UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

# Regeneration of Grassland after Removal of Pine Plantations in the North Eastern Mountain Grasslands of the Drakensberg Escarpment, Mpumalanga, South Africa.

Kruger Linda E[1]

Centre for Environmental Studies, University of Pretoria, Pretoria 0002, South Africa

Address correspondence to LE Kruger, email kruger.linda4@gmail.com

## Abstract

**Concern for the severe loss of biodiversity of grassland species is often voiced. Plantation forestry is known to cause extensive and long lasting disturbance of the natural environment in particular in areas such as the mountain grassland of the Drakensberg escarpment. The survey was conducted in the Graskop area on sites within pine plantations along the Treur River bordering the Blyde River Nature Reserve. The results showed that restoration of plant species biodiversity through natural succession, on cleared plantation sites, required periods longer than seven years and that the regeneration of a great many of the indigenous forb species remained uncertain. Two survey areas were selected and within each survey area, sampling sites were selected to represent three categories of vegetation namely, undisturbed grassland and sites where pine trees had been removed three and seven years previously. Samples of plants were collected from each of these sampling sites. Analysis by means of an classification technique determined the species composition of the disturbed sites in relation to that of the intact grassland. Wheel point surveys were also carried out on these sites to provided information on the vegetation cover, as well as the degree of species regeneration on each site. The variation in vegetation composition of the various plots was analysed by means of Detrended Correspondence Analysis (DCA) and Two-Way Indicator Species Analysis (TWINSPAN). The results showed three distinct species assemblages which corresponded with the three categories of sampling sites. Also that the indigenous forbs species comprised 68% of all the sampled species most of which had failed to regenerate in either the three or**

**seven year cleared plots. The most successful grass species in establishing and persisting in all sites were, *Eragrostis curvula* and *Loudetia simplex*. The fern, *Pteridium aquilinum* had a high prevalence on the disturbed grassland plots and the threat of its invasion of these habitats is compounded by the physical disturbance which eradication methods cause. Planning for grassland restoration involves cognizance of the complexity of grassland ecology, the influence of a multiplicity of environmental factors and the proximity of donor sites to the disturbed areas. Applying international restoration techniques used in grasslands of different origins to those of South African landscapes could result in disappointing and costly efforts. At best any attempt at managing grassland diversity should be preceded by an holistic investigation into the environmental conditions particular to the specific terrain and thereafter maintaining a conservative approach of allowing natural succession. The threat of invasive exotic species should be integral to conserving the integrity of the remaining intact natural grasslands in South Africa. It is acknowledged that in this study regeneration of grassland species on plantation sites cleared of pine trees three and seven years previously does not include a long time span such as needed for succession to take place but is useful in showing a trend in species re-colonization to resemble the vegetation of intact grassland, as well as highlighting the absence of a great number of indigenous forb species.**

**Key words**

Biodiversity, indigenous species, forbs, plantation forestry, conservation, restoration.

**Aim of the study**

The aim of the study was to determine whether regeneration of plant species on plantation sites which had been cleared of pine trees, three and seven years ago respectively, exhibited any trend of regeneration toward resembling plant assemblages of the natural grassland sites. The objectives were to determine (a) the discriminating species present on each sampling plot, (b) the extent of vegetation cover on the disturbed sites, (c) whether any species had failed to return, (d) whether re-colonization of disturbed sites was influenced by the passing of time by noting the trends in species composition between differently aged plots and (e) whether the disturbed plots resembled the original grassland in species composition.

**Introduction**

This study comprised the botanical section of a three part report on the floristic, vertebrate and invertebrate status of the study area in order to comply with the requirements of a mini thesis for the M(InstAgrar) Environmental Management degree at the University of Pretoria.

The grasslands of South Africa cover 349,174 km². Exotic plantations cover 12,573 km². Approximately 4,000 km² within these plantation areas are managed by forestry companies as conservation areas (Forestry Industry Environmental Committee, 2002). The grassland flora of the North-Eastern Transvaal Escarpment of the Drakensberg mountain range in South Africa is one of the main southern African centres of biodiversity, as well as an important secondary centre of endemism (Van Wyk & Smith 2001). Classified as the Drakensberg Afromontane Regional System in the Wolkberg Centre, it is an extraordinary centre of biodiversity, with more than 3,370 floral species occurring in these grasslands (Matthews et al. 1992; Van Wyk and Smith 2001). It is known that about 75% percent of the total mountain grassland biome has been transformed and that only a very small section thereof (2%) is conserved (Bredenkamp et al. 1999). The Wolkberg Centre, where this study took place, enjoys only 12% formal protection (State of the Environment Report, Mpumalanga, 2003).

Certain areas of the South African grasslands still represent evolutionary intact natural entities of the world's remaining original primary grasslands of ancient geological origin (Van Wyk and Malan 1988, Van Wyk A.E. 2006). Therefore, when considering international research in grassland restoration and conservation, an important difference in the ecology and biological status of the grasslands in South Africa and those of other continents must be noted, for many studies report on restoration in European grasslands where grassland are mainly of secondary origin having been transformed through decades of farming practices. These ecosystems no longer represent the original undisturbed grassland biodiversity and can only be considered as a bio-cultural heritage asset (Pywell et al. 2003; Gustavsson et al. 2007; Bischoff et al. 2009).

Loss of biodiversity in mountain grasslands happens mainly through the extensive habitat destruction by commercial forestry and the increase in rural population settlements which result in the intensified utilization of natural resources, particularly for pastures and crops (O'Connor 2005). Also contributing to the loss of biodiversity is the inadequate and often misplaced conservation efforts in the past which have resulted in the insufficient protection of natural grasslands (Matthews et al. 1993; Van Wyk and Smith 2001). Various conservation programmes such as the National Grassland Biodiversity Programme (Steyn 2005) and the Enkangala Grassland Project have been initiated. These programmes are endorsed by the Worldwide Fund for Nature (WWF) and funded by the Green Trust and the conservation of up to a million hectares of grassland is envisioned by enabling biodiversity stewardship projects on land belonging to private and communal landowners. The invasion by exotic invasive species remains serious threat to the integrity of the grasslands and control methods remain challenging to all landowners (Bromilow 2001).

Restoration of grassland through natural succession requires that the sites serving as the source of seeds and plant propagules should be in close proximity to the disturbed areas (Bischoff et al. 2009). Whereas restoration by means of direct management may include any one or more of the following manipulations; seed introduction (Pywell et al. 2002), soil manipulation by ploughing or vegetation clearing, nutrient application, topsoil removal, mowing of vegetation, or grazing by livestock or slash and burn practices (Pywell et al. 2003). A South England study concluded that the proximity of intact natural grassland sites to restoration areas proved more successful than artificial seeding procedures even though the seed mixture used was carefully selected and the N:P ratio of the soil nutrient status was correctly manipulated (Fagan et al. 2008). Research reports reflect the wide range of approaches to grassland restoration and serve to highlight its convoluted nature. This conclusion is further underscored by results of such studies as the effects of afforestation on soil nutrient status in pa'ramo grasslands (Farleya 2004), the germination capacity of soil seed banks of grasslands converted to pine plantation (Maccherini S. and De Dominicis 2003) and the restoration by seed addition outweighing soil fertility reduction on ex-arable grassland (Kardol et al. 2008). In contrast, it was found that differing management strategies of grasslands, such as continuous management, abandoning or restoring sites made no difference in the species richness found there (O¨ckinger et al. 2006). However, some evidence of the negative effects of abandoning disturbed sites was also found by these authors. Although regeneration of grassland species on land previously planted with coniferous species is still little described in international literature, Maccherini and De Dominicis (2003) writes that few propagules and seed of grassland species were found in soil samples taken under coniferous plantations. However, Cuevas and Zalba (2009) reported that regeneration of grassland species did occur after the felling of invasive alien trees if the removal thereof took place early enough after its establishment. In South Africa certain shade tolerant grassland species persisted within pine plantations but these areas are threatened by the invasion of the exotic species *Rubus cuneifolius,* as well as the physical disturbance caused by lumbering activities (O'Connor 2005). It can be gleaned from this multiplicity of environmental factors that restoration and monitoring projects which focus on species richness only, may produce biased assessments on the status of species diversity and habitat (Reitalu et al. 2009).

The effect of time on the regeneration of grassland species in disturbed land is very relevant as a number of studies have shown. It was found that he return of abandoned communal cropland land to indigenous grassland devoid of exotics took about 20 years and that grassland protected for some 50 years showed a species richness twice that of grazed grassland (O'Connor 2005). The removal of pine trees within a certain time to prevent permanent changes in soil properties was found of paramount for grassland restoration (Cuevas and Zalba 2009).

It is concluded from research results such as these, that the assessment methods, as well as the character and origin of the physical environment in which restoration is to take place should be considered with circumspection before deciding on a restoration approach in grassland.

Prior to 1972 uncontrolled afforestation took place and recent government directives have been issued in conjunction with permits and licenses to limit these practices but despite the legal, as well as forestry certification requirements, plantation establishment continues along the banks of perennial streams and in wetlands (Forestry Industry Environmental Committee, 2002). However, the Water Conservation and Demand Management Strategy for the Forest Sector in South Africa provides guidelines for forestry companies on the clearing of terrains for afforestation (Department of Water Affairs and Forestry, 2000).

## Study area

The study was conducted in the Treur River Valley on the London Forestry Station Farm 496K which is situated in the North Eastern Drakensberg escarpment, 35km north of Graskop, Mpumalanga. The survey sites were selected along the Treur River at an altitude of 1,500m and within the Blyde River Nature Reserve, as well as adjacent commercial pine plantations. Two survey areas were selected along the banks of the river within 5kms of each other. Survey area 1 was located at 24º 45'S, 30º52'E and Survey area 2 at 24º47'S, 30º53'E.

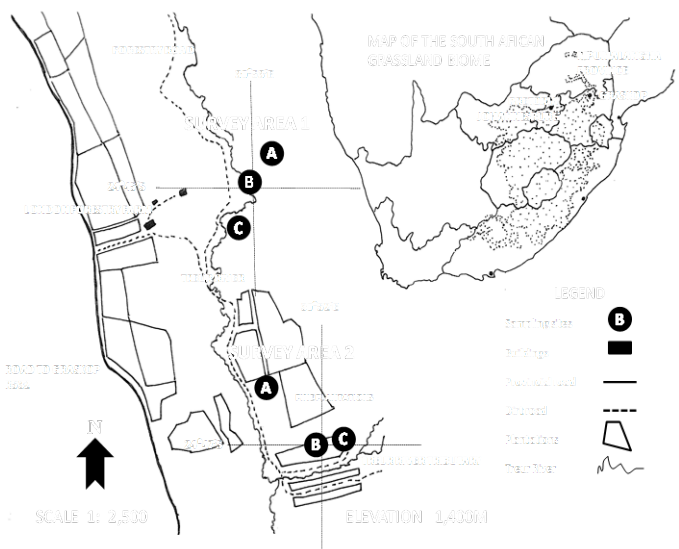


Fig 1. Map of the study area. of Survey areas 1 and 2 to show the positions of Sampling plots A, B and C in terms of the Treur River, the London Forestry Farm and the R532 provincial road to Graskop, South Africa. Source: 1:150 000 Topocadestral map, Government Printers, Pretoria and Van Wyk (2001).

The approach was to select two survey areas similar in vegetation composition, within which sampling sites could be selected in terms of the time after clearance of pine plantations. Sampling plots in each site represented, three years after clearance (sampling site A) seven years after clearance (sampling site B) and undisturbed grassland (sampling site C). The grassland plots have been intact for approximately 45 years (Professor J. W. H. Ferguson, 2005, University of Pretoria, Pretoria, personal communication) and served as an indicator of intact plant communities. Two plots of 100m² each were pegged out within each category of sampling site at a distance of 100m of each other, giving a total of 12 sampling plots.

The topography of the terrain consisted of a north-south orientated valley with a steep eroded ridge on the western bank of the river and gentle slopes to the east. The study area fell within a temperate climatic zone. Summers here are warm to cool with a high rainfall and thunderstorms, drizzle and mist occurring frequently. In winter it is cold and dry with occasional frosts (Matthews et al. 1993). The annual rainfall ranges from 708mm to 1,821mm with a mean rainfall of 1,321mm per annum (Matthews et al. 1993). The daily temperature varies from -8° in winter to 39° in summer with an average daily temperature of 15°C. The geology of the region comprises the Transvaal Super Group, the Black Reef Quartzite Formation, the Wolkberg group, the Timeball Hill Formation and the Chuniespoort Formation (Matthews et.al.1993). The soils of this region are complex but comprise two distinctive variations namely, soils with an acidic pH which developed from quartzite and shale rock and have a low nutrient base with minimal phosphorus content and soils derived from the Chuniespoort Formation which are high in nutrient levels, with an alkaline pH due to chemical weathering of the carboniferous and dolomite component of the basic parent rock(Matthews et.al.1993). These distinct soil types are known to give rise to particular vegetation assemblages (Tilman 1988 in O'Connor 2005)

**Methods**

Plant samples were taken from all twelve sampling plots during December 2003 and May 2004 to coincide with the flowering times of summer and autumn grassland species (Daubenmire 1986). Observation and weighting of the species' cover abundance was done according to the Braun-Blanquet cover-abundance scale and from this a phytosociological classification table was compiled (Van Der Maarel 1975; Mueller-Dombois and Ellenberg 1974; Gauch Jr 1982) (Appendix). Species were identified by literature searches (Gibbs et al. 1990; Grabandt 1985; Hobson and Jessop 1975; Onderstall 1984; Retief and Herman 1997; Schelpe and Anthony 1986; Van Wyk and Malan 1988; Van Wyk and Oudtshoorn 1999). Plant samples were compared with preserved specimens at the H.G.W.J. Schweickert Herbarium of the University of Pretoria and identification of species was verification by Professor G.J. Bredenkamp of the Department of Botany, University of Pretoria.

Two sets of Wheel point surveys were carried out on the same sites as the species sampling sites but each plot was increased to $200m^2$. Firstly, a survey of species canopy hits was done to determine the extent of vegetation cover on each plot and thereafter a survey of crown hits of species was done to determine the indicator species present on each plot (Tidmarsh and Havenga 1955).

**Data analysis**

The phyto-sociological classification table showed six groupings of species ordered according to their occurrence and abundance in the three years, seven years and grassland sampling plots (Appendix).

From the wheel point surveys data matrices were compiled for each sampling plot on the survey sites 1 and 2. Data tables of crown hits and canopy cover hits of species were compiled for all plots. Then data matrixes were compiled to show (a) the total percentage canopy hits on survey areas 1 and 2 combined which indicated the vegetation cover (Table 1a), (b) the total percentage mean canopy cover per species for each plot (Table 1b) and (c) the total percentage mean crown hits per species for each plot (Table 1c).

Thirdly, a detrended correspondence analysis (DCA) was undertaken using the CANOCO computer program (Jongman et al. 1995) (Figure 2). In the DCA analysis the DETR-POLY3, Biplot scaling, no transformation and the Hill's scaling method of weighting of species scores and sample site scores was used which identified the twenty species most significant in accounting for variance in species composition.

A dendogram illustrating the clustering pattern of species associations on sampling plots was compiled by means of the Two-Way Indicator Species Analysis method (TWINSPAN) (Hill 1979) (Figure 3). In order to determine the species associations with the sampling sites, a data analysis was done by compiling a two-way ordered table of species scores and sample plots by means of the TURBOVEG computer program (Dufrêné and Legendré 1997; Hill 1979; Van Groenewoud 1992).

**Results**

Phytosociological classification table

A total of 129 species were identified of which 112 were indigenous and were much more abundant in the grassland plots and very rare in the disturbed plots (Appendix). There were 82 indigenous forb species, 24 grass species, 3 tree species, and 2 fern species. The species present in the grassland as well as seven year plots amounted to 31 of which 5 species were exotic, 9 were grass species and 17 indigenous forbs. The three year plots yielded 19 species, 3 exotic species and 1 grass species. Eleven species were present on all three categories of sites of which *Eragrostis curvula* was the most prevalent followed by *Pteridium aquilinum*, *Commelina africana* var. *barbarea* and the exotic weeds, *Cyperus esculentus* and *Sonchus oleraceus.* However, *Pteridium aquilinum* was the most prevalent species in the cleared sites and appeared only rarely in the grassland plots. Nineteen exotic species were recorded of which the grassland sites contained 47%, the seven year sites 53% and the 3 year sites, 71% of these species**.** The species were *Rubus rigidus, Solanum mauritianum, Rumex sagittatus, Acacia dealbata, Sesbania punicea, Cyperus esculentus, Sonchus oleraceus*, *Plantago lanceolata*, and *Conyza bonariensis.*

Wheel Point survey

The results of the mean percentage vegetation cover based on canopy hits on all three categories of plots of Survey areas 1 and 2 combined, showed that the total vegetation cover for the grassland was 81%, the seven year plots 49% and the three year plots 59% (Table 1a).

The results of the total percentage mean canopy cover per species on the grassland, three and seven year old plots of Survey areas 1 and 2 (Table 1b) showed *Pteridium aquilinum* to be the most extensive vegetation cover on the three and seven year plots. Whereas *Eragrostis curvula* contributed towards the most cover on all three categories of sites and increasing from 3% on the three year plots to 21% on the seven year plots indicating it as successful pioneer grassland species. Other dominant grass species contributing to the vegetation cover on the grassland (18%) and seven year plots (8%) were *Loudetia simplex*, and on grassland plots *Themeda triandra* (15%) *and Monocymbium ceresiiforme* (7%) were the most abundant. Despite there being less abundance of certain species in the grassland plots than the seven year plots their canopy cover exceeded that of the disturbed plots and may be attributable to being more mature plants. However it indicated a gradual trend toward senescence in the grassland succession and an increased trend in species colonization on the disturbed plots.

The analysis of the total percentage crown hits per species on the grassland, three and seven year old plots revealed the following dominant species occurring in each (Table 1c). *Eragrostis curvula* was the most prevelent species on all three categories of plots followed by *Pteridium aquilinum* on the three and seven year plots, *Monocymium ceresciiforme* on the grassland plots and the invasive

*Cyperus esculentus,* which is typically found on disturbed sites, dominated the three year plots. The grass species indicating successful regeneration on the seven year plots was *Melinus nerviglume* and the forb *Tetraselago nelsonii*. This indicated a persistence of these species through succession over seven years. The only significance forb species were have appeared on both categories of cleared plots were, *Commelina africana var. barbarae* and to a lesser degree *Pentanisia angustifolia* and *Tetraselago nelsonii.*

Detrended Correspondence Analysis (DCA)

The correlation between the species and the plot scores in terms of a correlation coefficient index is shown by graph (Hill 1979; Gauch 1982; Ter Braak 1986) (Fig 2). Of the four axes, axes 1 and 2 were shown to contribute 35% of the percentage variance of species data and used to interpret the graphic representation of the species data. The Eigen values of the sample plots and species scores were 0.8331 on the first axis and 0.6100 on the second. Being closer to 1 than zero these values indicated a high degree of correspondence between species and sampling plots (Gauch, 1982; Pielou, 1984).The pattern of spatial distribution of species in terms of the three categories of sampling plots showed three distinct groups of discriminating species which corresponded with the distribution pattern of the sampling plots. Secondly, those species which had, according to the DCA percentage weighting, achieved a score >1 (Table 2) indicated which species served to discriminate most clearly between the different categories of sampling plots. The grassland sites were clearly differentiated from the three and seven year plots. The three year plots were discernible from the seven year sites as these appeared above and below the horizontal axis respectively. The distribution pattern of the plant species corresponded with that of the three categories of sampling plots. The DCA confirmed the existence of two distinct plant communities namely, the natural grassland and the disturbed grassland because these two categories of species associations were placed on either side of the vertical axis. The grassland species were *Themeda triandra, Loudetia simplex, Panicum natalense, Heteropogon contortis, Monocymbium cerisiiforme Trachypogon spicatus, Diheteropogon amplectens, Sporobolus pectinatus, Panicum maximum* and the forb *Vernonia natalensis.* Species associated with the disturbed sites were the exotics *Cyperus* *longus, Amaranthus hibridus, Sonchus oleraceus. Urochloa panicoides, Pteridium aquilinum, Panicum schinzii, Commelina africana* var. *barbarae, Eragrostis curvula* and *Melinus nerviglume.* Those species which were associated with the cleared sites as well as the grassland sites, indicated below the horizontal axis were *Themeda triandra, Loudetia simplex, Panicum natalense, Heteropogon contortis, Monocymbium cerisiiforme, Commelina africana* var. *barbarae, Eragrostis curvula and Melinus nerviglume.* However, *Eragrostis curvula* and forb *Commelina africana* var. *barbarae* were associated with the seven year sites which indicated a trend of regeneration over seven years of indigenous species. The exotic weeds, *Cyperus longus, Amaranthus hibridus, Sonchus oleraceus, Urochloa panicoides* and *Panicum schinzii* were associated mainly with the three year sites and is known to happen on disturbed sites but had diminished or disappeared in the older sites indication that they were effective pioneer species*.* The grass species *Eragrostis curvula, Loudetia simplex* were associated with the seven year sites. *Eragrostis curvula* and *Commelina africana* var. *barbarae* were associated with the three and seven year sites and indicated a gradual succession of these species from the three to the seven year plots.

<u>TWINSPAN analysis</u>

The dendogram illustrated two main clusters namely, the grassland group and a second group made up of the three year and seven year plots which also formed two distinct sub groups (Fig. 3). The configuration of the dendogram from the TWINSPAN analysis showed a corresponding pattern of clustering of species and sampling sites as the DCA. The indicator species identified by TWINSPAN corresponded with certain of the species identified in the classification table namely, *Helichrysum cephaloideum, Pentanisia angustifolia* and *Ipomea obscura* in all three categories of plots, *Acacia dealbata, Helichrysum acutatum* and *Helichrysum krausii* in the seven and three year plots, *Rubus rigidus* in the grassland and seven year plots and *Diospyros lycoidens* subsp. *sericea* and *Pennisetum macrourum* in the three year plots. The wheel point survey results of the most common species found to contribute to the mean percentage canopy cover had certain species in common with the results of the DCA percentage weighting in which species were identified to discriminate most clearly between the different categories of sites (Bold font Table 2) namely, *Eragrostis curvula, Loudetia simplex, Themeda triandra, Diheteropogon amplectens, Monocymbium ceresiiforme*, all from grassland sites. *Pteridium aquilinum* and *Amaranthus hybridus* from 3 year sites and *Melinus nerviglume* from 7 year sites (Table 2). This observation shows that both the DCA and Wheelpoint surveys analysis methods presented corresponding species in their results and this confirms that these species are the most characteristic grassland species which were also successful in regenerating on disturbed land.

**Discussion**

The cleared sites showed very little resemblance to the natural grassland in plant community composition. The conclusions drawn from this study are: (1) With the exception of the grass species *Eragrostis curvula, Melinus nerviglume, Panicum maximum, Loudetia simplex, Panicum natalense and Monocymbium ceresiiforme* regeneration of indigenous species after the disturbance by deforestation is extremely limited. (2) The plant assemblages found on the differently aged plots differed significantly from each other and even more so from the grassland plots. (3) Non-indigenous species were predominantly found on the cleared plots and *Pteridium aquilinum* had a high level of presence on these plots. Although most of the exotic species had diminished over time on the seven year plots compared to the three year plots, some continued to persist in the seven year as well as the natural grassland plots. (4) The grass species *Eragrostis curvula* proved the most characteristic species on all the plots. A limited number of the other indigenous grass species had successfully colonized the cleared sites and indicated that a trend towards the climax stage in succession existed. (5) The absence of most of the indigenous forb species from the cleared plots was very noticeable from the study results as they constituted two thirds of all species sampled. (6) Natural succession of indigenous forbs require longer periods than seven years to take place after disturbance. This result is underscored by the research findings of others such as Fagan et al. (2008) who predicted that it was a slow process which could require more than 60 years and O'Connor (2005) who concluded that abandoned communal cropland only reverted to indigenous grassland within 20 years, in the grassland of the southern Drakensberg. In their reference to the origin of Northern and Southern Hemisphere grasslands, Bredenkamp et al. (2002) state that succession after disturbance is slow and results in a secondary grassland which does not resemble the climatic climax grassland.

A variety of disturbance factors are considered to account for the loss of biodiversity in grasslands. Amongst others the loss of seed and propagule banks (Bischoff 2009), donor grassland sites being too distant from the disturbed sites for natural vectors to transport the seed (Muller et al. 1998) and the changes in soil properties caused by pine trees (Cuevas 2009). In recording their findings on the techniques used in restoration of grassland communities Pywell et.al. (2003) admit to the lack of understanding of the mechanisms creating natural species diversity in semi-natural grasslands. According to their study on the rehabilitation of coastal dune forests in Northern KwaZulu-Natal, Van Aarde et al. (1996) found that the sources of species were needed in close proximity to disturbed sites for natural succession to take place. Control methods for *Pteridum aquilinum* requires biannual cutting of this species, which will promote germination and establishment of indigenous species by exposing the soil to more light (Cox et al. 2008). However, management intervention by means of vehicles and can lead to increased disturbance which compromises the aim of achieving and maintaining stability in the existing plant community structure (Hirst et.al. 2005).

The findings of this study concurred with the findings reported by Neke and Du Plessis (2004); Pywell et al. (2002), and Kiehl et al. (2006) that regeneration of disturbed areas did not have a high success rate. The prudent action should be to protect areas with existing high species diversity for those areas which support rare species are indicative of land of high conservation value by virtue of their high genetic seed bank value. (Buhk et al. 2007).

Research projects, as in the case of this study, will need to be extended over much longer periods than seven years in order to determine the rate and success of natural regeneration of species after disturbance (Adler 2003). Meanwhile, the findings such as produced by this study, of the apparent inability of indigenous forbs species to regenerate successfully, highlighted the urgent necessity to conserve remaining intact grassland areas. The conservation management practice of relying on natural succession alone, presents a time constraint which implies the irreversible loss of indigenous and endemic species. Competition from exotic species, the effects of climate change and efforts to rehabilitate disturbed land only serve to increase the complexities of grassland restoration.

**Conclusion**

This study on grassland regeneration found that after seven years two distinct plant communities existed which showed no resemblance with each other. These were the disturbed grassland communities where pine plantation had been cleared and the natural intact grassland communities. The management practice of removing pine plantations and abandoning them to allow for natural succession to take place had resulted in the failure of plant communities to return to a natural grassland state. The apparent non-regeneration of most forbs highlighted in this study, points to the serious potential loss of grassland biodiversity through plantation forestry and incorrect restoration practices.

**Implications for Practice**

- It is imperative that remaining mountain grasslands should receive protection from all forms of disturbance.
- The invasive exotics *Pteridium aquilinum* should receive priority attention in grassland management.
- Careful consideration should be given to applying international restoration approaches to local grassland environments.
- All natural grassland fragments should receive protection in order to serve as seed and propagule bank for dispersal. This applies particularly to forestry companies who engage in clearing of sites and removal of pine trees.
- It must be noted that Pine trees should which remain in situ for periods longer than certain periods could result in permanent soil property changes.
- It is imperative that long term research on regeneration of plants species in South African grasslands be continued.
- Research results on grassland ecology must continue to inform all political and economic considerations in order to promote integrative, co-operative decisions regarding land use and conservation of grassland biodiversity by government departments, parastatals and private institutions.
- Public awareness of the threats facing grasslands must be encouraged as it fosters responsible resource use and ownership by those who ultimately rely on the natural environment for their livelihood.

**Acknowledgements**.

My sincere appreciation to Professor J. W. H. Ferguson and Dr M Robertson of the Centre for Environmental Studies, Zoology Department, and Professor G. J. Bredenkamp and Ms M. Deutchlander of the Botany Department, University of Pretoria. To Mr T.G. O'Connor my gratitude for his much valued review of this study.

**Table 1a**. Summary of the results of the wheel point survey of the mean percentage vegetation cover based on canopy hits on the grassland, three and seven year old plots of Survey areas 1 and 2.

| | Mean percentage canopy cover | | |
|---|---|---|---|
| Survey area 1 | **Grassland** | **3 yrs** | **7 yrs** |
| Plot 1 | 89 | 46 | 41 |
| Plot 2 | 80 | 31 | 72 |
| Survey area 2 | | | |
| Plot 1 | 76 | 50 | 57 |
| Plot 2 | 79 | 70 | 66 |
| Total | 81% | 49% | 59% |

**Table 1b.** Summary of the total percentage mean canopy cover per species on the grassland, three and seven year old plots of Survey areas 1 and 2.

| **Species** | **Grassland** | **3 yrs** | **7 yrs** |
|---|---|---|---|
| *Pteridium aquilinum* | | 29% | 12% |
| *Eragrostis curvula* | 18 % | 3% | 21% |
| *Loudetia simplex* | 18% | | 8% |
| *Themeda triandra* | 15% | | |
| *Monocymbium ceresiiforme* | 7% | | |
| *Helichrysum aureonitens* | 6% | | |
| *Pearsonia sessilifolia* | 6% | 5% | |
| Cyperus esculentus | | 3% | |
| *Amaranthus viridis* | | *5%* | |
| *Melinus nerviglume* | | | 13% |
| *Tetraselago nelsonii* | | | 8% |

**Table 1c.** Summary of the total percentage crown hits per species on the grassland, three and seven year old plots of Survey areas 1 and 2.

| **Species** | **Grassland** | **3 yrs** | **7 yrs** |
|---|---|---|---|
| *Eragrostis curvula* | 4% | 2% | 12% |
| *Pteridium aquilinum* | | 7% | 9% |
| *Cyperus esculentus* | | 5% | |
| *Melinus nerviglume* | | | 5% |
| *Monocymium ceresiiforme* | 3% | | |
| *Tetraselago nelsonii* | | | 3% |

**Table 2**. The combined results of (a) the most common species found to contribute to the mean percentage canopy hits in all three sampling sites according to the wheel point survey and (b) the results of the DCA percentage weighting scores >1 (bracketed in bold font) of species which served to discriminate most clearly between the different types of sampling site.

| Species | Grassland | 7 yrs | 3 yrs | Overall mean |
|---|---|---|---|---|
| *Eragrostis curvula* | 33; **(4.5)** | 15 | 3 | 17 |
| *Pteridium aquilinum* | 0 | 12 | 29; **(2.2)** | 14 |
| *Loudetia simplex* | 18; **(2.8)** | **(11)** | 0 | 10 |
| *Themeda triandra* | 15; (**3.6)** | 0 | 0 | 5 |
| *Pearsonia sessilifolia* | 6 | 0 | 5 | 4 |
| *Melinus nerviglume* | 0 | 8; **(3)** | 0 | 3 |
| *Helichrysum aureonitens* | 6 | 0 | 0 | 2 |
| *Diheteropogon amplectens* | 6; **(2)** | 0 | 0 | 2 |
| *Monocymbium ceresiiforme* | 7; **(2)** | 0 | 0 | 2 |
| *Amaranthus hybridus* | 0 | 0 | 5; **(3)** | 2 |
| *Sonchus oleraceus* | 0 | 0 | **(5)** | 0 |
| *Cyperus longus* | 0 | 0 | **(4)** | 0 |
| *Commelina africana* subsp. *barbarea* | 0 | **(3)** | 0 | 0 |
| *Vernonia natalensis* | **(3)** | 0 | 0 | 0 |
| *Panicum natalense* | **(2)** | 0 | 0 | 0 |
| *Sporobolus pectinatus* | **(2)** | 0 | 0 | 0 |
| *Panicum schinzii* | 0 | 0 | **(1.6)** | 0 |
| *Bryophytum* | 0 | 0 | **(1.6)** | 0 |
| *Urochloa panicoides* | 0 | 0 | **(1.5)** | 0 |
| *Panicum maximum* | 0 | **(1.3)** | 0 | 0 |
| *Heteropogon contortus* | **(1)** | 0 | 0 | 0 |

**Figure 2.** DCA of the plot and the species scores (Hill's scaling) illustrating the correlations between the spatial distributions of species in relation to the three categories of sampling sites.

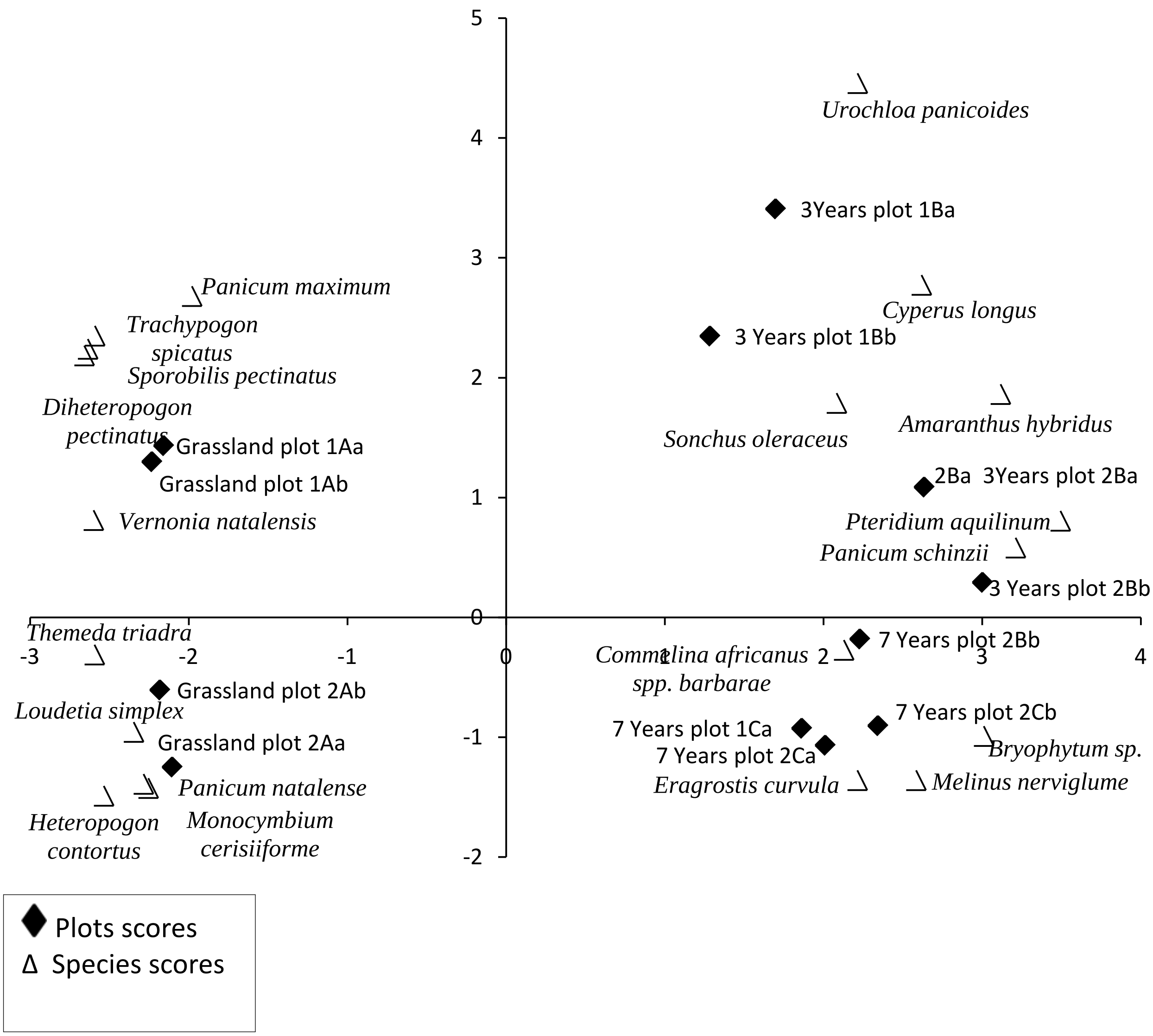

**Figure 3.** A dendogram by TWINSPAN analysis illustrating the clustering pattern of species associations on the plots of within the grassland, three and seven year sampling sites.

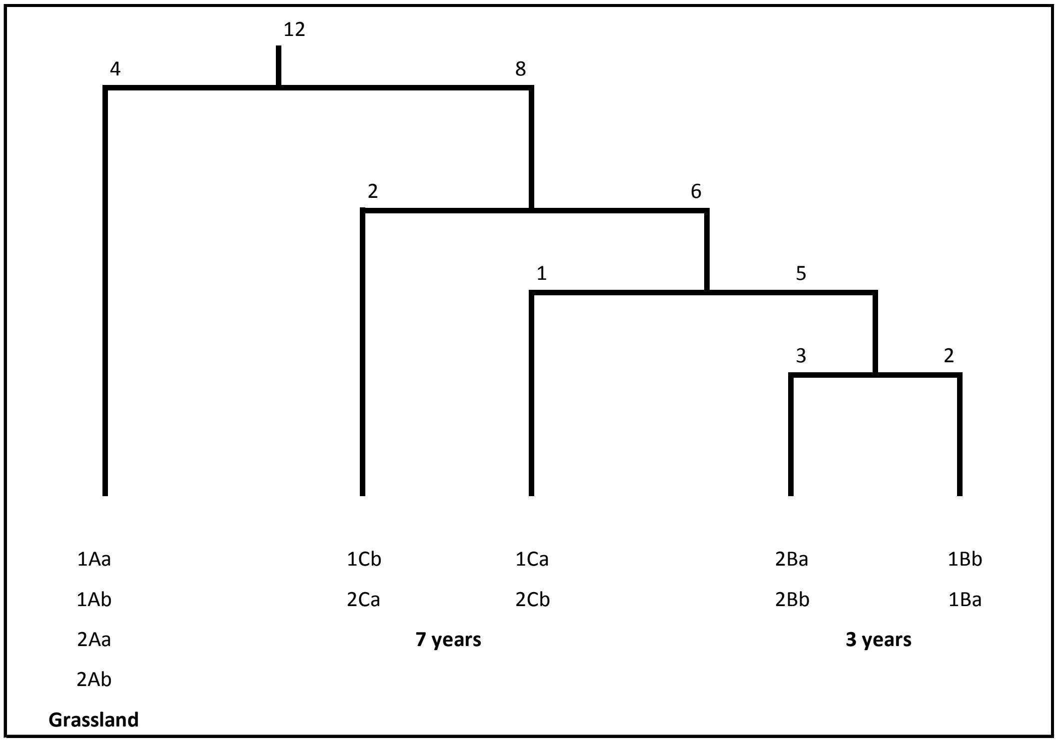

**Table 3.** Summary of indicator species identified by TWINSPAN

| *Grassland* | *7 years* | *3 years* |
|---|---|---|
| *Helichrysum cephaloideum*<br>*Pentanisia angustifolia*<br>*Ipomea obscura* | *Helichrysum cephaloideum*<br>*Pentanisia angustifolia*<br>*Ipomea obscura* | *Helichrysum cephaloideum*<br>*Pentanisia angustifolia*<br>*Ipomea obscura* |
| | *Acacia dealbata*<br>*Aristida congesta*<br>*Helichrysum acutatum*<br>*Helichrysum kraussii* | *Acacia dealbata*<br>*Aristida congesta*<br>*Helichrysum acutatum*<br>*Helichrysum kraussii* |
| *Rubus rigidus* | *Rubus rigidus* | |
| *Buddleja salviifolia*<br>*Senecio oxyriifolius* | | *Buddleja salviifolia*<br>*Senecio oxyriifolius* |
| | *Asplenium splendens*<br>*Commelina africana* var. *africana*<br>*Cyathea dregei*<br>*Cynodon dactylon*<br>*Cyperus rupestris*<br>*Gladiolus spp.*<br>*Helichrysum nudifolium*<br>*Helichrysum oligocephalum*<br>*Hibiscus pusilus*<br>*Anthospermum hispidulum*<br>*Kohautia amatymbica*<br>*Ledebouria ovatifolia*<br>*Lotononis calycina*<br>*Rumex sagittatus*<br>*Tristachya leucotrix*<br>*Verbena bonariensis* | |
| | | *Abaltgardia ovata*<br>*Diospyros lycoidens* subsp. *Sericea*<br>*Pennisetum macrourum*<br>*Pinus* spp |

APPENDIX. Phytosociological table of species and sampling plots. The cell entries denote the species' cover abundance according to the Braun-Blanquet cover-abundance scale.

| | Sampling site B (3 Years) | | | | Sampling site C (7 Years) | | | | Sampling site A (Grassland) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Survey area 1 | | Survey area 2 | | Survey area 1 | | Survey area 2 | | Survey area 1 | | Survey area 2 | |
| | Plot 1 | Plot 2 | Plot 1 | Plot 2 | Plot 1 | Plot 2 | Plot 1 | Plot 2 | Plot 1 | Plot 2 | Plot1 | Plot2 |
| *Eragrostis curvula** | | + | | 1 | 4 | 3 | 4 | 4 | | | 2 | |
| *Pteridium aquilinum* | + | 1 | 2 | 5 | + | 3 | + | | r | | | |
| *Commelina africana* var. *barbarea* | | + | | 9 | 4 | 3 | 4 | 4 | | | 2 | |
| *Sonchus oleraceus**** | + | 1 | r | 1 | | | | r | | | | r |
| *Cyperus esculentus**** | + | 1 | r | | + | | | | + | + | | |
| *Tetraselago nelsonii* | | r | | 1 | r | + | + | | | | r | |
| *Ipomea obscura* | r | | | | | 1 | | | | | + | + |
| *Helichrysum cephaloideum* | | | + | | | r | | | | | | r |
| *Pentanisia angustifolia* | + | + | r | r | | + | | | | r | + | |
| *Linum thunbergii* | | | | r | | | r | | + | r | r | |
| *Buddleja salviifolia* | | | r | | | | | r | | r | | |
| *Melinus nerviglume**** | | | 1 | 1 | 2 | 1 | 4 | 3 | | | | |
| *Bryophyta* | | | | 1 | | | | 2 | | | | |
| *Urochloa panicoides** | 2 | | | + | | | + | | | | | |
| *Cyperus longus**** | 1 | + | 1 | r | | | | r | | | | |
| *Andropogon eucomus** | | | | + | 1 | | | | | | | |
| *Conyza canadensis**** | | | r | 1 | | | | r | | | | |
| *Acacia dealbata**** | | | 1 | | | | | r | | | | |
| *Pinus* spp***. | | | r | 1 | | | | | | | | |
| *Helichrysum kraussii* | | | | + | | r | | r | | | | |
| *Helichrysum acutatum* | | | r | | r | | | | | | | |
| *Hibiscus microcarpus* | r | | | | r | | | | | | | |
| *Panicum maximum** | 1 | 1 | | | | | | | 4 | | | |
| *Helichrysum aureonitens* | | | r | r | | | | | | | 1 | 1 |
| *Acanthospermum hispidum* | | r | | | | | | | | r | | |
| *Conyza bonariensis**** | + | + | 1 | | | | | | | | | |
| *Cynodon dactylon**** | | 1 | | | | | | | | | | |
| *Cyperus rupestris**** | | | 1 | | | | | | | | | |
| *Helichrysum nudifolium* | | | 1 | | | | | | | | | |
| *Tristachya leucothrix** | | 1 | | | | | | | | | | |
| *Asplenium splendens* | | + | | | | | | | | | | |
| *Commelina africana* var. *Africana* | | + | | | | | | | | | | |
| *Lotononis calycina* | | + | | | | | | | | | | |
| *Verbena bonariensis* | + | | | | | | | | | | | |
| *Kohautia amatymbica* | | | r | | | | | | | | | |
| *Anthospermum hispidulum* | | r | | | | | | | | | | |
| *Cyathea dregei* | | | r | | | | | | | | | |
| *Diospyros lycoidens* subsp. *sericea* | | r | | | | | | | | | | |
| *Gladiolus* spp. | | | r | | | | | | | | | |
| *Helichrysum oligocephalum* | | r | | | | | | | | | | |
| *Hibiscus pusilus* | | | r | | | | | | | | | |
| *Ledebouria ovatifolia* | | | r | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Pennisetum macrourum** | | | | r | | | | | | | | |
| *Rumex sagittatus* | | r | | | | | | | | | | |
| *Loudetia simplex** | | | | | | 1 | | | 2 | 1 | 4 | 3 |
| *Panicum natalense** | | | | | | | 1 | | 1 | 1 | 4 | 2 |
| *Monocymbium ceresiiforme** | | | | | 1 | | | | 1 | 1 | 4 | 1 |
| *Tetraselago* spp. | | | | | | | + | + | | | + | 1 |
| *Oxalis obliquifolia* | | | | | | | 1 | | + | | + | |
| *Cyperus obtusiflorus* var. *flavissimus**** | | | | | | | + | | + | | + | |
| *Helichrysum pilosellum* | | | | | r | | | | + | r | + | |
| *Indigophera cryptantha* | | | | | | r | | | + | + | | r |
| *Lobelia erinus* | | | | | | | + | r | | | r | + |
| *Clutia monticola* | | | | | | | r | | + | r | | |
| *Fagodia tetraquetra angustifolia* | | | | | r | | | | r | + | | |
| *Rubus rigidus**** | | | | | r | | r | | | | + | |
| *Eucomis autumnalis* subsp. *clavata* | | | | | | | r | | r | r | | |
| *Plantago major* | | | | | r | | | | r | | | |
| *Rhynchosia monophylla* | | | | | r | | | | r | | | |
| *Oenothera indicora* | | | | | | r | | | r | | | |
| *Amaranthus hybridus**** | | | | | 1 | + | 2 | 2 | | | | |
| *Panicum schinzii** | | | | | | | 1 | 2 | | | | |
| *Panicum coloratum** | | | | | | 1 | | | | | | |
| *Pennisetum clandestinum** | | | | | 1 | | | | | | | |
| *Digitaria eriantha** | | | | | | 1 | | | | | | |
| *Amaranthus viridis**** | | | | | | + | | | | | | |
| *Tephrosia capensis** | | | | | | + | | | | | | |
| *Solanum mauritianum**** | | | | | + | r | | | | | | |
| *Abilgadtia ovate* | | | | | | | r | r | | | | |
| *Aristida congesta** | | | | | | | r | r | | | | |
| *Pavonia burchellii* | | | | | r | r | | | | | | |
| *Commelina krebsiana* | | | | | | r | | | | | | |
| *Cucumis zeyheri* | | | | | | r | | | | | | |
| *Senecio* spp.. | | | | | | | | r | | | | |
| *Sesbania punicea**** | | | | | | r | | | | | | |
| *Themeda triandra** | | | | | | | | | 2 | 2 | 3 | 3 |
| *Heteropogon contortus** | | | | | | | | | 2 | | 5 | |
| *Sporobolus pectinatus** | | | | | | | | | 3 | 3 | | |
| *Vernonia natalensis* | | | | | | | | | 1 | 1 | 1 | |
| *Trachypogon spicatus** | | | | | | | | | 3 | | | |
| *Diheteropogon amplectens** | | | | | | | | | 1 | 2 | | |
| *Hypoxis acuminate* | | | | | | | | | r | 1 | 1 | + |
| *Heteropogon amplectans** | | | | | | | | | | | 2 | |
| *Athanasia acerosa* | | | | | | | | | | | | 1 |
| *Eriosema cordatum* | + | | | | | | | | | r | 1 | + |
| *Monopsis decipiens* | | | | | | | | | | 1 | + | r |
| *Setaria sphacelata** | | | | | | | | | | | r | 1 |
| *Bulbostylis hispidula* | | | | | | | | | + | + | | 1 |
| *Crepis hypochoeridea* | | | r | | | | | | 1 | + | | |
| *Becium obovatum* | | | | | | | | | | + | + | + |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Pearsonia sessilifolia* | + | | + | + | | |
| *Kyllinga alba* | | | + | + | | |
| *Rhynchosia nitens* | | | + | + | | |
| *Acalypha schinzii* | | | | + | | |
| *Alloteropsis semialata* | | | + | | | |
| *Gnidia caffra* | | | + | | | |
| *Haplocarpa scaposa* | | | | | | + |
| *Hypoxis rigidula* | | | | | + | |
| *Justicea anagaloides* | | | | + | | |
| *Peacedadanum magalismontanum* | | | | | | + |
| *Rubus cuneifolius**** | | | | | + | |
| *Sphaeranthus incises* | | | | | | + |
| *Eriosema salignum* | | | + | r | | r |
| *Senecio coronatus* | | | r | + | | r |
| *Cyphia assimilis* | | | | | r | + |
| *Drima elata* | | | r | + | | |
| *Pentanisia prunelloides* | | | r | | + | |
| *Acalypha glandulifolia* | | | | + | r | |
| *Felicia* spp. | | | r | r | | r |
| *Knowltonia transvalensis* | | | r | r | r | |
| *Sebaea grandis* | | r | r | r | r | |
| *Acalypha* spp. | | | r | r | | |
| *Acalypha angustata* | | | r | | | |
| *Chamaesyce* spp. | | | r | | | |
| *Ajuga ophrydis* | | | r | | | |
| *Anthericum cooperi* | | | r | | | |
| *Argyrolobium tuberosum* | | | r | | | |
| *Cyperus fuirena**** | | | | r | | |
| *Dicoma anomala* | | | r | | | |
| *Hermania* spp. | | | r | | | |
| *Ledebouria zebrine* | | | | r | | |
| *Lotononis laxa* var. *multiflora* | | | | r | | |
| *Morea spathulata* | | | | | | r |
| *Ornithogalum tenuifolium* | | | | r | | |
| *Pelargonium luridum* | | | | r | | |
| *Plantago lanceolata* | | | r | | | |
| *Polygala hottentota* | | | r | | | |
| *Senecio inaequidens* | | | r | | | |
| *Sonchus* spp*** | | | | | | r |
| *Vernonia galpinii* | | | | | r | |

Grass species *    exotic species ***

**Literature cited**

A practical field procedure for identification and delineation of wetlands and riparian areas. Department of Forestry and Water Affairs. Edition 1. September 2005. URL http://www.dwaf.gov.za/Documents/Other/EnvironRecreation/WetlandZoneDelineationSep05.asp[Accessed 5 November 2009].

Acocks, J.P.H. 1953. Veld Types of South Africa. Botanical Survey Memoir No. 28. Department of Agriculture, Government Printer, Pretoria.

Adler, P.B., and W.K. Lauenroth. 2003. The power of time: spatiotemporal scaling of species diversity. Ecology Letters **6:**749–756.

Areas of Conservation Importance. 2003. Mpumalanga Parks Board. URL http://www.mpu.agric.za/SOER/Mpumalanga%20Publikit%20Web%20Version%20SoER%20()/indicators/biodiversity/Areas_of_Conservation_Importance.htm. [Site visited 25 October 2008].

Barbour, M. G., J. H. Burk and W. D. Pitts. 1980. Terrestrial plant ecology. The Benjamin/Cummings Publishing Company Inc., California.

Bischoff, A. G., Warthemann, and S. Klotz. 2009. Succession of floodplain grasslands following reduction in land use intensity: the importance of environmental conditions, management and dispersal. Journal of Applied Ecology **46:**241–249.

Blake, V. B., Schulze, U. Gerighausen, S. Küster, R. Rothe, H. Schulze, and M. Sineriz. 2007. The power of regeneration: lessons from a degraded grassland. Restoration Ecology **15:** No. 2:307-311.

Bredenkamp, G.J., and L. Brown. 2001. Vegetation:  A reliable ecological basis for environmental planning. Urban Green File, November/December issue: 38-39.

Bredenkamp, G.J., J.W.H. Ferguson, S.H. Foord, and W.H. De Frey. 1999. Floristic assessment of an afromontane grassland fragmentation experiment in a pine plantation. African Journal of Ecology **37:** 49-60.

Bredenkamp, G.J., F. Spada and E. Kazmierczak. 2002. On the origin of northern and southern hemisphere grasslands. Plant Ecology **163**:209-229.

Bromilow, C. 2001. Problem Plants of South Africa. Briza Publications, Pretoria.

Bruun, H.H., B. Fritzbøger, P. O. Rindel, and U.L. Hansen. 2001. Plant species richness in grasslands: the relative importance of contemporary environment and land-use history since the Iron Age. Ecography **24** No 5:569–578.

Buhk, C., C. Beierkuhnlein , A Jentz and V. Retzer. 2007. Predicting plant species richness and vegetation patterns in cultivated landscapes using distribution parameters. Agriculture, Ecosystems and Environment **122:** 446-452.

Bullock, W.L., and M.J. Samways. 2005. Conservation of flower-arthropod associations in remnant African grassland corridors in an afforested pine mosaic. Biodiversity and Conservation **14:**3093–3103.

Chappin III, F.S., P.A. Matson, and H.A. Mooney. 2002. Principles of Terrestrial Ecosystem Ecology. Spriger-Verlag, New York.

Clemens, F.E. 1928. Plant Succession and Indicators. The H.S. Wilson Company, New York City.

Cox, E.S., R.H.Marrs, R.J.Pakeman, M.G. Le Duc. 2008. Factors affecting the restoration of heathland and acid grassland on infested land across the United Kingdom: A multisite study. Restoration Ecology **16:**553-562.

Cuevas, Y. A., and S. M. Zalba. 2010. Recovery of native grasslands after removing invasive pines. Restoration Ecology **18**: 711-719

Dallwitz, M.J. 1990. Grasses of Southern Africa. National Botanical Research Institute, Pretoria.

Daubenmire, R. 1986. Plant communities: A textbook of plant synecology. Harper and Row, Publishers, Incorporated. New York.

Deall , G.B. 1985. A plant-ecological study of the Eastern Transvaal Escarpment in the Sabie area. MSc. Thesis. Department of Botany, University of Pretoria.

Dufrêne M., and P. Legendre. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. Ecological Monographs **67**(3)**:** 345-366.

Dunham,K.M. 1989. Vegetation-Environment Relations of a Middle Zambezi Floodplain. Vegetatio **82,** No. 1**:** 13-24. URL: http://www.jstor.org/stable/20038457 Accessed: 21/07/2010 04:43.

Dunne, N. 2000. The Impact of Environmental Certification on the Forest Products Supply chain. A report prepared as part of the South Africa Country Study for the international collaborative research project steered by IIED: Instruments for sustainable private sector forestry. International Institute for Environment and Development and CSIR-Environmentek, London.

Fagan, K.C., R.F. Pywell., J.M. Bullock and R.H. Marrs. 2008. Do restored calcareous grasslands on former arable fields resemble ancient targets? The effects of time, methods and environment on outcomes. Journal of Applied Ecology **45:**1293-1303.

Farleya, K.A., and E.F. Kellyb. 2004. Effects of afforestation of a páramo grassland on soil nutrient status. Forest Ecology and Management **195:**281–290.

Feoli, E., and L. Orloci.1991. Computer assisted vegetation analysis. Kluwer Academic Publishers, Dordrecht, Netherlands.

Forestry Industry Environmental Committee. 2002. Environmental Guidelines for Commercial Forestry Plantations in South Africa. Rivonia, South Africa.

Fowler, J., L. Cohen, and P. Jarvis. 1998. Practical Statistics for Field Biology 2$^{nd}$ Ed, John Wiley and Sons, Chichester.

Gauch Jr., H. G. 1982. Multivariate analysis in community ecology. Cambridge University Press, Cambridge.

Geldenhuys, G.J. 1997. Native forest regeneration in pine and eucalypt plantations in Northern Province, South Africa. Forestry Ecology and Management **99:**101-115.

Gibbs R., N.P.Anderson, L. Baker ,M.J. Dallwitz, L. Koekemoer G.E., M.G.E. Watson and L. Smook. 1990. Grasses of Southern Africa. National Botanical Research Institute, Pretoria.

Golding J.S., editor. 2002. Southern African Plant Red Data List. Southern African Botanical Diversity Network. SABONET. Report 14.

Grabandt, K. 1985. Weeds of crops and gardens in Southern Africa. Seal Publishing (Pty) Limited, Johannesburg.

Gustavsson, E., T. Lennartsson B, and M. Emanuelsson. 2007. Land use more than 200 years ago explains current grassland plant diversity in a Swedish agricultural landscape. Biological Conservation **138:**47-59.

Hartnett, D. C. 2006. Below-ground bud banks increase along a precipitation gradient of the North American Great Plains: a test of the meristem limitation hypothesis. New Phytologist **171** Issue 2**:**81-89.

Hill, H.O. 1979. TWINSPAN- a Fortran program for arranging multivariate data in an ordered two-way table by classification of individuals and attributes. Cornell University Press, New York.

Hill, H.O. and H.G. Gauch.1980. Detrended Correspondence Analysis: An Improved Ordination Technique. Vegetatio **42:**No 1/3**.** URL: http://www.jstor.org/stable/20145789 Accessed: 21/07/2010 04:30.

Hirst, R.A., R.F. Pywell, R.H. Marrs, and P.D. Putwain. 2005. The resilience of calcareous and mesotrophic grasslands following disturbance. Journal of Applied Ecology **42**:498-506.

Hobson, N.K., and Jessop, J.P. 1975. Veld plants of Southern Africa. Macmillan South Africa, Johannesburg.

Howe, H. F. 1995. Succession and fire season in experimental prairie plantings. Ecology **76**:No. 6 1917-1919.

Huntley, B.J. 1991. Biotic Diversity in Southern Africa: Concepts and Conservation. Oxford University Press. Cape Town, South Africa.

Jongman, R. H. G., C. J. F. Ter Braak and O. F. R. Van Tongeren.1995. Data analysis in community and landscape ecology. Cambridge University Press, London, United Kingdom.

Kardol A., van der Wal T.M., Bezemer, W. de Boer H., Duyts R. Holtkamp and W.H. van der Putten. 2008. Restoraton of species rich grasslands on ex-arable land: seed addition outweighs soil fertility reduction. *Biol*ogical *Conservation* **141**: 2208–2217.

Kiehl, K., A. Thormann, and J. Pfadenhauer. 2006. Evaluation of initial restoration measures during the restoration of calcareous grasslands on former arable fields. Restoration Ecology **14:** No. 1 148-156.

Kirsten, S., and M.A. Du Plessis. 2004. The Threat of Transformation: Quantifying the Vulnerability of Grasslands in South Africa. Conservation Biology **18**: 446-477.

Kopecký, K., J. Dostàlek, and T. Frantík. 1995. The use of the deductive method of syntaxonomic classification in the system of vegetational units of the Braun-Blanquet approach. Vegetatio, **117:**95-112.

Kruger to Canyons Biosphere Reserve Information, South Africa. URL http://www.unesco.org/mabdb/br/brdir/directory/biores.asp?code=SAF+04&mode=all [Accessed 20 November 2008.

Loreau, M. 2010. From populations to ecosystems: theoretical foundations for a new ecological synthesis. Princeton University Press, Princeton.

Low, A.B., and A.G. Rebello. 1996. Vegetation of Southern Africa, Lesotho and Swaziland. Department of Environmental Affairs and Tourism, Pretoria, South Africa.

Luken, J.O. 1990. Directing ecological succession. Chapman and Hall, London.

Maccherini, S., and V. De Dominicis. 2003. Germinable soil seed-bank of former grassland converted to coniferous plantation. Ecological Research **18**:739-751.

Malan, G., E. Meyer, and M.D. Panagos. 2007. Riparian-zone rehabilitation in pine plantations: grassland woodland for plants and birds. South African Journal of Wildlife Research **37**: No. 2 159-178.

Mpumalanga State of the Environment Report. 2003. Mpumalanga Department of Agriculture, Conservation and Environment. Nelspruit.

Marais, A.J. 2005. Resource utilization of the Chacma baboon in different vegetation types in the North-Eastern Transvaal Sourveld: Blyde Canyon Nature Reserve. Research dissertation for Magister Technologiae. Department of Nature Conservation, Horticulture and Landscaping, University of Southern Africa.

Martin, L. M., K. A. Moloney, and B. J. Wilsey. 2005. An assessment of grassland restoration success using species diversity components. Journal of Applied Ecology, **42:**327-336.

Matthews, W.S., G.J. Bredenkamp and N. van Rooyen. 1992. The phytosociology of the high altitude hygrophilous vegetation regions of the north-eastern mountain sourveld in the Transvaal, South Africa. Phytocoenologia, **20**(4)**:**559-574

Matthews, W. S., van Wyk, A.E. and G.J. Bredenkamp. 1993. Endemic flora of the North-Eastern Transvaal Escarpment, South Africa. Biological Conservation **63:**83-94.

Mueller-Dombois, D., and H. Ellenburg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons Incorporate, New York.

Muller, S., T. Dutoit, D. Alard, and F. Gréviliot. 1998. Restoration and rehabilitation of species-rich grassland ecosystems in France: a review. Restoration Ecology **6:**94-101.

Neke, K.S., and M.A. Du Plessis. 2004. The threat of transformation: quantifying the vulnerability of grasslands in South Africa. Conservation Biology **18:** 466-477.

Newman, E. I. 2000. Applied ecology and environmental management. 2nd edition. Blackwell Science, Oxford.

O'Connor, T.G., G. J.Bredenkamp. 1997. Grassland. Pages 215-244 in R.M.Cowling , D.M. Richerdson, and S.M.Pierce, editors. Vegetation of Southern Africa, Cambridge University Press, Cambridge.

O'Connor, T.G. 2005. Influence of land use on plant community composition and diversity in Highland Sourveld grassland in the Southern Drakensberg, South Africa. Journal of Applied Ecology **42:**975-988.

Őckinger, E., A.K. Eriksson, and H.G. Smith. 2006. Effects of grassland abandonment, restoration and management on butterflies and vascular plants. Biological Conservation **133:**291-300.

Onderstall, J. 1984. Transvaalse Laeveld en Platorand, Veldblomgids van Suid Afrika 4. Botanical Society of South Africa.

Odum, E. P. 1959. Fundamentals of Ecology. W.B. Saunders Company, Philadelphia.

Öster, M., K. Ask, S. A. O. Cousins, and O. Erikson. 2009. Dispersal and establishment limitation reduces the potential for successful restoration of semi-natural grassland communities on former arable fields. Journal of Applied Ecology, **46:**1266-1274.

Overview of developments in the Forestry Industry. 1997. International Trade Statistics Data in the table is taken from the COMTRADE database of the United Nations Statistics Division. Copyright by the United Nations All rights reserved. Used with permission.URL http://www.intracen.org/tradstat/sitc3-3d/ep251g htm. [Accessed: 10 September 2008].

Palmer, M.W. 1993. Putting Things in Even Better Order: The Advantages of Canonical Correspondence Analysis. Ecology, **74:** No 8 2215-2230. URL: http://www.jstor.org/stable/1939575. [Accessed: 21/07/2010 04:46].

Parker, R.E. 1979. Introductory Statistics for Biology 2nd Ed, The Cornel Press Ltd, Southhampton.

Peet, R.K., R.B. Allen, J.S. Case, and R.G. Knox. 1988. Putting Things in Order: The Advantages of Detrended Correspondence Analysis. The American Journalist, **131:**No 6 924-934. URL: http://www.jstor.org/stable/2461824. [Accessed: 21/07/2010 04:46].

Pielou, E. C. 1984. The interpretation of ecological data. John Wiley & Sons, New York.

Pywell, R. F., J. M. Bullock, A. Hopkins, K. J. Walker, T. H. Sparks, M. J. W. Burke, and S. Peel. 2002. Restoration of species-rich grassland on arable land: assessing the limiting processes using a multi-site experiment. Journal of Applied Ecology **32:**294-309.

Pywell, R. F., J. M. Bullock, D. B. Roy, P Rotherby, L. Warman, and K.J.Walker. 2003. Plant traits as predictors in ecological restoration. Journal of Applied Ecology **40:** 65-77.

Pywell, R. F., J. M. Bullock, G. Masters, J. B. Tallowin, K. J. Walker, and A. Warman. 2007. Enhancing diversity of species-poor grasslands: and experimental assessment of multiple constraints. Journal of Applied Ecology **44:** 81-94.

Regier, H. A. 1993. *The* Notion of Natural and Cultural Integrity. Institute of Environmental Studies, University of Toronto, Toronto, Ontario. In Ecological Integrity and the Management of Ecosystems as edited by Woodley S., Kay J., and G. Francis. St Lucie Press.

Regulations on the National Forests Act, 1998 Act no. 84 of 1998. Department of Agriculture, Forestry and Fisheries. 29 April 2009. URL http://www.dwaf.gov.za/Documents/Forestry/NFA1998Regulations29April2009.pdf [Accessed 11 November 2009].

Reitalu, T., M.T. Sykes, L.J. Johansson, M. Lönn, K. Hall, M. Vandewalle, and H.C. Prentice. 2009. Small scale plant species richness and evenness in semi-natural grasslands respond differently to habitat fragmentation. Biological Conservation **142**:899-908.

Retief, E., and P.P.J. Herman. 1997. Plants of the Northern Provinces of Southern Africa: keys and diagnostic characters. Strelitzia **6**, National Botanical Institute, Pretoria.

Schelpe, E.A.C.L.E., and N.C. Anthony. 1986. Flora of Southern Africa. Government Printer, Pretoria.

Sluis, W. J. 2002. Patterns of richness and composition in re-created grassland. Restoration Ecology, **10:**677-684.

Snyman, H. A. 2004. Short-term influence of fire on seedling establishment in a semi-arid grassland of South Africa**.** South African Journal of Botany **70** Issue 2:215-226.

Spedding, C.R.W. 1971. Grassland ecology. Clarendon Press, Oxford.

Steyn, L. 2005. Progress Report on the National Grasslands Biodiversity Programme. 2005. In Grassroots: Newsletter of the Grasslands Society of Southern Africa, **5:** No 4

Sustainable Forest development in South Africa. White paper March 1997. Ministry of Water Affairs and Forestry. Pretoria. URL http://www2.dwaf.gov.za/dwaf/cmsdocs/25Forestry%20White%20Paper.htm. [Accessed 11 November 2009].

The legal regime applicable to wetlands and wetland rehabilitation. URL http://www.dwaf.gov.za/wfw/Legal/Docs/doc/Presentation%20March%202001rev2.doc [Accessed 20 November 2008].

Ter Braak, C.J.F. 1986. Canonical Correspondence Analysis: A new eigenvector technique for multivariate direct gradient analysis. Ecology **67:**5 1167-1179.

Ter Braak, C.J.F. 1987. The Analysis of Vegetation-Environment Relationships by Canonical Correspondence Analysis. Vegetatio **90:**No1/3**:** 67-77. URL: http://www.jstor.org/stable/20038104 [Accessed: 21/07/2010 04:39].

Tidmarsh, C.E.M.,and C.M. Havenga. 1955. The wheel point method of survey and measurement of semi-open grasslands and Karoo vegetation in South Africa. Memoir 29, Botanical Survey 29 of South Africa, National Botanical Institute, Pretoria South Africa.

Tilman, D., J. M.H.Knops, and P.B. Reich. 2006. Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature **441:** issue 7093 629-632.

Tivy, J. 1993. Biogeography. 3rd Edition. Longman Scientific and Technical, Essex, England.

Tow, P.G., and A. Lazenby. 2001. Competition and succession in pastures. CABI Publishing, New York.

Van Aarde R.J., Ferreira S.M., Kritzinger J.J., van Dyk P.J., Vogt M., and Wassenaar T.D. 1996. An evaluation of habitat rehabilitation on coastal dune forests in Northern KwaZulu-Natal South Africa. Restoration Ecology **4:** 334–345.

Van Der Maarel, E. 1975. The Braun-Blanquet Approach in Perspective. Vegetatio **30** No.3**:**213-219.

Van Groenewoud, H. 1992. The robustness of Correspondence, Detrended Correspondence and TWINSPAN Analysis. Journal of Vegetation Science **3:** No. 2 239-246.

Van Jaarsveld, A. S., J. W. H. Ferguson, and G. J. Bredenkamp. 1997. The Groenvaly grassland fragmentation experiment: design and initiation. Agriculture, Ecosystems and Environment **68:**139-150.

Van Tongeren, O.F.R. 1988. Some models for secondary succession in grasslands and heathlands. Quick Service Drukkerij, Enschede.

Van Wyk A.E. 2006. Presentation on Southern African Grasslands: Aspects of its biodiversity, dynamics and management. Geasphere Conference, 13 November 2006, Nelspruit. http://www.geasphere.co.za/articles/grasslands.htm

Van Wyk, A.E., and G.F. Smith. 2001. Regions of floristic endemism in Southern Africa. Umdaus Press, Pretoria.

Van Wyk, B., and S. Malan. 1988. Die veldblomme van die Witwatersrand- en Pretoria-gebied. Struik Uitgewers, Kaapstad.

Van Wyk, E., and F. Van Oudtshoorn. 1999. Guide to grasses of Southern Africa. Briza Publications, Pretoria.

Waldhardt, R. 2003. Biodiversity and landscape: summary, conclusions and perspectives. Agriculture, Ecosystems and Environment **98**:305–309.

Waldhardt, R., and A. Otte. 2003. Indicators of plant species and community diversity in grasslands. Agriculture, Ecosystems and Environment **98**:339–351.

Water conservation and demand management strategy for the forest sector in South Africa. Department of Water Affairs and Forestry. May 2000. http://www.dwaf.gov.za/docs/Other/WaterUseConservation/WCWDMimpAug04.pdf. [Accessed 6 November 2009].

Wildi, O. 2010. Data Analysis in Vegetation Ecology. Wiley-Blackwell, United Kingdom.

WWF South Africa. Grassland vision becomes a reality. http://www.wwf.org.za/what_we_do/green_trust/?3361/Grasslands-vision-becomes-a-reality. [Accessed 6 November 2009]

Xu, Z., X. Han, H. Ren, S. Wan and G. Zhu. 2010 . The influence of historical land use and water availability on grassland restoration. Restoration Ecology **18**:217-225

Zaloumis, N.P. and W.J. Bond. 2011. Grassland restoration after afforestation: No direction home? Austral Ecology **36:**357-366.