Grass intercept distance (cm) = basal cover		
Swartkops	Treatment (T)	14	0.496	0.926	0.104	2477.973	0.143	0.143	29,008.874	0.200	0.200
	Season (S)	1	0.386	0.537	0.006	4737.878	0.097	0.097	11,244.844	0.470	0.470
	T*S	14	0.687	0.778	0.138	1333.425	0.665	0.665	16,653.124	0.683	0.683
	Error	60	0.000	0.000	0.000	1664.872	0.000	0.000	21,282.753	0.000	0.000
(Fig. 2)	Year (Y)	3	**4.124**	**0.007**	**0.064**	**941.589**	**0.019**	**0.019**	**414,591.030**	**0.000**	**0.000**
	Y*T	42	1.012	0.461	0.191	195.708	0.906	0.906	5124.171	0.512	0.512
	Y*S	3	1.965	0.121	0.032	129.752	0.704	0.704	8936.704	0.166	0.166
	Y*T*S	42	0.780	0.828	0.154	191.863	0.918	0.918	3999.491	0.846	0.846
	Error	180	0.000	0.000	0.000	276.183	0.000	0.000	5224.153	0.000	0.000
			Forb species richness (n)			Forb number of intercepts (n) = abundance			Forb intercept distance (cm) = canopy cover		
Rietvlei	Treatment (T)	14	1.360	0.977	0.977	167.582	0.598	0.598	19,066.942	0.407	0.407
	Season (S)	1	0.469	0.720	0.720	235.225	0.275	0.275	1872.336	0.748	0.748
	T*S	14	1.208	0.987	0.987	99.332	0.916	0.916	19,648.681	0.379	0.379
	Error	60	3.614	0.000	0.000	193.617	0.000	0.000	17,917.761	0.000	0.000
(Fig. 2)	Year (Y)	3	**6.158**	**0.000**	**0.000**	**331.151**	**0.001**	**0.001**	**11,739.047**	**0.034**	**0.034**
	Y*T	42	0.642	0.464	0.464	47.349	0.779	0.779	3670.488	0.609	0.609
	Y*S	3	5.106	0.000	0.000	73.588	0.287	0.287	5772.832	0.229	0.229
	Y*T*S	42	0.464	0.887	0.887	61.854	0.376	0.376	3976.336	0.480	0.480
	Error	180	0.636	0.000	0.000	58.006	0.000	0.000	3976.106	0.000	0.000

(*continued*)

(*Continued*)

SITE	EFFECT	DF	F	P	η_p^2	F	P	η_p^2	F	P	η_p^2
			Grass species richness (n)			Grass number of intercepts (n) = abundance			Grass intercept distance (cm) = basal cover		
Rietvlei	Treatment (T)	14	**0.791**	**0.029**	**0.029**	1060.919	0.063	0.063	13,594.449	0.394	0.394
	Season (S)	1	**2.669**	**0.011**	**0.011**	**19,506.944**	**0.000**	**0.000**	**252,969.025**	**0.000**	**0.000**
	T*S	14	0.193	0.924	0.924	509.927	0.609	0.609	5519.995	0.955	0.955
	Error	60	0.386	0.000	0.000	596.211	0.000	0.000	12,602.822	0.000	0.000
(Fig. 2)	Year (Y)	3	**7.981**	**0.000**	**0.000**	**66,680.452**	**0.000**	**0.000**	**2226,117.958**	**0.000**	**0.000**
	Y*T	42	0.326	0.175	0.175	308.263	0.433	0.433	7372.341	0.797	0.797
	Y*S	3	**2.869**	**0.000**	**0.000**	**4990.493**	**0.000**	**0.000**	**456,031.981**	**0.000**	**0.000**
	Y*T*S	42	0.179	0.931	0.931	250.157	0.751	0.751	6158.554	0.936	0.936
	Error	180	0.264	0.000	0.000	299.544	0.000	0.000	9177.852	0.000	0.000

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