AN ASSESSMENT OF THE EFFECTS OF STRIP AND TRENCH MINING IN MOPANEVELD - ASSESSING VELD RECOVERY

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Research Methodology B

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Introduction

In the eastern Lowveld, land has been purchased for game conservation since 1930s. Most of these land purchases in the early days were for establishment of cattle farms which was later abandoned, and converted to wildlife areas (Parsons *et al.* 1997). This resulted with the establishment of private nature reserves by the 1960s (Peel *et al.* 2005). The primary goal of protected areas is to preserve biodiversity (Parsons *et al.* 1997). Mopaneveld is a semi-arid vegetation type that is sensitive to severe disturbances in natural areas, and its functioning. North-eastern Lowveld of South Africa is poorly suited for agriculture but rich in mineral resources such as copper, iron and salt resources (Killick & Miller 2013). Phalaborwa is known for mining activities. This includes open-pit mining, the summit of Lolwe hill mined from 1965 which was riddled with old shafts, trenches and adits for oxidised ores (Bernhard, 1971). Mining and human settlement transformed portions of Phalaborwa-Timbavati Mopaneveld (Rutherford *et al.* 2006). Cooke *et al.* (2002) found that removal of soil and vegetation for mining destructs natural ecosystems, and (Richard, Dean & Milton 2010) reported that such conversions are amongst the main ecological impacts caused by mining. Stable herbaceous composition is positively influenced by trees, therefore clearing trees results with more grass production followed by decline in high quality productive grasses (Peel *et al.* 2012). Structural variables of matching undisturbed areas may possibly serve as reference point for comparison of variables at disturbed sites (Van Aarde 1996), since sufficient knowledge of vegetation structure and composition of certain areas prior to disturbance is often not available (Cairns 1988).

Competitive exclusion arises when natural productivity is high, e.g. sites that are not exposed to significant disturbance, and disturbed with low intensity in contrast with extreme disturbance (Grime, 1973). Species richness can range to extreme level at some moderate level of disturbance during intermediate disturbance hypothesis theory (Loucks 1970; Grime 1973; Connell 1978; Huston 1979, 1994; Tilman, 1983). Species composition of certain area can be modified as a result of localized extinction of resident species in association with species replacements and additional species to the area (Fox & McKay 1981). Species evenness reveals how the equally abundances (number of individuals, biomass and cover) are distributed among species (Goldsmith *et al.* 1986; Ludwig & Reynolds 1988; Morrison *et al.* 1992).

The measurements and analyses of floristic herbaceous composition, structure and climatic variability will enhance the effective ecological management decisions (Peel *et al.* 2012). Rainfall variability may possibly bring significant change in the species composition of the herbaceous layer in savanna over 1 to 2 years period (O'Connor 1991). Salvaging and returning topsoil, mulch, seeds and plants improve retaining and preservation of natural resources. This is achieved by using nets and mulch to control wind scour and contouring the soil surface to retrain water. Restoration process should be practiced throughout the mining process on strip mines. This approach successfully rehabilitated mined dune sands at Richards Bay, Kwazulu-Natal (Richard, Dean & Milton 2010). Rehabilitation enhances the sustainable utilization of natural resources at disturbed natural environment. Suitable restoration practice should aim on retaining resources, ecosystem function and biodiversity. Fragmented post-mining sites provide important ecological functions for wildlife (Weiermans & Van Aarde 2003).

The study was initiated by South African Environmental Observation Network (SAEON), with the need to provide baseline data to monitor herbaceous species composition over time after an extreme disturbance event. Determining the extent of the problem and rehabilitation measures at the study area will assist on recommendations of setting the environmental objectives for post mining land use. Such findings will enhance factual land use options assembled on the return of the herbaceous biodiversity for ecosystem health and functioning of mined areas of Mopaneveld.

One of the objectives of Lowveld monitoring programme is to determine the current trends and to detect changes of natural resources in the Lowveld (Peel *et al.* 2012). So, baseline data gathered from this study for long-term monitoring of the herbaceous layer at Pompey will assist for this objective. Strip mining alters the natural ecosystem and is especially detrimental in semi-arid regions, such as Mopaneveld. We need to understand the dynamic nature of recovery after a major disturbance, to be able to inform mitigation measures to assist those ecological processes and functions which did not recover sufficiently. Recovery of these ecosystem processes (returning the land to some degree of its former state) is especially important in Mopaneveld bordering important conservation areas such as the Kruger National Park. A first step to assess recovery is to compare transformed areas (strip mined sites), disturbed (trench mined sites) with untransformed (natural area sites) in terms of herbaceous floristic composition (species richness), diversity, density, composition, vegetation cover, biomass, height and structure.

Research problem of the study

To determine the nature and extent of damage and subsequent recovery of vegetation in Mopaneveld due to mining activities.

Key questions of the study

Is there biodiversity loss or does various mining treatments increase species composition of the herbaceous layer?

Does herbaceous vegetation of Mopaneveld recover after human disturbance such as mining?

Aim

The aim of the study is to quantify the differences between the treatments to assess the effect of unaided strip mining rehabilitation practices.

Objectives

1. To assess and compare species composition of herbaceous layer in mining sites with natural areas of Mopaneveld.
2. To gather baseline data for long-term monitoring of the herbaceous layer of strip-mine at Pompey silica mine, Phalaborwa in Limpopo Province of South Africa.
3. To contributes towards the benchmarking of mine lands against natural Mopaneveld.

Hypothesis

Mining activities were expected to have a big detrimental impact on the nature of veld, with limited recovery.

Study Area

The study area is located near Phalaborwa in the Limpopo Province of South Africa (Figures 1 & 2). It was 8.40ha in size. Study sites were located at Pompey (silica strip mine and protected reserve) (23°49' S, 31°04' E) (Figure 3). The vegetation of the study area falls in the Mopaneveld Bioregion of the Savanna Biome and is classified as Phalaborwa-Timbavati Mopaneveld. The vegetation unit is classified as least threatened and is well conserved in

Kruger National Park and other nature reserves (Mucina and Rutherford 2006). Vegetation is characterized by a grassy ground layer and a distinct upper-layer of woody plants.

The study area experience summer rainfall with very dry winters. Annual precipitation ranges from 400 to 600 mm and mean monthly maximum and minimum temperatures for Phalaborwa is 38.4°C and 5.7°C for January and July. Pompey had a wet season during the study, an area with a mean annual rainfall of 480 mm. Quarts-feldspar rocks of the Makhutswi Gneiss are mainly dominating the geology except in northwest regions where Lekkersmaak Granite intrudes. The dominant land type in the Phalaborwa system is the Fb-type (Mucina & Rutherford, 2006), which indicates the presence of lime in the soil (Bezuidenhout, 2009) with clay soils prevailing in bottomlands and sandy soils expected on uplands (Venter *et al*., 2003; Bezuidenhout, 2009). Diagnostic herbs are: *Evolvulus alsinoides*, *Heliotropium steudneri*, *Hemizygia elliottii*, *Ipomoea magnusiana* and *Kohautia virgata*. Important graminoids of the area are: *Digitaria eriantha*, *Eragrostis rigidior*, *Pogonarthria squarrosa*, *Andropogon gayanas*, *Brachiaria nigropedata*, *Melinis repens*, *Panicum maximum*, *Perotis patens*, *Schmidtia pappophoroides* and *Themeda triandra* (Mucina & Rutherford 2006).

The nature of strip mine requires spacious areas to be mined in a series of strips and not deep underneath the surface. It is preferably practiced where the surface of the ground and the ore body are relatively horizontal (Bullivant 1987). The practice scenery of strip mining destroys biological diversity (Van Aarde, Wassenaar & Guldemond 2011) including herbaceous layer in mined areas of Mopaneveld. Strip mined sites in Pompey was used for stock piling for future use and this mining activity was performed using bulldozers. Soils and tree layers were removed and there was no rehabilitation done. Trench mined sites in the study area was used for environmental immediate uses. This mining activity was performed with back actor and the trenches were two meters wide and ranging from fifty to hundred meters long and they were fifty to hundred meters apart. Study area was associated with low utilization grazing intensities confined to African buffalo (*Syncerus caffer*), African elephants (*Loxodonta africana*), hippopotamus (*Hippopotamus amphibius*) and mixed antelope.

Fire and grazing are main drivers of ecosystem functioning in savanna (Tainton & Mentis 1984, O'Connor 1994). Herbivory is more significant than fire in Lowveld in terms of impacting the herbaceous vegetation (Peel *et al.* 2005). Mopaneveld species adapted to evolutionary history of being tolerant to grazing (Cingolani *et al.* 2005) and disturbance (Rutherford *et al.* 2006).

Methodology

The study area, Pompey, was stratified into three treatments, namely strip mined, trench mined and natural areas (see figure 4) for the lay-out of the plots across treatments. Twenty quadrats were randomly placed in each treatment, but this process was limited by security issues. The choice of twenty (20) fixed frame quadrats per treatment was based on SAEON's Mopaneveld study in the Kruger National Park, which indicated that a set of 15 repeats is optimal to sample 95% of the herbaceous diversity of a treatment. Area based sampling (Plot techniques) of 1m² fixed frame quadrat was used to sample herbaceous floristic parameters. A total of sixty (60) quadrats were sampled. GPS reading were recorded for each quadrat (Figure 4). Cover percentages of grass, forbs, bare soil and dead plant material was visually estimated for each plot (Figure 5). All herbaceous species within the plots were identified up to species level and all individuals were counted (total counts) see figure 6 as an example of demonstrating how herbaceous layer were sampled. The tallest herbaceous plant in each plot was identified and its height measured. Biomass for each plot was measured by randomly throwing a 100cm² square within the quadrat (Figure 7), and it was repeated twice. Rooted herbaceous material within squares was harvested (cut plot method) and dried. Field data was recorded in a data matrix. Voucher specimens of all species were deposited in the A.P Goossens Herbarium (PUC) at North West University (Potchefstroom campus). Examples of herbarium specimens see figures 8 to 10 according to various treatments sampled in Pompey. Unknown specimens were identified by the Pretoria National Herbarium (PRE).

Descriptive statistics presented statistical means of three Pompey treatments that was sampled whereby data was used to draw tables and figures. Levene Test of Homogeneity of Variances was then applied to the data sets and when the P-value ($P< 0.05$) was less than 0.05 meant that the data was heterogeneous and Kruskal-Wallis test was done and therefore there was no need for post-hoc. Data processing proceeded with One-way Anova in the cases where the P-value ($P> 0.05$) of the data set was more than 0.05 after the Levene test. One-way analysis of variance (ANOVA) by means of Statistica version 10 was applied to the data sets and this was executed to test significant variation in species diversity, richness and biomass of the herbaceous vegetation across three different treatments (Statsoft 2010). In the cases where results was statistically significant, post-hoc was conducted to compare sample means pair wise of all three various treatments (Tukey unequal N HSD (Honest Significant Difference) test) to test which treatments were significantly higher or lower than others (Quinn & Keough, 2002). The following indices were used for data analysis: Total species (S), Total individuals (N), Margalef's species richness (d), Pielou's evenness (J'), Shannon-Wiener diversity index (H') and Simpson's index of diversity (1-Lambda).

Results and discussion

The study hypothesised that mining activities were expected to have a big detrimental impact on the nature of veld with limited recovery. Strip mined declined floristic composition of the herbaceous layer in mining areas of Mopaneveld, including species richness, diversity, composition, cover, biomass, height and structure. The results attested the original hypothesis to be true, as hypothesized herbaceous floristic composition in mining areas of Mopaneveld declined significantly with strip mined except biomass. As would be expected strip mining lead to a loss of herbaceous vegetation composition in mining areas of Mopaneveld.

Assessing veld recovery by analysing the nature of the recovery

Dominant herbaceous species and grass succession across study sites.

Strip mined sites were dominated by few herbaceous plant species with high percentage covers, the rest of species were covering average and low percentages. *Urochloa mosambicensis* (Hack.) Dandy., were the most dominant herbaceous plant in strip mined with 881 records followed by *Aristida adscensionis* L. and *Aristida bipartita* (Nees) Trin + Rupr. Single dominant species led to lowest species richness and diversity in strip mined (Table 1). Combination pattern of forbs and grass species dominance: (*Ocimum americanum* L. var. *americanum, Leucas glabrata* (Vahl.) Sm. var. *glabrata and Aristida adscensionis* L.) were demonstrated in trench mined sites see table 2. Counter-balanced percentage cover and number of records were maintained by dominance of various types of herbaceous layer displayed in control treatment of the study area (natural areas) with highest species richness (Table 3).

Life forms of grasses and invasiveness of forbs in strip mined, trench mined and natural areas.

Pioneer grasses in Pompey were least in natural areas and more in trench and strip mined (Table 4). Strip mined were dominated by fast colonising pioneer species. Peak sub-climax and climax grasses were associated with natural areas as expected (Table 4). Mining treatments comprised of more annual grasses in comparison to natural areas of the study area (Table 4), which was expected as disturbances such as mining leads to production of more annual grasses. However; natural areas had more perennial grasses in contrast with mining treatments of the study area (Table 4). More leaf material production of perennial grasses is known to be essential for ecosystem sustainability. Indigenous forbs were mostly recorded in natural areas and decreasing to strip mined areas, whereas exotic forbs were more in mining treatments (Table 4). *Achyranthes aspera* L. var. *aspera*, *Hybanthus enneaspermus* (L.) F.Muell. var. *enneaspermus*, *Bidens bipinnata* L., *Mollugo nudicaulis* Lam. *and Portulaca oleracea* L. were only five exotic forb species recorded across study sites, most frequently in trench mined. No exotic grasses were recorded in Pompey. Mining disturbance in the study sites did not brought significant change of exotic herbaceous species composition. Several studies reported that alien plant species are rare in Phalaborwa-Timbavati vegetation unit (Rutherford and Powrie 2010a, b, 2011, 2013).

Growth forms, grass palatability and ecological status of herbaceous layer in strip mined, trench mined and natural areas.

No climbers were recorded in the study area. Dwarf shrubs, forb and succulents declined with mining disturbance in Pompey (Figure 15). This finding indicates that mining is having detrimental effects on the patterns of growth forms in mined sites of Mopaneveld. Most palatable grasses with high grazing values were associated with less disturbed sites. Decreaser grasses were highest in natural areas and least in strip mined. Natural areas composed of high numbers of productive grasses that are important for grazers. Palatable grass species ranged from natural areas to trench mines in Pompey. Ecological status of grasses that increase with disturbing gradient are Increaser ii grasses, and they correlated with strip mines in Pompey.

Indicator species and frequency of herbaceous layer in the study area

Aristida adscensionis L. is associated with extreme disturbance and diminished from furthermost to least disturbed sites in the study sites. Forb species such as *Physalis alkekengi* (Chinese lanterns) is a primary species, serving as an indicator species of disturbed sites such as strip mined sites. *Urochloa mosambicensis* (Hack.) Dandy., *Aristida adscensionis* L. and *Ocimum americanum* L. var. *americanum* were herbaceous species with most frequent records across the Pompey treatments. Most dominant grass species recorded were *Urochloa mosambicensis* (Hack.) Dandy., *Aristida adscensionis L.* and *Schmidtia pappophoroides* Steud., dominant forb species were *Ocimum americanum* L. var. *americanum*, *Leucas glabrata* (Vahl.) Sm. var. *glabrata* and *Ocimum filamentosum* (Forssk.) Chiov.

Composition of herbaceous layer across treatments

Species composition of herbaceous layer in strip mined, trench mined and natural areas.

Difference in species composition across land-use types were analysed by conducting a Non-metric Multi-Dimensional Scaling analysis (NMDS) in Primer 6 version 1.1.15 (2012) see figure 11. One-Way ANOVA in Statistica 10 were used to test for statistical significant variance of herbaceous floristic compositions across various treatments of study area. Species composition declined significantly from natural areas to strip mined sites ($p>0.05$, Table 7). Mining activities resulted with reducing species composition of herbaceous vegetation in Mopaneveld (Table 7). Total number of species per plot showed highly significant differences across treatments ($p=0.000$, Table 8). Mean number of species per plot declined significantly from protected areas to furthermost disturbed sites: natural areas with 16 herbaceous species per plot, trench mined with 15 and strip mined with 10 species per plot (Table 8). Such disturbance might result in loosing species of important conservation importance such as endemic species or possibility to extinction. Heavy grazing in strip mined sites was attributable to diminishing the herbaceous species composition (Rutherford & Powrie, 2013). The outcomes attested that some herbaceous species disappeared from the ecosystem as a result of mining disturbances. This result was attributable to the number of herbaceous species per plot declined significantly.

A total of 154 herbaceous plant species were recorded within sixty sampling plots across three different treatments (Appendix 1). Number of recorded herbaceous species in Pompey were lowest in strip mined (Appendix 2: 65 species) and highest in natural areas (Appendix 3: 108 species), whereas trench mined had 102 herbaceous plant species (Appendix 2).

Diversity patterns across treatments

Diversity and attributes of herbaceous layer in strip mine, trench mined and natural areas.

Species diversity and attributes of the herbaceous layer revealed noticeable variations for determining the diversity patterns of herbaceous vegetation across treatments in Pompey (Table 7, Figure 12). Both Shannon-Wiener diversity index and Simpson's index of diversity tested highest at natural areas and lowest in strip mines (Table 7, Figure 12). Species richness varied significantly across treatments ($p=0.000$, Table 7, Figure 13), highest species richness was associated with control site (natural areas) and lowest in strip mines.

There was statistical significant of species density across treatments (Table 7). Extreme disturbed site (strip mined) produced highest number of species density and less disturbed (trench mined) revealed moderate species density, whereas natural areas displayed the lowest species density. Total numbers of individuals (species density) showed highly significant differences across treatments ($p<0.05$, Table 7), highest numbers of individuals were found in strip mining as expected. Strip mines displayed the most uneven plant communities and with highest species density, dominated by pioneer *Urochloa, Aristida* and *Tragus* species. There was statistical variation of species evenness across treatments ($p=0.000$, table 7). Nevertheless species evenness is mostly un-even in natural areas in contrast with strip mines.

Diversity patterns regarding species turn-over of herbaceous vegetation validated visible variations across treatments in Pompey. Dataset of the study area was stratified into subunits. The total actual number of species (gamma diversity) was then divided into the effective number of compositionally dissimilar subunits (beta diversity). Consequently, the mean effective number of species per such subunit (alpha diversity) (Tuomisto 2010). Total species diversity observed in the dataset (gamma diversity) was statistically significant at Pompey. Differentiation of diversity amongst tested treatments (beta diversity), increased as the level of alpha diversity inclined. This increased as the effect of more treatments being sampled. Beta diversity diminished from undisturbed site to disturbed treatments. It measured the turnover of species alongside spatial landscape (Pompey) in the mining areas of Mopaneveld. Strip mined comprised of least species diversity (Figure 12), with highly significant species density among sampled treatments (Table 7).

Alpha diversity is low at strip mined with significant total individuals across sampled sites. Transformed and disturbed sites had low alpha diversity in contrast with undisturbed treatment. Both alpha and beta diversities confirmed depreciation from natural Mopaneveld to disturbed treatments in Pompey. Whereas gamma diversity did not revealed natural recovery with time at the study sites after disturbed gradient, in sensitive semi-arid Mopaneveld compared to prior disturbance.

Structural differences across treatments

Abundance, percentage covers (forbs, grass, bare and dead material) and height of herbaceous layer in strip mines, trench mines and natural areas.

ANOVA was used to test for significant structural differences across treatments by analysing species abundance, growth forms, percentage cover and height of herbaceous layer in the study sites.

Structural differences of herbaceous vegetation in the study sites were found to be negatively affected by disturbance, due to deteriorating abundance (biomass, dead material percentage cover, growth forms and height). Though, herbaceous biomass did not vary significantly across treatments (Table 7). Dead material and grass cover percentages varied significantly across treatments ($p<0.05$, Table 9). Greatest dead material cover percentages of herbaceous vegetation were correlated with least disturbed sites (Natural areas). Most percentage of grass cover was recorded in strip mined compared to other treatments ($p<0.05$, Table 9). No significant variation of forb cover percentage were found ($p<0.05$, Table 9). Significant variation of bare soil cover were tested ($p<0.05$), mostly in trench mined. Dead material cover was highly significant ($p<0.05$), highest found in natural areas and least in strip mined. No significant variation in forbs percentage cover could be confirmed, whereas grass cover percentage was significant across treatments. Highest numbers of individual grasses found in strip mined contributed to significant grass cover percentages between treatments. Disturbance decreases the height of herbaceous layer (Shackleton, 2000; Rutherford, Powrie & Thompson, 2012). Height of herbaceous layer was highly significant across treatments ($p=0.000$, Table 7) in the study sites. Highest average height was recorded in natural areas in contrast with strip mined as would be expected due to removal of trees and high utilization of herbivory. Consequently, height of herbaceous vegetation did not increase with disturbance (Table 7).

Biomass and other variables of herbaceous layer in strip mined, trench mined and natural areas

Herbaceous productivity does not necessarily decline with heavy grazing (Kelly & Walker 1977; Shackleton, 1993). No significant variation of herbaceous biomass was confirmed in Pompey P-value ($P>0.05$, Table 7), although mean biomass was highest in natural areas (Table 6). Biomass results does not compliment reports from (Barnes, 1984, Scholes, 1987) that clearing woody vegetation increase herbaceous biomass, as sites with cleared woody vegetation (strip mined sites) comprised of lowest herbaceous biomass in Pompey.

Control site demonstrated representable results of herbaceous layer in terms of palatable grasses, grazing values, plant succession, ecological status, native and perennial grasses in comparison with disturbed sites. Disturbance and transformation of natural areas of Mopaneveld attested to have caused negative impact on species composition, diversity patterns and structural differences of herbaceous vegetation. Pompey experienced wet season during the study, which contributed to high number of herbaceous species recorded in arid vegetation unit of Mopaneveld. Natural areas were sampled to serve as benchmark of the precise representative of the herbaceous layer in Mopaneveld. The comparison of the transformed (strip mined) and disturbed (trench mined) with natural area was dynamic for testing the ecosystem attributes that are important for evaluating restoration programme. Rehabilitation measures will address the functionality and is aimed at restoring ecosystem goods and services.

Species density varied significantly across treatments and correlated with higher levels of disturbance (Table 7). Competition is a contributing factor of low species densities in severe disturbed sites, though there are low percentages of competitive exclusion at undisturbed sites. Drought and grazing are factors persuading environmental stress that may cause low occurrence of species of high competitive index in vegetation of high species density. Increasing damage pressure on species density and effect of collective environmental stress therefore conforms between the two phenomena. Productivity is high at low environmental stress conditions and competitive exclusion arises in consequence of species of high competitive index reaches maximum vigour and low species density. Competitive species fall in vigour at high environmental stress conditions and there is survival of species with lower competitive ability. Lack of tolerant species limited species density at extreme environmental stress (strip mined) as it was expected. Intermediate range of physical gradient (trench mined) revealed excessive diversity as the study sites was altered by disturbance. Tolerant small quantity of species was persistent at peak intensities and species density declined (Grime, 1973).

Conclusion

Strip mined sites reduced herbaceous floristic composition in Mopaneveld, nevertheless increasing the density and the grass cover percentage. Species composition, richness and density are floristic compositions of herbaceous layer that were found to be deteriorating in strip-mines of mined Mopaneveld. Species composition of herbaceous layer was highly significant across sampled treatments. This result answers the key question of the study, stated to found whether various mining treatments decrease or increase herbaceous biodiversity in the study sites.

Age after mining activities and tree cover were the major factors affecting the herbaceous layer recovery to pre-disturbance states. Tree-forb co-existence requires further investigation, but current findings suggest that tree plantings could enhance the recovery of the herbaceous layer of Mopaneveld after strip mined. From the conservation management point of view strip mining should be prohibited due to its detrimental impacts on the ecosystem. It is therefore advised that in future mining organizations and affected parties must ensure the rehabilitation projects after mining practices for the environmental sustainability.

Herbaceous vegetation in mining areas of Mopaneveld indicated that they are not recovering with age after strip mining. Extreme environmental disturbances should be avoided in Mopaneveld vegetation due to its sensitivity and slow or no level of recovery. Overgrazing, soil erosion and decrease land-value for optional land use after strip mining are some of the possible environmental health problems that the land might experience in future. Therefore in conclusion it is advised that land-owners must make cautious ecological practices to avoid losing some endemic herbaceous vegetation and other natural resources of dynamic importance.

Baseline data collected this study from and such findings are significant for long-term monitoring of herbaceous Mopaneveld and are also helpful for future research projects. They will assist as reference point data for different post mining land-uses in disturbed areas of Mopaneveld. Meanwhile SAEON is concerned with the monitoring of environmental change over the long-term of Mopaneveld; subsequently these finding implications are vital for current and future environmental sustainability. Landowners in disturbed sites or portions will make improved management decision of herbaceous vegetation for the functioning of the ecosystem health. Environmental Impact Assessment should be pre-requisite for any practices on environment to avoid environmental threats. Environmental implementation and management compliances are essential to be carried out throughout the mining operation period (Act 107/1998 of National Environmental Management Act). It is recommended that in future there must be appropriate management and implementation plans that will be carried-out throughout the period of mining practices.

Land owners such as conservation managers, commercial and communal farmers in Mopaneveld will benefit from these findings for production value of herbaceous vegetation and stocking rates of animals. Based on these overall findings strip mines should not be recommended as a healthy environmental practice for impacts on Mopaneveld herbaceous vegetation, on account of reducing the ecological value of the ecosystem. The land use systems will change after mining and it is recommended that Pompey should be used for grazing due to high number of palatable herbaceous species. Herbivore distribution is positively influenced by the amount and state of palatable vegetation.

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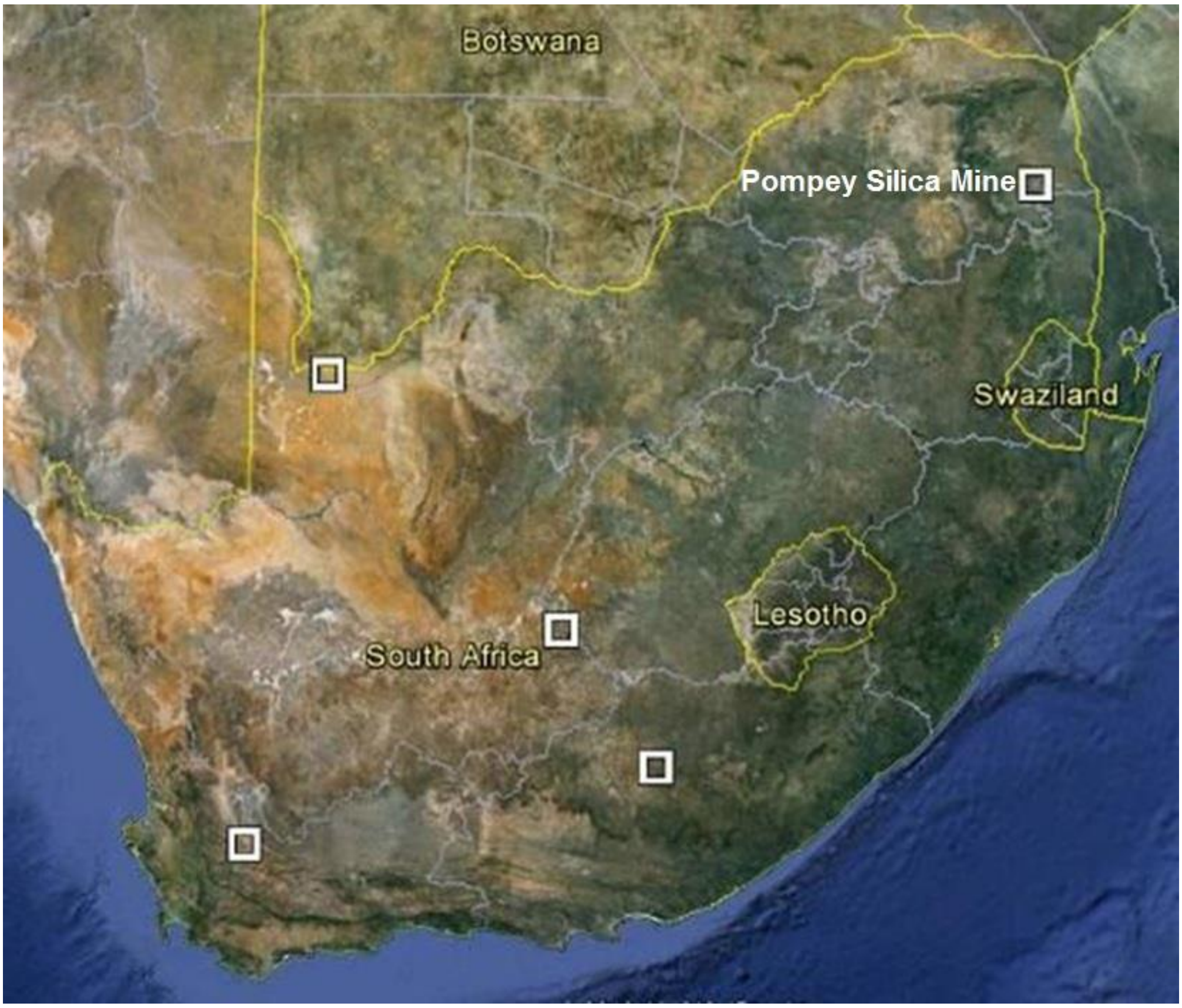


Figure 1: Map of the study area (Pompey silica mine) on a national scale.

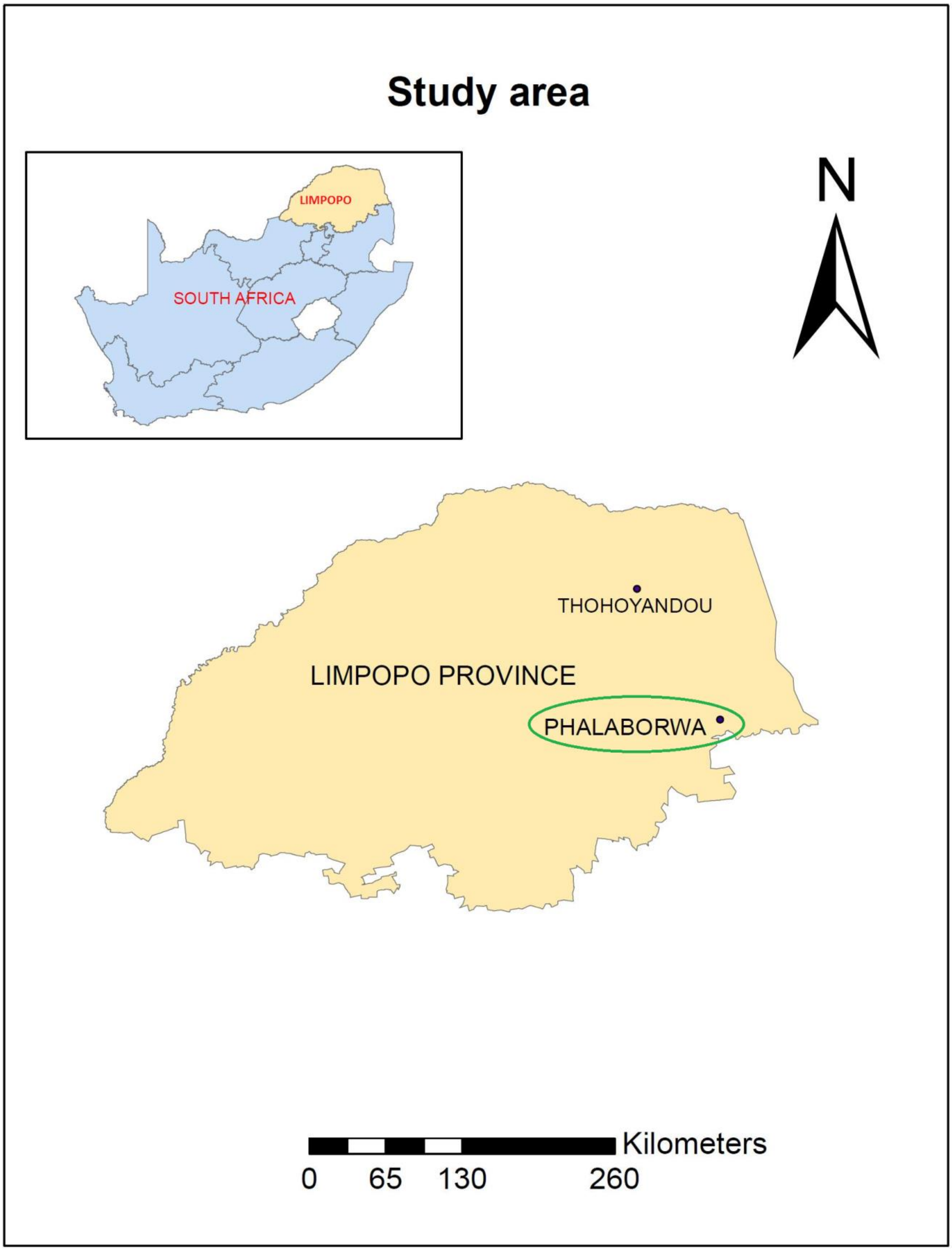


Figure 2: Map of the study area on a provincial and national scale.

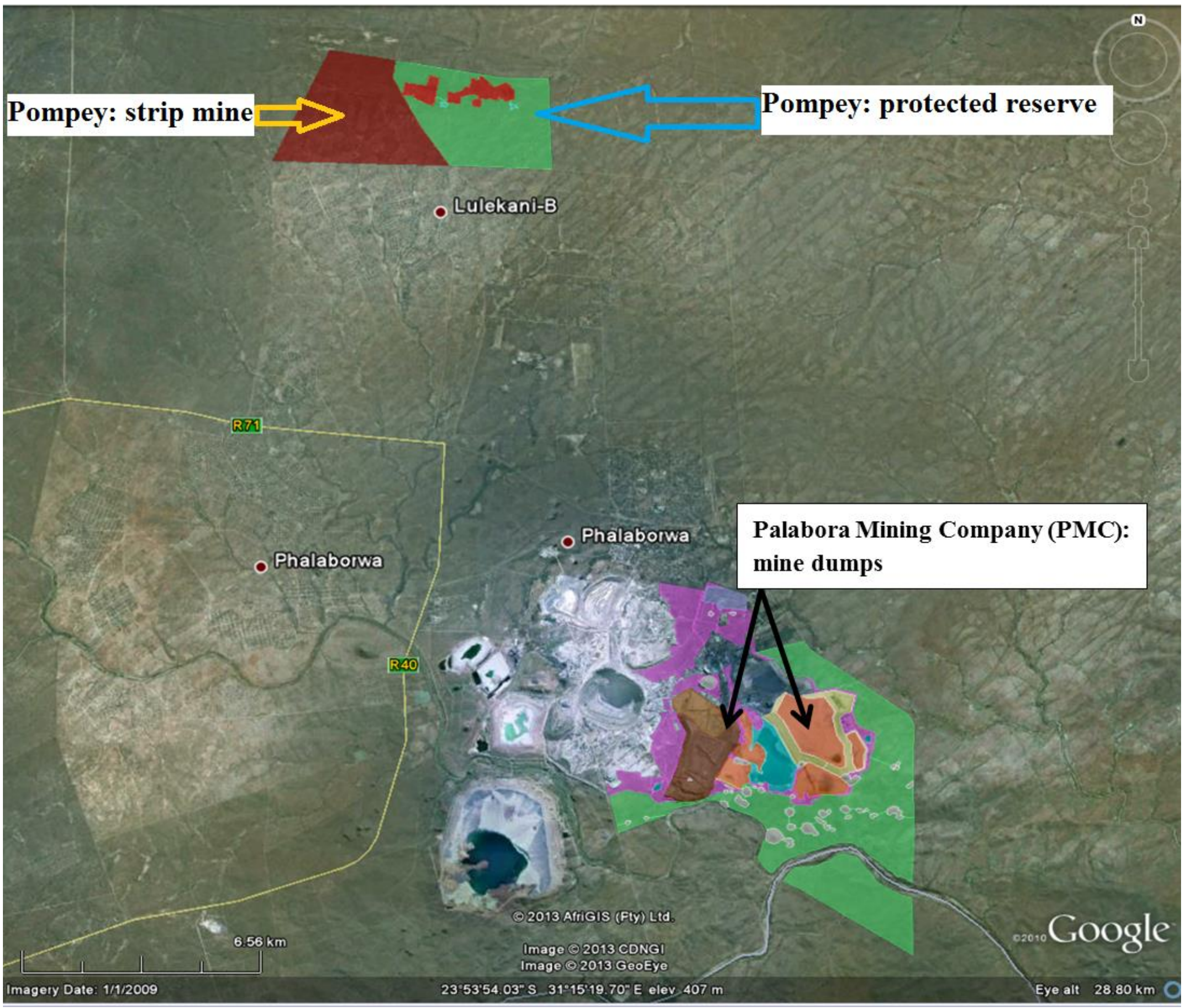


Figure 3: Map of the study area indicating division of Pompey strip mine and protected reserve on a regional scale.

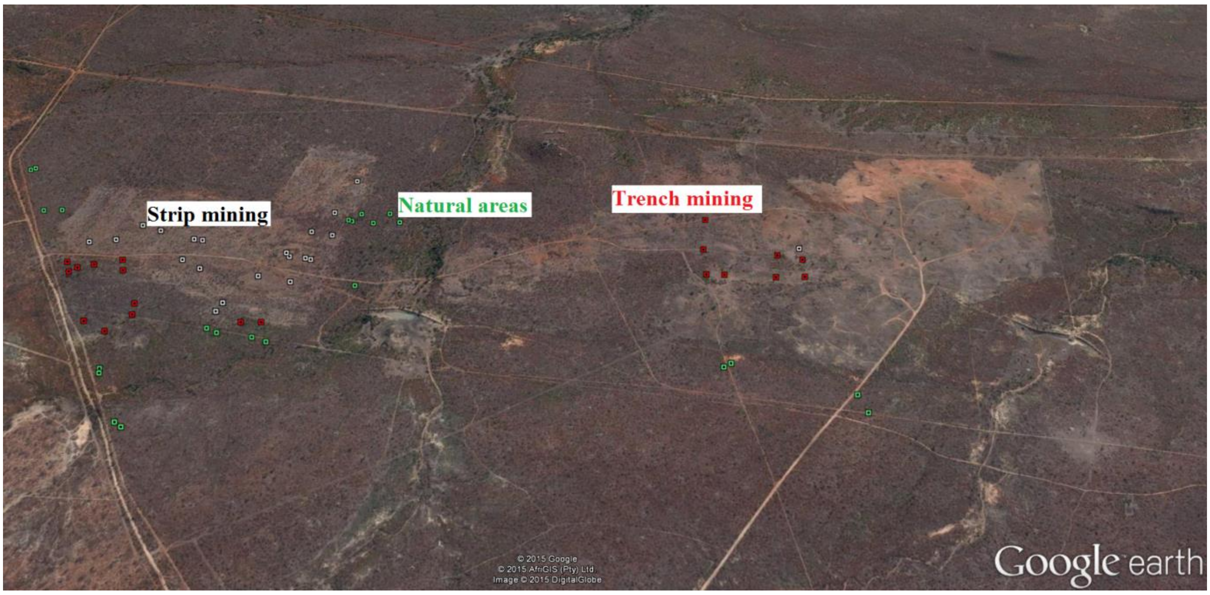


Figure 4: Positioning and GPS coordinates of the 1m² plots of herbaceous species sampling across treatments namely, strip mining, natural areas, and trench mining in Pompey.

Figure 5: 1m² fixed frame quadrat used to sample herbaceous vegetation in Pompey.

Figure 6: Researchers sampling herbaceous vegetation in the study area.

Figure 7: 100cm² frame quadrat used to sample herbaceous biomass in Pompey.

Figure 8: A.P Goossens Herbarium specimen of *Urochloa mosambicensis* (Hack.) Dandy sampled in strip mined of Pompey.

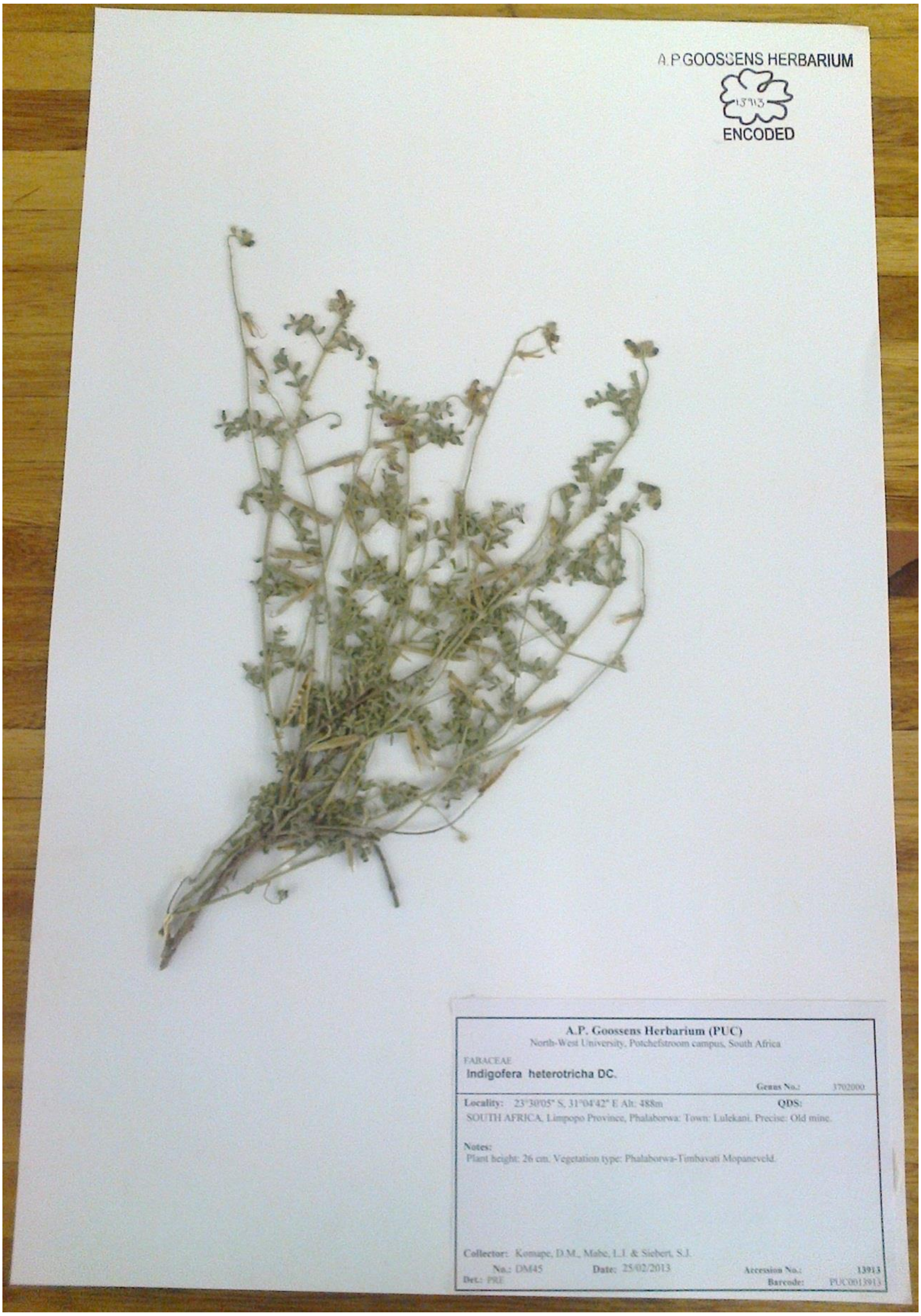


Figure 9: A.P Goossens Herbarium specimen of *Indigofera heterotricha* DC sampled in trench mined (also called Trench mined) in Pompey.

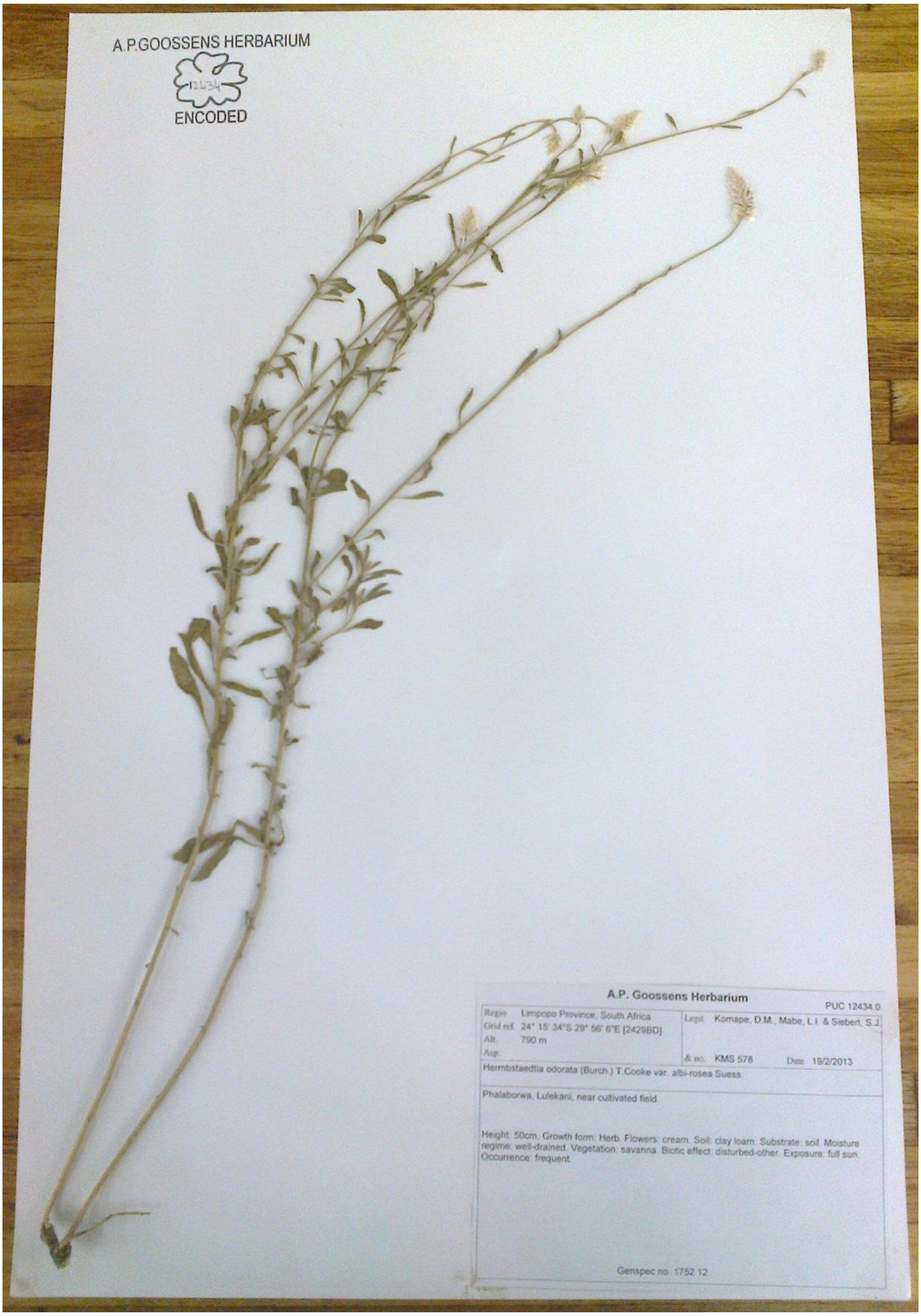


Figure 10: A.P Goossens Herbarium specimen of *Hermbstaedtia odorata* (Burch.) T.Cooke var. *albi-rosea* Suess sampled in natural areas of Pompey.

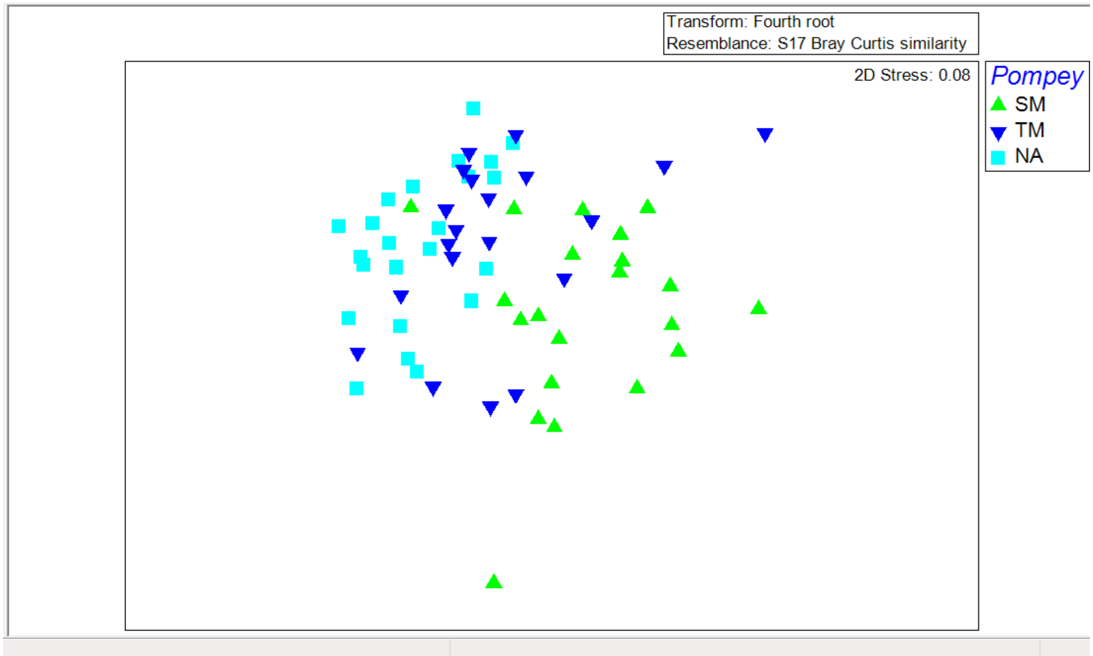
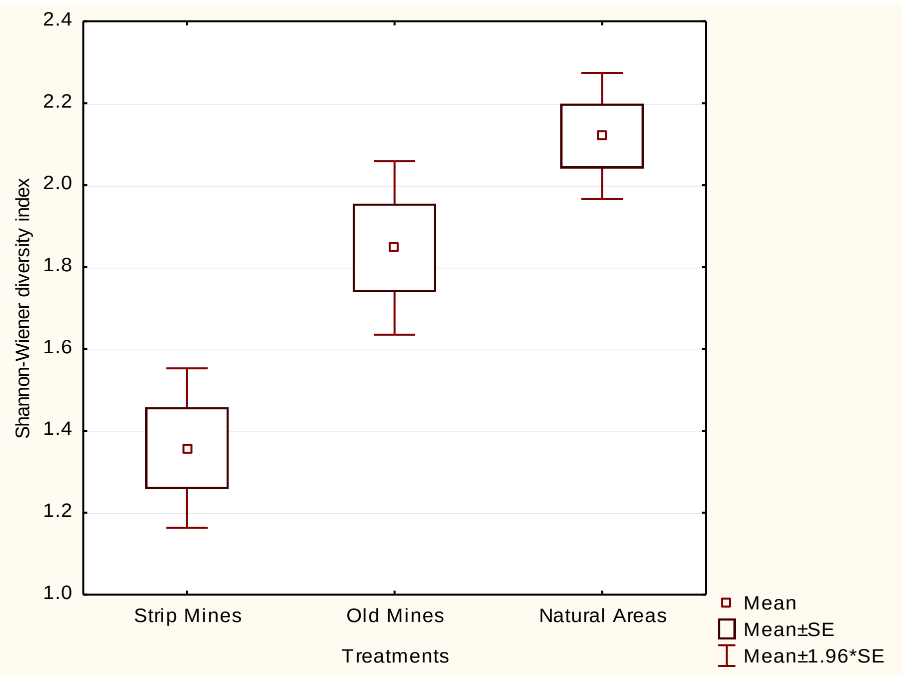


Figure 11. Multi-dimensional Scaling (MDS) scatterplots of species assemblages across study area.

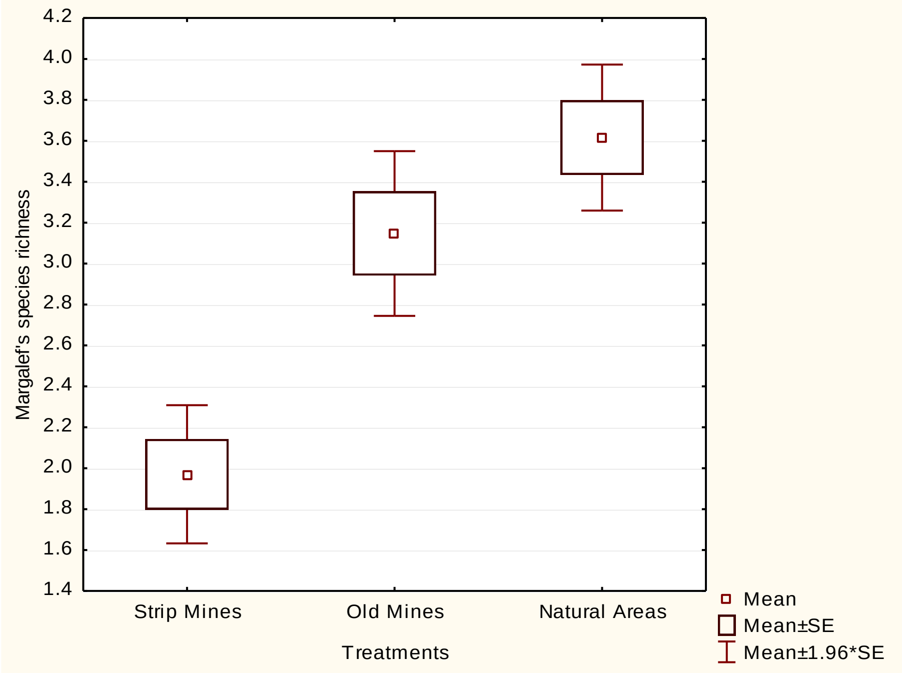
Species diversity:



±*

Figure 12: Mean Shannon-Wiener diversity index values (p= 0.000001) across three different treatments.

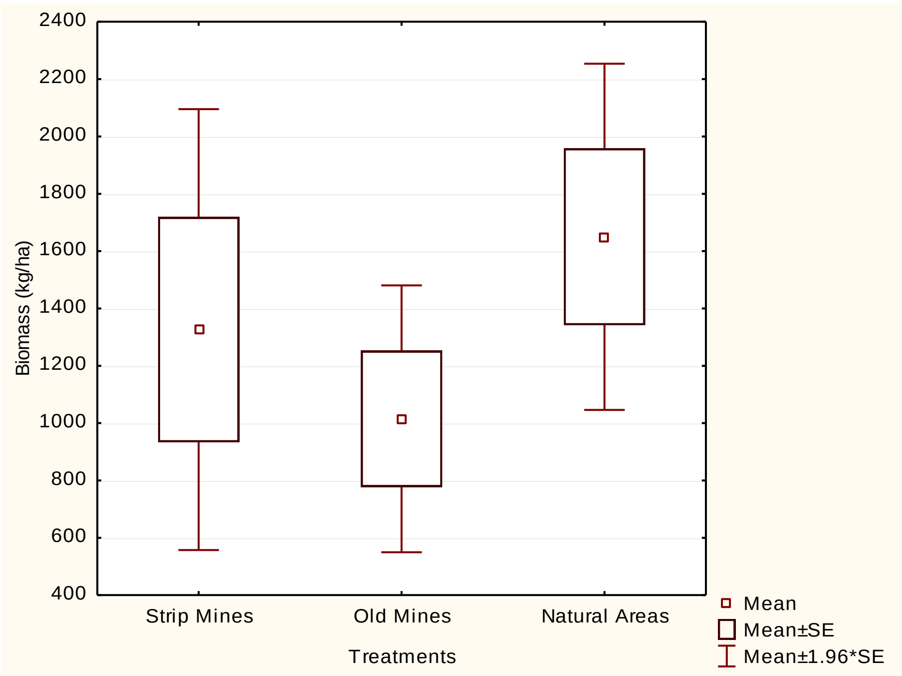
Species richness:



±*

Figure 13: Mean Margalef's species richness (p= 0.000000) across three different treatments.

Biomass :



±*

Figure 14: Mean biomass in Kilograms per hectare (p=0.4), statistically non-significant between three different treatments.

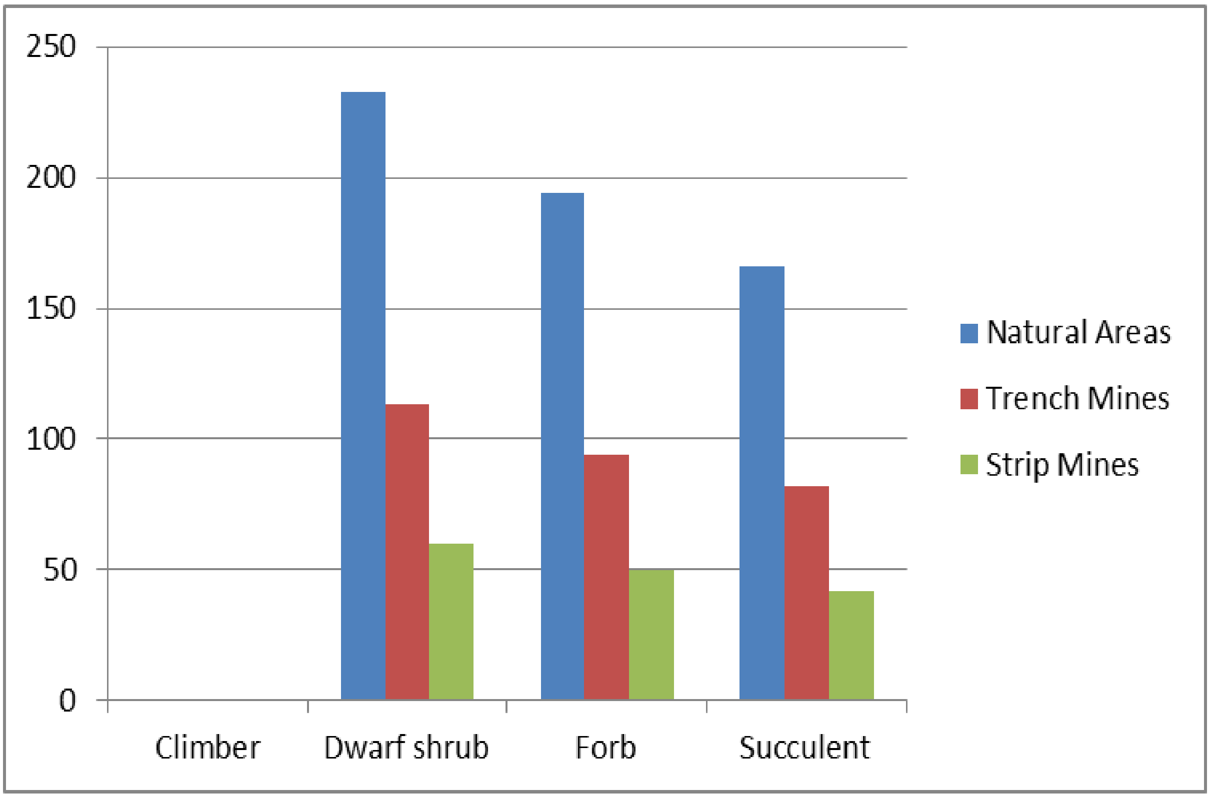


Figure 15: Growth forms of herbaceous vegetation across Pompey treatments.

Table 1: Five dominant herbaceous species recorded in strip mined of Pompey.

Strip mined sites		
Dominant herbaceous species	Percentage (%)	Number of records
Urochloa mosambicensis (Hack.) Dandy.	32	881
Aristida adscensionis L.	21	546
Aristida bipartita (Nees) Trin + Rupr.	7	187
Schmidtia pappophoroides Steud.	6	167
Ocimum americanum L. var. *americanum*	4	123
Total numbers of recorded species: 65		

Table 2: Five dominant herbaceous species recorded in trench mined of Pompey.

Trench mined sites		
Dominant herbaceous species	Percentage (%)	Number of records
Ocimum americanum L. var. *americanum*	21	461
Leucas glabrata (Vahl.) Sm. var. *glabrata*	8	177
Aristida adscensionis L.	5	115
Kyphocarpa angustifolia (Moq.) Lopr.	5	110
Brachiaria deflexa (Mez) Clayton.	4	83
Total numbers of recorded species: 102		

Table 3: Five dominant herbaceous species recorded in natural areas of Pompey.

Natural Areas		
Dominant herbaceous species	Percentage (%)	Number of records
Ocimum americanum L. var. *americanum*	7	97
Urochloa mosambicensis (Hack.) Dandy.	6	87
Panicum maximum Jacq.	5	79
Bothriochloa radicans (Lehm.) A.Camus.	4	63
Brachiaria xantholeuca (Schinz) Stapf.	4	55
Total numbers of recorded species: 108		

Table 4: Life forms of grasses and invasiveness of forbs in three treatments of Pompey.

	Strip mined sites	Trench mined sites	Natural areas
Annual grasses	7	12	6
Perennial grasses	13	19	24
Indigenous forbs	45	71	80
Exotic forbs	1	3	1

Table 5: Grass succession across three treatments of Pompey.

	Strip mined sites	Trench mined sites	Natural areas
Pioneers	11	13	8
Sub-climax	8	9	11
Climax	2	8	11

Table 6: Descriptive table of herbaceous biomass (kg/ha) across sampled treatments of Pompey.

Breakdown Table of Descriptive Statistics (Pompeye Variables) N=64 (No missing data in dep. var. list)			
Treatments	Biomass (kg/ha) Means	Biomass (kg/ha) N	Biomass (kg/ha) Std.Dev.
SM	1326.19(	21	1798.37(
OM	1015.00(	20	1061.91:
NA	1650.00(	23	1477.48:
All Grps	1345.31:	64	1482.48:

Table 7: One-way analysis of variance of the mean values of herbaceous species composition, species density, species evenness, species richness and diversity, biomass and height in Pompey. *df, degrees of freedom*; SS, sum of squared differences; MS, mean square; F, whether variability between and within treatments differ significantly; s.e., standard error; *p, p-values* significant relationships (p<0.05) are indicated with * across treatments.

Response	**Source**	***df***	**SS**	**MS**	**F**	***P***
Species composition	Treatment	2	384.5433	192.2716	10.30217	0.000140*
	s.e.	61	1138.457	18.66323	10.30217	0.000140*
Species density	Treatment	2	52024.73	26012.36	8.237941	0.000681*
	s.e.	61	192615.4	3157.629	8.237941	0.000681*
Species evenness	Treatment	2	0.389698	0.194849	11.83327	0.000045*
	s.e.	61	1.004437	0.016466	11.83327	0.000045*
Species richness	Treatment	2	31.10642	15.55321	20.94879	0.000000*
	s.e.	61	45.28881	0.742440	20.94879	0.000000*
Shannon diversity	Treatment	2	6.485322	3.242661	16.91335	0.000001*
	s.e.	61	11.69504	0.191722	16.91335	0.000001*
Biomass	Treatment	2	4324999	2162499	0.983441	0.379873
	s.e.	61	134133595	2198911	0.983441	0.379873
Height	Treatment	2	19105.95	9552.973	19.49079	0.000000*
	s.e.	61	29897.79	490.1277	19.49079	0.000000*

Table 8: Descriptive table of the mean values of herbaceous total number of species per plot 1m² across strip mining (SM), trench mined (OM) and natural areas (NA) in Pompey.

Breakdown Table of Descriptive Statistics (Pompeye Variat N=64 (No missing data in dep. var. list)			
Treatments	Total species Means	Total species N	Total species Std.Dev.
SM	10.3809!	21	3.57038:
OM	15.3000(	20	4.64644;
NA	15.8260(	23	4.63830:
All Grps	13.8750(	64	4.91676(

Table 9: One-way analysis of variance of the mean values of herbaceous percentage covers of forb, grass, dead material and bare soil in Pompey. *p*, *p-values* significant relationships ($p<0.05$) are indicated with * across treatments.

Percentage cover	*P-value*
Forb	0.305377
Grass	0.000004*
Dead material	0.000004*
Bare soil	0.005941*

Appendix 1: Species list of herbaceous layer recorded in Pompey treatments.

1. *Acalypha indica* L.
2. *Acanthaceae DM 46*
3. *Achyranthes aspera* L. var. *aspera*
4. *Acrotome hispida* Benth.
5. *Agathisanthemum bojeri* Klotzsch subsp. *bojeri*
6. *Andropogon gayanus* Kunth.
7. *Aptosimum lineare* Marloth & Engl. Var. *lineare*
8. *Aristida adscensionis* L.
9. *Aristida bipartita* (Nees) Trin + Rupr.
10. *Aristida congesta* Roem. & Schult. *barbicollis* (Trin & Rupr.) De Winter.
11. *Aristida scabrivalvis* Hack. subsp. *contracta* (De Winter) Melderis.
12. *Barleria lancifolia* T.Anderson.
13. *Bidens bipinnata* L.
14. *Blepharis integrifolia* (L.F.) E.Mey.ex *Schinz* var. *integrifolia*
15. *Bothriochloa insculpta* (Hochst. ex A. Rich.) A. Camus.
16. *Bothriochloa radicans* (Lehm.) A.Camus.
17. *Brachiaria deflexa* (Mez) Clayton.
18. *Brachiaria xantholeuca* (Schinz) Stapf.
19. *Bulbostylis humilis* (Kunth) C.B Clarke.
20. *Calostephane divaricata* Benth.
21. *Cenchrus ciliaris* L.
22. *Chamaecrista absus* (L.) Irwin & Barneby.
23. *Chloris roxburghiana* Schult.
24. *Chloris virgata* Sw.
25. *Chlorophytum recurvifolium* (Baker) C.Archer & Kativu.
26. *Cissus quadrangularis* L.
27. *Clerodendrum ternatum* Schinz.
28. *Commelina africana* L. var. *krebsiana* (Kunth) C.B. Clarke.
29. *Commelina benghalensis* L.
30. *Commelina livingstonii* C.B. Clarke.
31. *Corbichonia decumbens* (Forssk.) Exell.
32. *Corchorus asplenifolius* Bursh.
33. *Corchorus confusus* Wild.
34. *Crabbea velutina* S.Moore.

35. *Crotalaria sphaerocarpa* Perr. ex DC. subsp. *sphaerocarpa*
36. *Cucumis africanus* L.F.
37. *Cucumis anguria* L.var. *longaculeatus* J.H. Kirkbr.
38. *Cymbopogon caesius* (Hook. & Arn.) Stapf.
39. *Cyperus indecorus* Kunth var. *inflatus* (C.B. Clarke) Kok.
40. *Cyperus obtusiflorus* Vahl var. *obtusiflorus*
41. *Cyperus rupestris* Kunth var. *rupestris*
42. *Dactyloctenium aegyptium* (L.) Willd.
43. *Dactyloctenium australe* Steud.
44. *Dactylectenium geminatum* Hack.
45. *Dicoma tomentosa* Cass.
46. *Digitaria eriantha* Steud.
47. *Dolichos trilobus* L.subsp. *transvaalicus* Verdc.
48. *Enneapogon cenchroides* (Licht. ex Roem. & Schult.) C.E.Hubb.
49. *Enneapogon scoparius* Stapf.
50. *Enteropogon macrostachyus* (Hochst. ex A.Rich.) Munro ex Benth.
51. *Eragrostis gummiflua* (Nees).
52. *Eragrostis lehmanniana* Nees var. *lehmanniana*
53. *Eragrostis nindensis* Ficalho & Hiern.
54. *Eragrostis rigidior* Pilg.
55. *Eragrostis superba* Peyr.
56. *Eragrostis trichophora* Coss. & Durieu.
57. *Euphorbia neopolycnemoides* Pax & K.Hoffm.
58. *Evolvulus alsinoides* (L.) L.
59. *Fockea angustifolia* K.Schum.
60. *Gnidia rubescens* B.Peterson.
61. *Heliotropium ciliatum* L. Kaplan.
62. *Heliotropium lineare* (A.DC.) Gürke.
63. *Heliotropium strigosum* Willd.
64. *Hemizygia spp.* (Benth.) Briq.
65. *Hermannia boraginiflora* Hook.
66. *Hermannia glanduligera* K.Schum.
67. *Hermbstaedtia odorata* (Burch.) T.Cooke var. *albi-rosea* Suess.
68. *Heteropogon contortus* (L.) Roem. & Schult.
69. *Hibiscus micranthus* L.f.
70. *Hibiscus sidiformis* Baill.
71. *Hybanthus enneaspermus* (L.) F. Muell. var. *enneaspermus*
72. *Hyperthelia dissoluta* (Nees) W.P. Clayton.
73. *Indigastrum costatum* (Guill. &. Perr.) subsp. *macrum.* (E.Mey.) Schrire.
74. *Indigofera heterotricha* DC.
75. *Indigofera nebrowniana* J.B.Gillett.
76. *Indigofera rhytidocarpa* Benth. ex Harv. *subsp. rhytidocarpa*
77. *Indigofera trita* L.F. subsp. *subulata* (Vahl. ex Poir) Ali.
78. *Indigofera vicioides* Jaub. & Spach var. *rogersii* (R.E.Fr.) J.B Gillett.
79. *Ipomoea cairica* (L.)
80. *Ipomoea magnusiana* Schinz.
81. *Ipomoea obscura*(L.) Ker-Gawl.
82. *Ipomoea plebeia* R.Br.
83. *Ipomoea sinensis* (Desr.) Choisy subsp. *blepharosepala* (Hochst. ex. ARich.) Verdc.
84. *Justicia flava* (Vahl.) Vahl.

85. *Justicia matammensis* (Schweinf.) Oliv.
86. *Justicia protracta* (Nees) T.Anderson subsp. *protracta*
87. *Kohautia virgata* (Willd.) Bremek.
88. *Kyllinga alba* (Nees).
89. *Kyphocarpa angustifolia* (Moq.) Lopr.
90. *Lantana rugosa* Thunb.
91. *Ledebouria revoluta* (L.f.) Jessop.
92. *Leucas glabrata* (Vahl.) Sm. var. *glabrata*
93. *Leucas sexdentata* Skan.
94. *Limeum dinteri* G.Schellenb.
95. *Limeum viscosum* (J.Gay) Fenzl. subsp. *viscosum* var. *viscosum*
96. *Megalochlamys revoluta* (Lindau.) Vollesen subsp. *cognata* (N.E Br.) Vollesen.
97. *Melhania acuminata* Mast. var. *acuminata*
98. *Melhania prostata* DC.
99. *Melinis repens* (Willd.) Zizka subsp. *repens*
100. *Merremia palmata* Hallier f.
101. *Microcharis galpinii* N.E. Br.
102. *Mollugo cerviana* (L.) Ser. ex DC. var. *cerviana*
103. *Monsonia glauca* R.Kunth.
104. *Nidorella anomala* Steetz.
105. *Ocimum americanum* L. var. *americanum*
106. *Ocimum filamentosum* (Forssk.) Chiov.
107. *Ophioglossum polyphyllum* A, Braun.
108. *Oropetium capense* Stapf.
109. *Panicum coloratum* L. var. *coloratum*
110. *Panicum deustum* Thunb.
111. *Panicum maximum* Jacq.
112. *Pavonia burchellii* (DC.) R.A. Dyer.
113. *Pavonia transvaalensis* (Ulbr.) A.Meeuse.
114. *Phyllanthus incurvus* Thunb.
115. *Phyllanthus maderaspatensis* L.
116. *Phyllanthus parvulus* Sond. var. *garipensis* (E. Mey. ex. Dršge) Radcl –sm.
117. *Pogonarthria squarrosa* (Room. & Schult) Pilg.
118. *Polygala erioptera* DC.
119. *Polygala sphenoptera* Fresen. var. *sphenoptera*
120. *Portulaca hereroensis* Schinz.
121. *Portulaca oleracea* L.
122. *Portulaca quadrifida* L.
123. *Portulaca trianthemoides* Bremek.
124. *Pupalia lappacea* (L.) A.Juss. var. *lappacea*
125. *Rhinacanthus xerophilus* A.Meeuse.
126. *Rhynchosia minima* (L.) DC. var. *minima*
127. *Rhynchosia totta* (Thunb.) DC.
128. *Ruellia cordata* Thunb.
129. *Schmidtia pappophoroides* Steud.
130. *Secamone parvifolia* (Oliv.) Bullock.
131. *Seddera suffruticosa* (Schinz.) Hallier. F.
132. *Sericorema remotiflora* (Hook. F.) Lopr.
133. *Setaria pumila* (Poir.) Roem. & Schult.

134. *Sida ovata* Forssk.
135. *Solanum delagoense* Dunal.
136. *Sorghum versicolor Andersson*
137. *Spermacoce senensis* (Klotzsch) Hiern.
138. *Sporobolus fimbriatus* (Trin) Nees.
139. *Sporobolus nitens* Stent.
140. *Sporobolus panicoides* A.Rich.
141. *Streptopetalum serratum* Hochst.
142. *Talinum arnotii* Hook. F.
143. *Tephrosia purpurea* (L.) Pers. subsp. *leptostachya* (DC.) Brummitt var. *leptostachya*
144. *Themeda triandra* Forsk.
145. *Tragia rupestris* Sond.
146. *Tragus berteronianus* Schult.
147. *Tribulus terrestris* L.
148. *Tricholaena monachne* (Trin.) Stapf & C.E Hubb.
149. *Urochloa mosambicensis* (Hack.) Dandy.
150. *Urochloa oligotricha* (Fig. & De Not.) Henrad.
151. *Urochloa panicoides* P.Beauv.
152. *Vigna unguiculata* (L.) Walp. subsp. *dekindtiana* (Harms) Verdc. var. *leptostachya*
153. *Waltheria indica* L.
154. *Zornia glochidiata* DC.

Appendix 2: Herbaceous species recorded in strip mined sites of Pompey Silica Mine.

1. *Aristida adscensionis* L.
2. *Aristida bipartita* (Nees) Trin + Rupr.
3. *Aristida congesta* Roem. & Schult. *barbicollis* (Trin & Rupr.) De Winter.
4. *Blepharis integrifolia* (L.F.) E.Mey.ex Schinz var. *integrifolia*
5. *Brachiaria xantholeuca* (Schinz) Stapf.
6. *Calostephane divaricata* Benth.
7. *Cenchrus ciliaris* L.
8. *Chloris virgata* Sw.
9. *Commelina livingstonii* C.B. Clarke.
10. *Corbichonia decumbens* (Forssk.) Exell.
11. *Corchorus asplenifolius* Bursh.
12. *Corchorus confusus* Wild.
13. *Cucumis africanus* L.F.
14. *Cucumis anguria* L.var. *longaculeatus* J.H. Kirkbr.
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19. *Dolichos trilobus* L.subsp. *transvaalicus* Verdc.
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21. *Enneapogon scoparius* Stapf.
22. *Eragrostis nindensis* Ficalho & Hiern.
23. *Eragrostis rigidior* Pilg.
24. *Evolvulus alsinoides* (L.) L.
25. *Eragrostis lehmanniana Nees var. lehmanniana*

26. *Heliotropium strigosum* Willd.
27. *Hermbstaedtia odorata* (Burch.) T.Cooke var. *albi-rosea* Suess.
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35. *Kyphocarpa angustifolia* (Moq.) Lopr.
36. *Leucas glabrata* (Vahl.) Sm. var. *glabrata*
37. *Leucas sexdentata* Skan.
38. *Limeum dinteri* G.Schellenb.
39. *Limeum viscosum* (J.Gay) Fenzl. subsp. *viscosum* var. *viscosum*
40. *Microcharis galpinii* N.E Br.
41. *Nidorella anomala* Steetz.
42. *Ocimum americanum* L. var. *americanum*
43. *Ocimum filamentosum* (Forssk.) Chiov.
44. *Panicum maximum* Jacq.
45. *Phyllanthus incurvus* Thunb.
46. *Phyllanthus maderaspatensis* L.
47. *Phyllanthus parvulus* Sond. var. *garipensis* (E. Mey. ex. Dršge) Radcl –sm.
48. *Polygala erioptera* DC.
49. *Portulaca hereroensis* Schinz.
50. *Portulaca oleracea* L.
51. *Polygala sphenoptera* Fresen. var. *sphenoptera*
52. *Portulaca quadrifida* L.
53. *Pupalia lappacea* (L.) A.Juss. var. *lappacea*
54. *Schmidtia pappophoroides* Steud.
55. *Sericorema remotiflora* (Hook. F.) Lopr.
56. *Sida ovata* Forssk.
57. *Solanum delagoense* Dunal.
58. *Sporobolus nitens* Stent.
59. *Talinum arnotii* Hook. F.
60. *Tephrosia purpurea* (L.) Pers. subsp. *leptostachya* (DC.) Brummitt var. *leptostachya*
61. *Tragus berteronianus* Schult.
62. *Tribulus terrestris* L.
63. *Urochloa mosambicensis* (Hack.) Dandy.
64. *Urochloa panicoides* P.Beauv.
65. *Zornia glochidiata* DC.

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2. *Acanthaceae DM 46*
3. *Achyranthes aspera* L. var. *aspera*
4. *Acrotome hispida* Benth.
5. *Agathisanthemum bojeri* Klotzsch subsp. *bojeri*
6. *Andropogon gayanus* Kunth.
7. *Aptosimum lineare* Marloth & Engl. Var. *lineare*
8. *Aristida adscensionis* L.

9. *Aristida bipartita* (Nees) Trin + Rupr.
10. *Aristida congesta* Roem. & Schult. *barbicollis* (Trin & Rupr.) De Winter.
11. *Aristida scabrivalvis* Hack. subsp. *contracta* (De Winter) Melderis.
12. *Barleria lancifolia* T.Anderson.
13. *Blepharis integrifolia (L.F.) E.Mey.ex Schinz var. integrifolia*
14. *Brachiaria deflexa* (Mez) Clayton.
15. *Brachiaria xantholeuca* (Schinz) Stapf.
16. *Bulbostylis humilis* (Kunth) C.B Clarke.
17. *Calostephane divaricata* Benth.
18. *Cenchrus ciliaris* L.
19. *Chloris virgata* Sw.
20. *Chlorophytum recurvifolium* (Baker) C.Archer & Kativu.
21. *Cissus quadrangularis* L.
22. *Clerodendrum ternatum* Schinz.
23. *Commelina africana* L. var. *krebsiana* (Kunth) C.B. Clarke.
24. *Commelina benghalensis* L.
25. *Commelina livingstonii* C.B. Clarke.
26. *Corchorus asplenifolius* Bursh.
27. *Corchorus confusus* Wild.
28. *Crabbea velutina* S.Moore.
29. *Crotalaria sphaerocarpa* Perr. ex DC. subsp. *sphaerocarpa*
30. *Cucumis anguria* L.var. *longaculeatus* J.H. Kirkbr.
31. *Cymbopogon caesius* (Hook. & Arn.) Stapf.
32. *Cyperus indecorus* Kunth var. *inflatus* (C.B. Clarke) Kok.
33. *Cyperus rupestris* Kunth var. *rupestris*
34. *Dicoma tomentosa* Cass.
35. *Digitaria eriantha* Steud.
36. *Enneapogon cenchroides* (Licht. ex Roem. & Schult.) C.E.Hubb.
37. *Enneapogon scoparius* Stapf.
38. *Enteropogon macrostachyus* (Hochst. ex A.Rich.) Munro ex Benth.
39. *Eragrostis gummiflua* (Nees).
40. *Eragrostis rigidior* Pilg.
41. *Eragrostis trichophora* Coss. & Durieu.
42. *Euphorbia neopolycnemoides* Pax & K.Hoffm.
43. *Evolvulus alsinoides* (L.) L.
44. *Fockea angustifolia* K.Schum.
45. *Gnidia rubescens* B.Peterson.
46. *Heliotropium lineare* (A.DC.) Gürke.
47. *Heteropogon contortus* (L.) Roem. & Schult.
48. *Hibiscus micranthus* L.f.
49. *Hibiscus sidiformis* Baill.
50. *Hybanthus enneaspermus* (L.) F. Muell. var. *enneaspermus*
51. *Indigofera heterotricha* DC.
52. *Indigofera rhytidocarpa* Benth. ex Harv. *subsp. rhytidocarpa*
53. *Indigofera trita* L.F. subsp. *subulata* (Vahl. ex Poir) Ali.
54. *Indigofera vicioides* Jaub. & Spach var. *rogersii* (R.E.Fr.) J.B Gillett.
55. *Ipomoea obscura* (L.) Ker-Gawl.
56. *Justicia protracta* (Nees) T.Anderson subsp. *protracta*
57. *Kohautia virgata* (Willd.) Bremek.
58. *Kyllinga alba* (Nees).

59. *Kyphocarpa angustifolia* (Moq.) Lopr.
60. *Lantana rugosa* Thunb.
61. *Ledebouria revoluta* (L.f.) Jessop.
62. *Leucas glabrata* (Vahl.) Sm. var. *glabrata*
63. *Leucas sexdentata* Skan.
64. *Megalochlamys revoluta* (Lindau.) Vollesen subsp. *cognata* (N.E Br.) Vollesen.
65. *Melhania prostata* DC.
66. *Melinis repens* (Willd.) Zizka subsp. *repens*
67. *Microcharis galpinii* N.E. Br.
68. *Mollugo cerviana* (L.) Ser. ex DC. var. *cerviana*
69. *Monsonia glauca* R.Kunth.
70. *Ocimum americanum* L. var. *americanum*
71. *Ocimum filamentosum* (Forssk.) Chiov.
72. *Oropetium capense* Stapf.
73. *Panicum coloratum* L. var. *coloratum*
74. *Panicum maximum* Jacq.
75. *Pavonia transvaalensis* (Ulbr.) A.Meeuse.
76. *Phyllanthus incurvus* Thunb.
77. *Phyllanthus maderaspatensis* L.
78. *Phyllanthus parvulus* Sond. var. *garipensis* (E. Mey. ex. Dršge) Radcl –sm.
79. *Polygala erioptera* DC.
80. *Polygala sphenoptera* Fresen. var. *sphenoptera*
81. *Portulaca trianthemoides* Bremek.
82. *Pupalia lappacea* (L.) A.Juss. var. *lappacea*
83. *Rhynchosia totta* (Thunb.) DC.
84. *Ruellia cordata* Thunb.
85. *Schmidtia pappophoroides* Steud.
86. *Seddera suffruticosa* (Schinz.) Hallier. F.
87. *Setaria pumila* (Poir.) Roem. & Schult.
88. *Solanum delagoense* Dunal.
89. *Spermacoce senensis* (Klotzsch) Hiern.
90. *Sporobolus fimbriatus* (Trin) Nees.
91. *Sporobolus panicoides* A.Rich.
92. *Streptopetalum serratum* Hochst.
93. *Talinum arnotii* Hook. F.
94. *Tephrosia purpurea* (L.) Pers. subsp. *leptostachya* (DC.) Brummitt var. *leptostachya*
95. *Tragia rupestris* Sond.
96. *Tragus berteronianus* Schult.
97. *Tricholaena monachne* (Trin.) Stapf & C.E Hubb.
98. *Urochloa mosambicensis* (Hack.) Dandy.
99. *Urochloa panicoides* P.Beauv.
100. *Vigna unguiculata* (L.) Walp. subsp. *dekindtiana* (Harms) Verdc. var. *leptostachya*
101. *Waltheria indica* L.
102. *Zornia glochidiata* DC.

Appendix 4: Herbaceous species recorded in Pompey protected reserve (Natural areas of Mopaneveld).

1. *Acalypha indica* L.
2. *Acrotome hispida* Benth.

3. *Aptosimum lineare* Marloth & Engl. Var. *lineare*
4. *Aristida adscensionis* L.
5. *Aristida bipartita* (Nees) Trin + Rupr.
6. *Aristida congesta* Roem. & Schult. *barbicollis* (Trin & Rupr.) De Winter.
7. *Aristida scabrivalvis* Hack. subsp. *contracta* (De Winter) Melderis.
8. *Bidens bipinnata* L.
9. *Blepharis integrifolia* (L.F.) E.Mey.ex *Schinz* var. *integrifolia*
10. *Bothriochloa insculpta* (Hochst. ex A. Rich.) A. Camus.
11. *Bothriochloa radicans* (Lehm.) A.Camus.
12. *Brachiaria xantholeuca* (Schinz) Stapf.
13. *Bulbostylis humilis* (Kunth) C.B Clarke.
14. *Calostephane divaricata* Benth.
15. *Cenchrus ciliaris* L.
16. *Chamaecrista absus* (L.) Irwin & Barneby.
17. *Chloris roxburghiana* Schult.
18. *Clerodendrum ternatum* Schinz.
19. *Commelina africana* L. var. *krebsiana* (Kunth) C.B. Clarke.
20. *Commelina benghalensis* L.
21. *Commelina livingstonii* C.B. Clarke.
22. *Corbichonia decumbens* (Forssk.) Exell.
23. *Corchorus asplenifolius* Bursh.
24. *Corchorus confusus* Wild.
25. *Crabbea velutina* S.Moore.
26. *Cucumis anguria* L.var. *longaculeatus* J.H. Kirkbr.
27. *Cyperus obtusiflorus* Vahl var. *obtusiflorus*
28. *Dicoma tomentosa* Cass.
29. *Digitaria eriantha* Steud.
30. *Dolichos trilobus* L.subsp. *transvaalicus* Verdc.
31. *Enneapogon cenchroides* (Licht. ex Roem. & Schult.) C.E.Hubb.
32. *Enneapogon scoparius* Stapf.
33. *Enteropogon macrostachyus* (Hochst. ex A.Rich.) Munro ex Benth.
34. *Eragrostis rigidior* Pilg.
35. *Eragrostis superba* Peyr.
36. *Euphorbia neopolycnemoides* Pax & K.Hoffm.
37. *Evolvulus alsinoides* (L.) L.
38. *Heliotropium ciliatum* L. Kaplan.
39. *Hemizygia spp.* (Benth.) Briq.
40. *Hermannia boraginiflora* Hook.
41. *Hermannia glanduligera* K.Schum.
42. *Hermbstaedtia odorata* (Burch.) T.Cooke var. *albi-rosea* Suess.
43. *Heteropogon contortus* (L.) Roem. & Schult.
44. *Hibiscus micranthus* L.f.
45. *Hibiscus sidiformis* Baill.
46. *Hyperthelia dissoluta* (Nees) W.P. Clayton.
47. *Indigastrum costatum* (Guill. &. Perr.) subsp. *macrum.* (E.Mey.) Schrire.
48. *Indigofera heterotricha* DC.
49. *Indigofera nebrowniana* J.B.Gillett.
50. *Indigofera trita* L.F. subsp. *subulata* (Vahl. ex Poir) Ali.
51. *Indigofera vicioides* Jaub. & Spach var. *rogersii* (R.E.Fr.) J.B Gillett.
52. *Ipomoea cairica* (L.)

53. *Ipomoea magnusiana* Schinz.
54. *Ipomoea obscura*(L.) Ker-Gawl.
55. *Ipomoea plebeia* R.Br.
56. *Ipomoea sinensis* (Desr.) Choisy subsp. *blepharosepala* (Hochst. ex. ARich.) Verdc.
57. *Justicia flava* (Vahl.) Vahl.
58. *Justicia matammensis* (Schweinf.) Oliv.
59. *Justicia protracta* (Nees) T.Anderson subsp. *protracta*
60. *Kohautia virgata* (Willd.) Bremek.
61. *Kyllinga alba* (Nees).
62. *Kyphocarpa angustifolia* (Moq.) Lopr.
63. *Lantana rugosa* Thunb.
64. *Ledebouria revoluta* (L.f.) Jessop.
65. *Leucas glabrata* (Vahl.) Sm. var. *glabrata*
66. *Leucas sexdentata* Skan.
67. *Limeum viscosum* (J.Gay) Fenzl. subsp. *viscosum* var. *viscosum*
68. *Megalochlamys revoluta* (Lindau.) Vollesen subsp. *cognata* (N.E Br.) Vollesen.
69. *Melhania acuminata* Mast. var. *acuminata*
70. *Melhania prostata* DC.
71. *Merremia palmata* Hallier f.
72. *Microcharis galpinii* N.E. Br.
73. *Ocimum americanum* L. var. *americanum*
74. *Ocimum filamentosum* (Forssk.) Chiov.
75. *Ophioglossum polyphyllum* A, Braun.
76. *Oropetium capense* Stapf.
77. *Panicum coloratum* L. var. *coloratum*
78. *Panicum deustum* Thunb.
79. *Panicum maximum* Jacq.
80. *Pavonia burchellii* (DC.) R.A. Dyer.
81. *Phyllanthus incurvus* Thunb.
82. *Phyllanthus maderaspatensis* L.
83. *Phyllanthus parvulus* Sond. var. *garipensis* (E. Mey. ex. Dršge) Radcl –sm.
84. *Pogonarthria squarrosa* (Room. & Schult) Pilg.
85. *Polygala erioptera* DC.
86. *Pupalia lappacea* (L.) A.Juss. var. *lappacea*
87. *Rhinacanthus xerophilus* A.Meeuse.
88. *Rhynchosia minima* (L.) DC. var. *minima*
89. *Rhynchosia totta* (Thunb.) DC.
90. *Ruellia cordata* Thunb.
91. *Schmidtia pappophoroides* Steud.
92. *Secamone parvifolia* (Oliv.) Bullock.
93. *Setaria pumila* (Poir.) Roem. & Schult.
94. *Sida ovata* Forssk.
95. *Solanum delagoense* Dunal.
96. *Sorghum versicolor Andersson*
97. *Sporobolus fimbriatus* (Trin) Nees.
98. *Streptopetalum serratum* Hochst.
99. *Talinum arnotii* Hook. F.
100. *Tephrosia purpurea* (L.) Pers. subsp. *leptostachya* (DC.) Brummitt var. *leptostachya*
101. *Themeda triandra* Forsk.

102. *Tragia rupestris* Sond.
103. *Tragus berteronianus* Schult.
104. *Urochloa mosambicensis* (Hack.) Dandy.
105. *Urochloa oligotricha* (Fig. & De Not.) Henrad.
106. *Vigna unguiculata* (L.) Walp. subsp. *dekindtiana* (Harms) Verdc. var. *leptostachya*
107. *Waltheria indica* L.
108. *Zornia glochidiata* DC.