The impact of cattle grazing on a recently rehabilitated grassland ecosystem in an open cast coal mine in Mpumalanga, South Africa.

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Executive summary

Rehabilitated areas from open cast coal mines are often utilized as planted pastures for cattle grazing. There are, however, challenges with the productivity and stability of these pastures emanating from stockpiling of the topsoil and its subsequent return to the area. The soil compaction and crust formation which often result from this process lead to poor growth performance of the grass sward. As a result such areas can only support a limited number of cattle and they carry a high risk of overgrazing followed by land degradation. The present study was designed to examine the impact of grazing by cattle on the development of the vegetation after rehabilitation of Block I at Khutala Collieries near Ogies, Mpumalanga. For this aim we set up ten 'exclosures', which are 5 x 5 m areas where grazers are excluded by a fence. Inside and outside each of these we determined the plant species composition and biomass. We also took soil samples. This was done in 2017 and repeated in 2018.

With regard to the plant species composition we found that many of the species that occur naturally in the area were missing and that there were many species present which are not listed for the area. Furthermore, most of the grass species found were indicative of overgrazing. The 2017 species and biomass data were used to estimate the carrying capacity of the area, which was compared to the grazing pressure based on the number and weight of the cattle grazing the area. According to this estimate the cattle herd was approximately three times what the area could support. Overgrazing is therefore highly likely.

To test whether the vegetation was developing in a particular direction we used a multivariate analysis approach which uses plant abundance data of all species to position a site in a two dimensional plot. When this is done repeatedly one can connect the points for a given site by arrows to determine in which 'direction' that site is developing. When this is done for a number of sites within an ecosystem it becomes possible to monitor where the ecosystem as a whole is developing towards. If one also includes the sites from a benchmark area in the analysis one can monitor whether the rehabilitated area is developing towards the benchmark area or not. This procedure was carried out with our data from 2017 and 2018. The result was ambivalent in that the arrows were pointing in all directions. The explanation for this may be that the period of one year between surveys is very short in vegetation succession terms and the pattern in the figure is mostly noise. Alternatively, it may mean that the system as a whole is not developing in any particular direction and each site is following its own trajectory. To decide between these two alternative explanations it is necessary to repeat the vegetation survey after 3 to 5 years (i.e.2020 – 2022).

Apart from the plant species composition and low biomass another sign of ecosystem degradation was the poor ground cover of the vegetation. On average the percentage bare ground was 56 in 2017 and 52 in 2018. In some patches, however, it was as high as 80. Over the one year between the first and the second the percentage bare ground decreased slightly, but we could not discern a significant effect of grazing. It is likely, however, that the effect of grazing (and trampling) will become apparent after a longer period of three to five years.

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1 Introduction

Coal mining companies are making considerable efforts to rehabilitate the landscape after open cast mining, recreating natural contours, returning the top soil, sowing grasses and controlling erosion. The ultimate aim of these efforts is to return the land to a state where it can be used again, either for agriculture or grazing [1]. However, the decision whether the land has reached that point is not easy to make. On the one hand the mines cannot afford to keep managing the areas for too long, on the other it may take a long time for the areas to be stabilised sufficiently for a handover. Thus, it is in the interest of the mines that the rehabilitation process is effective and efficient. Effective in this context means that the rehabilitation process leads to the goals which are set for it and efficient means that it does so in minimum time and at minimum cost.

The type of mining at the site where the research has been performed is strip mining. This means that mining and rehabilitation happen simultaneously and continuously. The mining/rehabilitation process consists of a number of steps. First the topsoil is removed and stockpiled. Then the same is done with the overburden. Then, after the coal has been removed, the overburden is returned to its original place and the contours of the landscape as much as possible restored. Following this the topsoil is restored and an attempt is made to revegetate the area.

After rehabilitation, vegetation succession commences, which is a process which takes place on a timescale of decades, if not centuries. This process is influenced by regular veld fires and grazing [2]. Natural grazing has an important function in grassland ecosystems in that it stimulates growth, prevents the accumulation of moribund material and promotes species diversity. However, grazing intensity in most natural systems is generally much lower than in meadows grazed by cattle. Such meadows are therefore vulnerable to overgrazing which may lead to veld degradation and erosion.

South Africa is blessed with a large body of research on grazing, its effects on the veld and veld management strategies [2-8]. However, not much is known about the effects of grazing on previously mined, newly rehabilitated areas. What has been established is that soil conditions in such areas are in many cases not conducive for plant growth, due to soil compaction and loss of fertility [9]. As a result, ground cover is poor, there is low species diversity and growth is slow. Under these conditions recovery of grass plants after being grazed will be slow. Thus, even at a moderate stocking rate, the production of the grasses may be lower than the consumption rate, which inevitably leads to overgrazing followed by deterioration of the veld. In addition, trampling of the soil by the cattle hoofs may lead to further compaction [10, 11]. On the other hand the manure which the cattle produce may improve the soil structure by increasing the organic matter content [12].

The two hypothesized effects of cattle on the rehabilitated veld are not necessarily mutually exclusive. Which one prevails would depend on the stocking rate and the grazing system used. When grazing is continuous, the negative effect may not occur at a very low stocking density, but if one is to increase the density a tipping point will be reached where the veld starts to deteriorate. In the case of rehabilitated veld this tipping point would be reached at a relatively low density.

The paragraph above is hypothetical and insufficient research has been performed on grazing at mining rehabilitation sites to be able to establish the ideal grazing regime which would aid the process of rehabilitation. Such research is complex and would require the researchers to control grazing intensities over periods of several years in a large number of experimental sites. The research presented here is meant to provide a starting point. It is relatively simple in that it contrasts grazing with no grazing in a rehabilitated mining area. Timing and intensity of the grazing, as well as interventions such as mowing or fertilization, are determined by the farmer who leases the camp where the experiment took place. The experiment consisted of erecting a number of exclosures in this camp and comparing the vegetation development inside the exclosures (ungrazed) with outside (grazed).

The rehabilitated areas at Khutala Collieries, in particular Block I, which has been rehabilitated from 2008 and where grazing commenced in 2012, offered an excellent opportunity for this research, which is intended to improve our understanding of the effect of grazing on rehabilitated veld.

2 Materials and methods

2.1 The research site

Khutala Collieries is an opencast coal mine which is situated 55 km west of Witbank in Mpumalanga. The main office buildings are located on the farm Cologne 34-IS. Khutala is located on the Witbank coalfields. The project study area is located on the farm Leeuwfontein and Schoongezicht. Site preparation was initiated in March 1984 and the first coal was mined in August 1986 with delivery to Kendal Power Station in November 1986. The mining area investigated is Block I which has Block I extension A and Block I extension B (Fig. 1). These blocks have been rehabilitated since mining ceased in 2005.

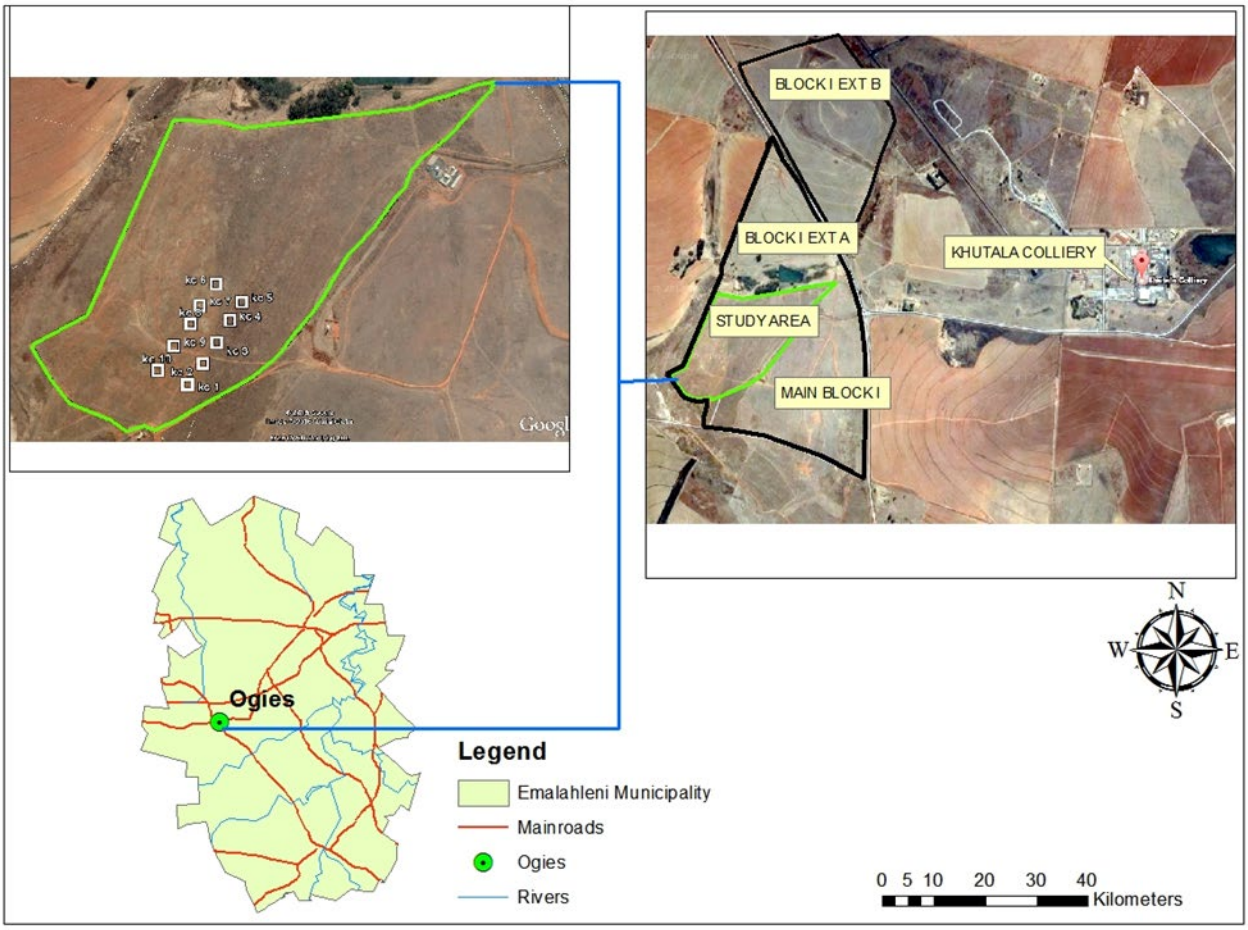

Figure 1 The research site

2.1.1 Vegetation

The vegetation in the area is classified as Eastern Highveld Grassland. Mucina and Rutherford [13] describe the landscape and vegetation in this vegetation unit as follows: Slightly to moderately undulating plains, including some low hills and pan depressions. The vegetation is short dense grassland dominated by the usual highveld grass composition (*Aristida, Digitaria, Eragrostis, Themeda, Tristachya* etc.) with small, scattered rocky outcrops with wiry, sour grasses and some woody species (*Senegalia caffra, Celtis africana, Diospyros lycioides* subsp. *lycioides, Parinari capensis, Protea caffra, P. welwitschii* and *Searsia magalismontanum*).

2.1.2 Climate

Strongly seasonal summer rainfall, with very dry winters. The mean annual precipitation (MAP) varies between 650 and 900 mm (overall average: 726 mm) and is relatively uniform across most of this vegetation unit, but increases significantly in the extreme southeast. The coefficient of variation in MAP is 25% across most of the unit, but drops to 21% in the east and southeast. Incidence of frost from 13 to 42 days, but higher at higher elevations [13].

2.1.3 Altitude

The region is situated within an altitudinal range of 1 520–1 780 m, but also as low as 1 300 m asl [13].

2.1.4 Land use

The dominant land use in the study area is livestock farming, primarily with cattle in the commercial farms and mixed herds of cattle, sheep and goats in the communal farms [14].

2.1.5 Geology

Khutala Collieries is located on the Witbank Coalfield which is one of the major coalfields in South Africa. The geology of this coalfield is made up of dolerite sills generally about 50 m thick, which occur throughout the coalfield and caused large-scale displacements where they intersect the coal seams. There is an important dyke in the area, the well-known Ogies Dyke which is about 15 m thick [15]. There are five major seams that are mined in this area. The depths of these seams for underground mining ranges from about 30 metres to about 110 metres. The number 1 seam is about 1.5 to 2.0 m thick. The number 2 seam has an average thickness of 6 m, The number 3 seam is about 0.5m, The number 4 seam is 2.5 m to 5.0 m thick and widens to the west where it is in excess of 6.0 m and the number 5 seam has an average thickness of 1.5 m to 2.0 m. The latter is found approximately 25 m above the No. 4 seam and is on average 30 m below the surface [16].

2.1.6 The site

The research took place at Khutala Collieries in Ogies, Mpumalanga. It is partly an open-cast coalmine. After mining the open-cast pits are rehabilitated by reshaping the landscape and restoring the topsoil which was stockpiled during mining operations. The soil is then planted with grasses. Eventually, after the area has been stabilised, the land is returned to the community. Our research is located in Khutala, Block I, which had been rehabilitated in 2008.

2.2 The exclosure experiment

In November 2016 ten 5 x 5m exclosures were placed in the area along two parallel elevational transects (Fig. 1 & 2). The exclosures are spaced evenly along the transects. Both inside and outside each exclosure three vegetation surveys were carried out at random points using a 1m^2 steel frame.

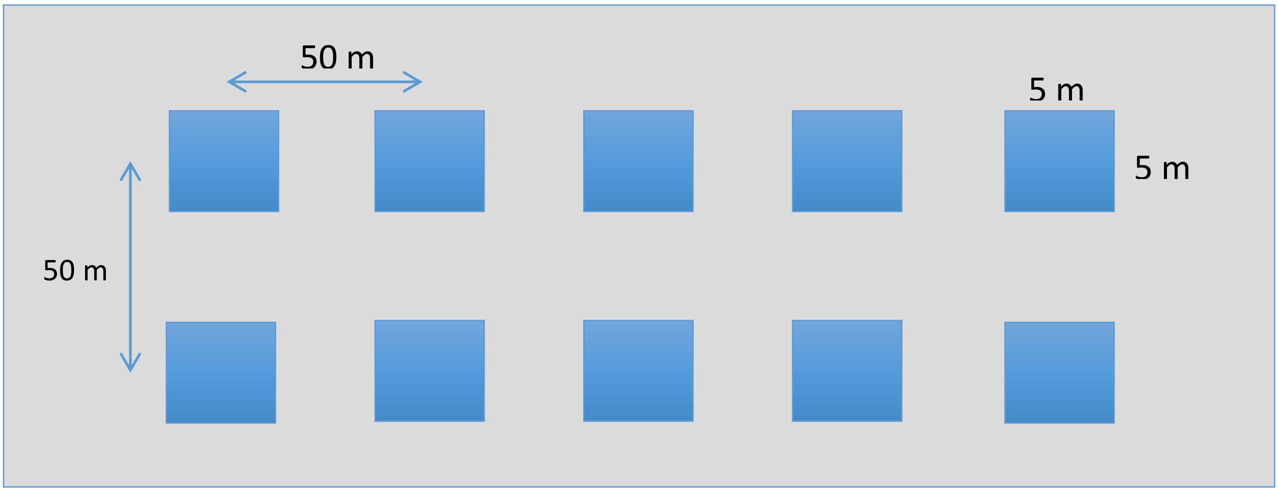

Figure 2 Arrangement of the exclosures in two parallel transects. The exclosures are not drawn to scale.

The areas covered by the various plant species as well as bare patches were sketched in 100 x 100 mm frames on graph paper after which for each species the cover percentage was determined. To measure the biomass we used a disc pasture meter. We dropped it in each of 4 quadrants of the quadrat after which we recorded the average of the four readings. We converted the readings to biomass using a table in [17], which is based on calibrations done in the Kruger National Park. For each exclosure we also took two random soil samples; one inside and one outside the exclosure. The soil samples were subsequently sent to an accredited soil laboratory for analysis.

2.3 Benchmarking

In 2018 two benchmark areas were identified (Fig. 3). Farm1 is an unmined area with planted pastures. Farm 2 is a natural intact land which is not mined or planted with pasture. The common activity in these farms is grazing, although the grazing intensity differs between the farms.

Figure 3 Location of the benchmark sites

At Farm1 two 50 x 20m areas were selected in each of which 10 random sample points were selected for vegetation surveys which were carried out in the way described in section 2.2. Biomass was also measured and at each sample point a soil sample was taken. At Farm 2 the same was done except that there was one 50 x 20m plot where 10 sample points were selected.

2.4 The herd

The experimental area was grazed by 130 head of cattle, which varied in size from calves to full-grown bulls. To estimate the grazing intensity of this herd we needed to convert its number to animal units. For this purpose, the mass of each animal was estimated by the farmer after which all masses were summed to obtain the total mass of the herd. This number was divided by the mass of one animal unit, for which we used the standard value of 450 kg [17]. Information on the periods over which the experimental area was grazed and other information about management of the area, such as grass cutting or fertilization, was obtained from the farmer.

2.5 Soil sampling and analysis

During the 2017 surveys we took 20 top soil samples using a sampling augur. Of these samples 10 were taken at random points inside each exclosure and 10 others outside of each within four meters from the perimeter. The depth to which the augur was sunk was approximately 20 cm. The samples were analysed for pH, electrical conductivity, nutrients and texture.

2.6 Data analysis

The gazing regime of the herd will be obtained through key informant interview with the farmer. The number of grazing units in the herd was determined by estimating cow weights by eye (by a specialist) and dividing the total weight of the herd by 450 kg, and this number will be compared with the carrying capacity of the area.

The effect of grazing was analysed by comparing all univariate variables measured inside and outside the exclosures (biomass, area of bare ground, species richness) in two-way repeated measure ANOVAs using exclosure (in/out) as one factor and exclosure number as another.

The multivariate data (cover percentages by species) were analysed using the method described in [18].

3 Results and Discussion

3.1 Plant species composition

The plant species composition is of fundamental importance as it determines both biodiversity and the quality of the grazing. Table 1 lists the grass species identified in the experimental sites and the two benchmark sites. For each species the ecological status according to Van Oudtshoorn [19] has been indicated.

Table 1 Identified grass species in the experimental area and the two benchmark areas

Nr	Grass species name	Common name	Grazing value*	Ecological status*
1	*Agrostis eriantha*	Black bent	Low	Unknown
2	*Andropogon eucomus*	Snowflake grass	Low	Increaser III grass
3	*Chloris virgata*	Feather fingergrass	Average	Increaser III grass
4	*Cortaderia selloana*	Pampas grass	Low	Unknown
5	*Cynodon dactylon*	Couch grass	Low	Increaser II grass
6	*Digitaria erientha*	Finger grass	Low	Decreaser grass
7	*Eragrostis chloromelas*	Lehman lovegrass	Average	Increaser II grass
8	*Eragrostis gummiflua*	Love grass	Low	Increaser II grass
9	*Eragrostis plana*	Tough lovegrass	Low	Increaser II grass
10	*Eragrastis curvula*	Weeping lovegrass	Average	Increaser II grass
11	*Eustachys paspaloides*	Fan grass	High	Decreaser grass
12	*Hyparrhenia hirta*	Thatching grass	Average	Increaser I grass
13	*Imperata cylindrica*	Cogon grass	Low	Increaser I grass
14	*Panicum schinzii*	Bluegrass	High	Increaser II grass
15	*Paspalum dilatatum*	Dallies grass	High	Exotic grass
16	*Pennisetum clandestinum*	Kikuyu grass	High	Exotic grass
17	*Setaria pumila*	Pigeon grass	Average	Increaser II grass
18	*Sporobolus africanus*	Ratstail dropseed	Low	Increaser III grass
19	*Urochloa mocambicensis*	Bushveld signal grass	Average	Increaser II grass
20	*Urochloa panicoides*	Garden signal grass	Low	Increaser II grass

*According to [19]

The terms under ecological status have the following meanings:

Decreaser	Decreases in abundance when the area is underutilized or overgrazed, or the burning regime is inadequate.
Increaser I	Increases in abundance when there is underutilization or insufficient burning. Usually unpalatable climax species.
Increaser II	Increases in abundance when there is overgrazing or too frequent burning. Usually pioneer or subclimax species.
Increaser III	Unpalatable climax species which occur in overgrazed veld.
Exotic	Non-indigenous species

For comparison we have listed the grass species which should naturally occur in the area according to Mucina and Rutherford [13] (Table 2). Of these species only six have been identified in the experimental and benchmark sites. Furthermore, there are 14 species in Table 1 which have not been listed for the area by Mucina and Rutherford [13].

Table 2 Grass species characteristic for the Eastern Highveld Grassland [13]

Nr	Species	Ecological status	Nr	Species	Ecological status
1	*Aristida aequiglumis*	Unknown	21	*Themeda triandra*	Decreaser
2	*A. congesta*	Increaser II	22	*Trachypogon spicatus*	Increaser I
3	*A. junciformis* subsp. *galpinii*	Increaser III	23	*Tristachya leucothrix*	Increaser I
4	*Brachiaria serrata*	Decreaser	24	*T. rehmannii*	Unknown
5	*Cynodon dactylon*	Increaser II	25	*Alloteropsis semialata* subsp. *eckloniana*	Increaser I
6	*Digitaria monodactyla*	Increaser II	26	*Andropogon appendiculatus*	Decreaser
7	*D. tricholaenoides*	Decreaser	27	*A. schirensis*	Increaser I
8	*Elionurus muticus*	Increaser III	28	*Bewsia biflora*	Unknown
9	*Eragrostis chloromelas*	Increaser II	29	*Ctenium concinnum*	Increaser I
10	*E. curvula*	Increaser II	30	*Diheteropogon amplectens*	Decreaser
11	*E. plana*	Increaser II	31	*Eragrostis capensis*	Increaser II
12	*E. racemosa*	Increaser II	32	*E. gummiflua*	Increaser II
13	*E. sclerantha*	Increaser II	33	*E. patentissima*	Unknown
14	*Heteropogon contortus*	Increaser II	34	*Harpochloa falx*	Increaser I
15	*Loudetia simplex*	Increaser II	35	*Panicum natalense*	Decreaser
16	*Microchloa caffra*	Increaser II	36	*Rendlia altera*	Increaser III
17	*Monocymbium ceresiiforme*	Decreaser	37	*Schizachyrium sanguineum*	Increaser I
18	*Setaria sphacelata*	Decreaser	38	*Setaria nigrirostris*	Unknown
19	*Sporobolus africanus*	Increaser III	39	*Urelytrum agropyroides*	Increaser I
20	*S. pectinatus*	Unknown			

dominant species
rare species

occurs in Table 1

With regard to the ecological status, only one species in table 1 is of the Decreaser type while all others are Increasers, Exotic or Status unknown. Of the species that are naturally occurring in the area there are eight out of 39 which are classified as Decreasers, of which five are common (Table 2). Of the six species table 2 has in common with Table 1, none are Decreasers.

The species abundances based on cover percentages are shown in Figure 4. *Eragrostis curvula* stands out as most abundant in all areas except benchmark site 2. Another abundant grass in all areas is *Cynodon dactylon*. *Hyparrhenia hirta*, in contrast, is highly abundant in the experimental area (Block I), but does not occur in the benchmark sites. *Pennisetum clandestinum* is also unique for Block I, but it was planted there to cover bare patches (Mabuduga, pers. comm.). Benchmark site 2 has a few unique species, such as *Andropogon eucomus*, *Agrostis eriantha, Eragrostis gummiflua* and *Imperata cylindrica* which occur at moderate densities. *Setaria pumila,* on the other hand, is unique for benchmark site 1 where it occurs at a low density. Comparing between Block I 2017 and 2018 we note a moderate increase in the density of forbs, while *Cynodon dactylus, Hyparrhenia hirta and Eragrostis plana* decreased in abundance.

A breakdown of the vegetation cover in ecological categories shows that the experimental area (block I) and the benchmark sites are dominated by Increaser II species (Fig. 5). Benchmark area 1 stands out with a 74% cover by Increaser II species. This is explained by the dominance of *Eragrostis curvula* in this area (Fig. 4). Another noticeable feature of figure 5 is the complete absence of Decreaser species. This seems contradictory to the presence of one Decreaser in the list of species for all three sites (Table 1). This species, *Eustachys paspaloides,* occurs in block I, but its cover percentage is so low that it rounds to zero.

To compare species composition between the experimental area and the two benchmark areas and examine how the vegetation in the experimental area is developing we used the method described in Stam and Thovhakale [18]. The resulting correspondence analysis plot is shown in figure 6. The vectors in this figure are pointing in all directions, which can be interpreted in different ways. It could mean that the vegetation in the area is simply not developing in one particular direction, either because it is barely developing at all because it is close to its climax composition or because the area as a whole is like a mosaic of patches which are all developing in different directions. Alternatively, the period separating the two surveys may be too short as compared to the timescale over which succession happens and the pattern observed is noise while the signal of succession will only become apparent if measured over a longer time period. The latter explanation is not unlikely as a year is short in succession terms. The first explanation is unlikely as not enough time has passed since the rehabilitation of the area (2008) to reach a climax state. The second explanation is plausible, however. To be able to distinguish between this explanation and the third it is necessary to perform a third survey after a longer period.

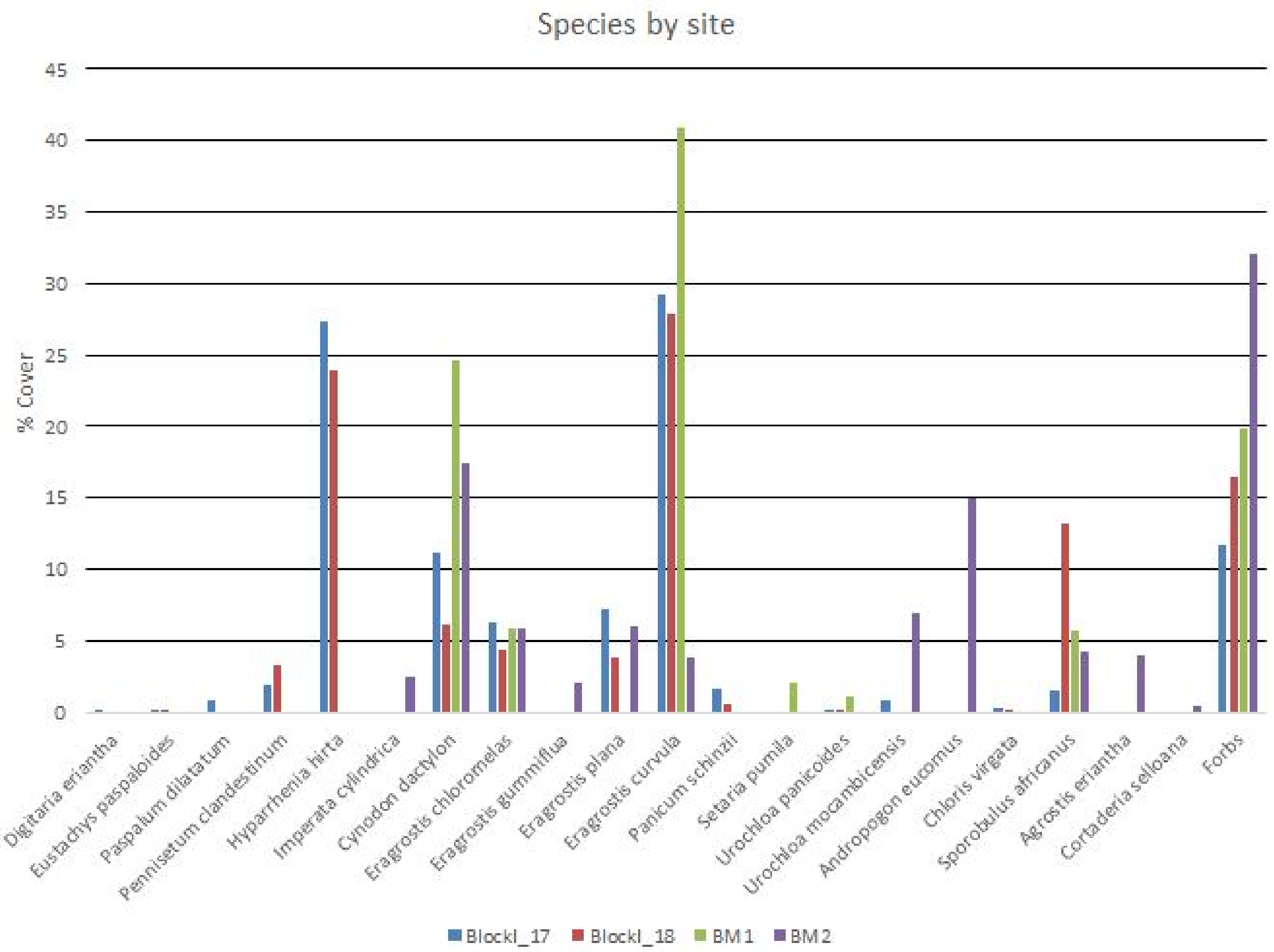

Figure 4 Species composition in the experimental area (Block I) in 2017 and 2018, and the two benchmark sites. Percentages are based on cover.

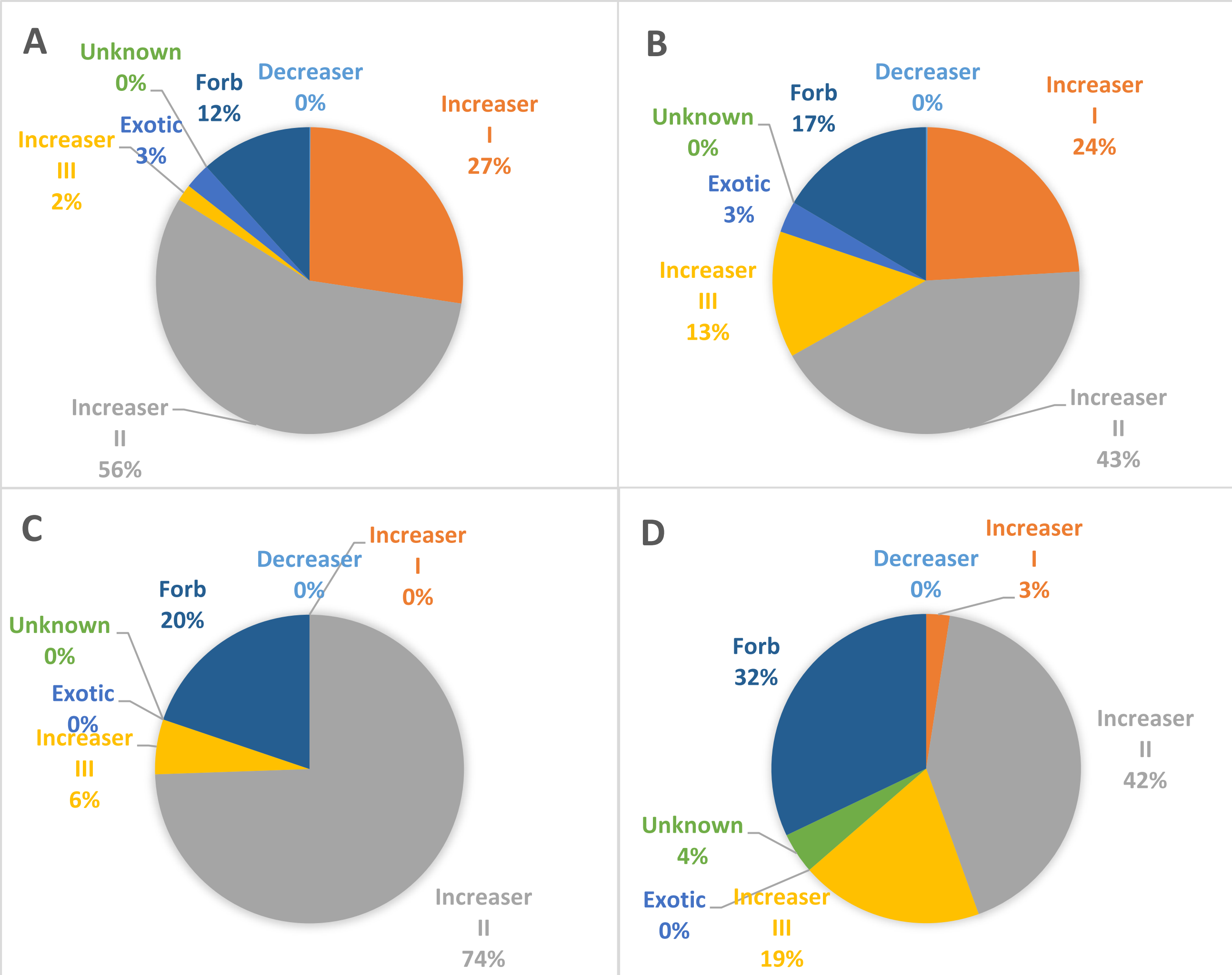

Figure 5 Breakdown of vegetation cover in ecological categories. A: block I in 2017, B: block I in 2018, C: benchmark area 1, D: benchmark area 2.

Figure 6 is too chaotic to be able to see the effect of the exclosures on the vegetation development. This pattern may also become apparent after a longer time period. Another way to visualize the effect of the exclosures on the vegetation is by plotting the behaviour of individual plant species (Fig. 7). It is apparent from Figure 7 that different grass species respond differently to being grazed. For instance, *Hyparrhenia hirta* increased its cover inside the exclosures, while it decreased outside of them. *Eragrostis curvula* on the other hand increased its cover both inside and outside the exclosures, but much more inside. *Eragrostis plana, E. chloromelas* and *Cynodon dactylon* all decreased in density between 2017 and 2018, but much more so inside the exclosures than outside. Possibly these grasses are more affected by the competition from *H. hirta* than the grazing. The rest of the species occur in too low densities or show too little change in cover to be significant.

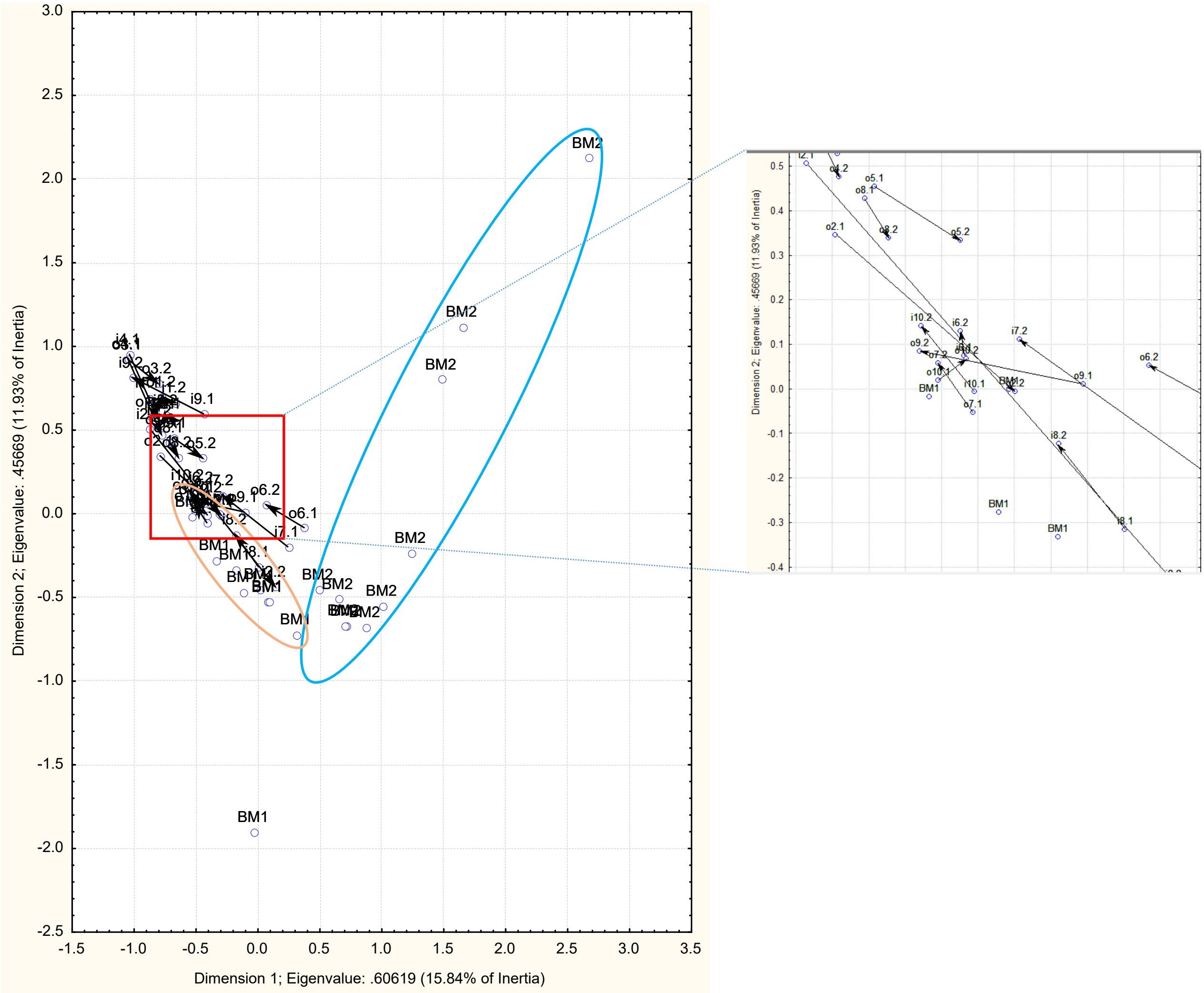

Figure 6 Correspondence analysis on vegetation surveys in Block I and the two benchmark areas. Points of repeat surveys in the rehabilitation areas are connected by vectors. The points of the benchmark areas have been encircled by ellipses. The red square indicates an area in the graph which has been enlarged.

3.2 Biomass

3.3 Ground cover

A considerable percentage of the rehabilitated area had no ground cover. In some plots the percentage of bare ground could be as high as 80%. This obviously makes the area highly vulnerable to erosion. It is important to know, therefore, whether the percentage bare ground is changing over time and, if so, whether this change is affected by grazing. Table 3 shows the results of a repeated measures ANOVA on the ground cover data. The change over time is in this table indicated by the factor TIME, the effect of which is significant at the α = 0.05 level. Fortunately, the change is a decrease (Fig. 8), though not large (4 %). The effect of grazing is indicated by the factor InOut which stands for inside or outside the exclosures. The interaction effect of time and grazing (TIME * InOut) indicates whether the amount of change

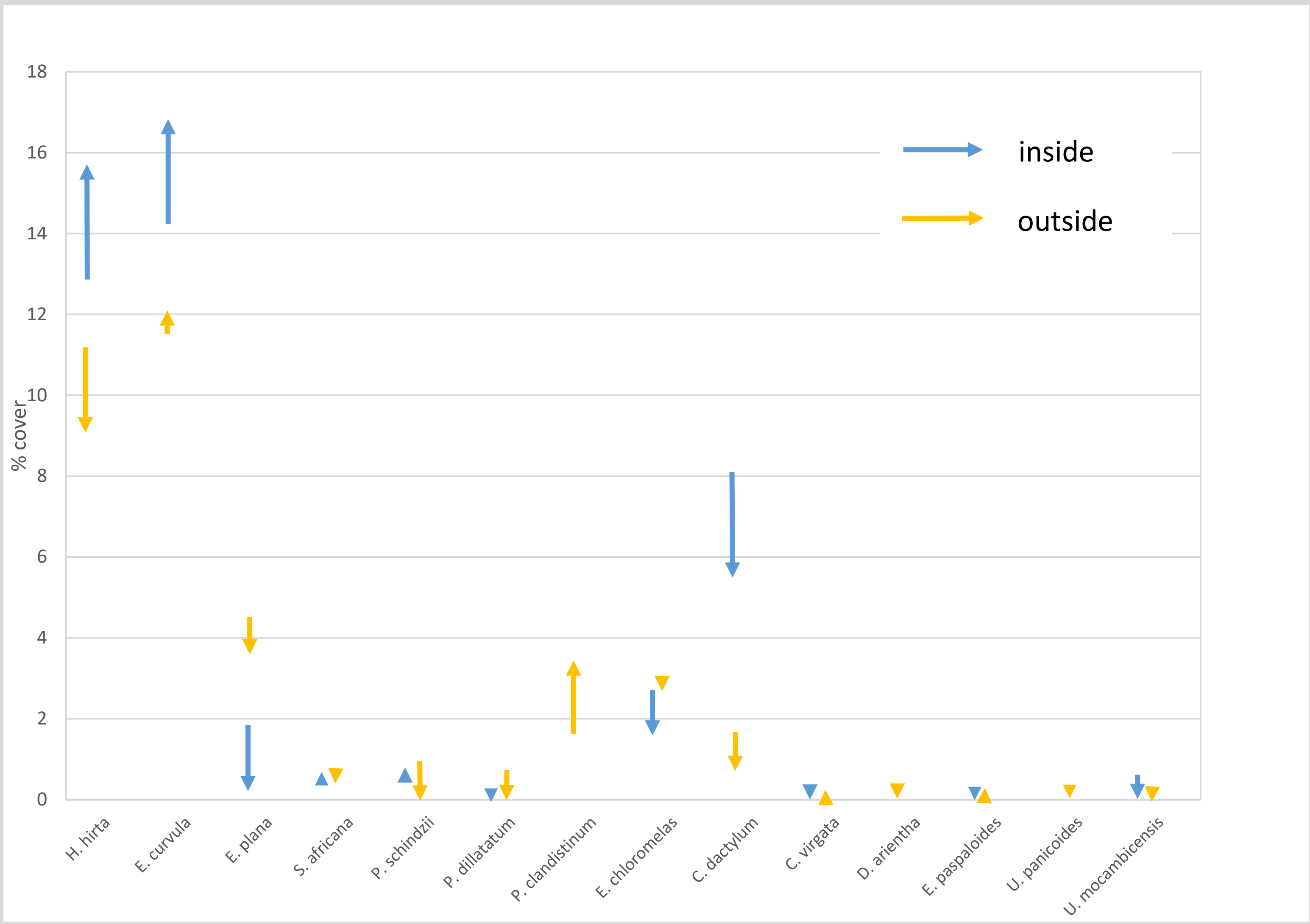

Figure 7 Grass cover changes between 2017 and 2018. The arrows connect the cover in 2017 (tail) with that of 2018 (head). Blue arrows are for cover inside exclosures while orange arrows are for outside of them.

Table 3 Repeated measures ANOVA on bare ground data.

	SS	df	MS	F	p
Intercept	346737.0	1	346737.0	918.34	0.0000
InOut	760.7	1	760.7	2.0148	0.1635
Excl	12224.1	9	1358.2	3.5973	0.0023
InOut*Excl	3240.1	9	360.0	0.9535	0.4915
Error	15102.7	40	377.6		
TIME	602.7	1	602.7	5.2794	0.02689
TIME*InOut	194.7	1	194.7	1.7055	0.19903
TIME*Excl	3660.7	9	406.7	3.5627	0.00250
TIME*InOut*Excl	1344.7	9	149.4	1.3087	0.26301

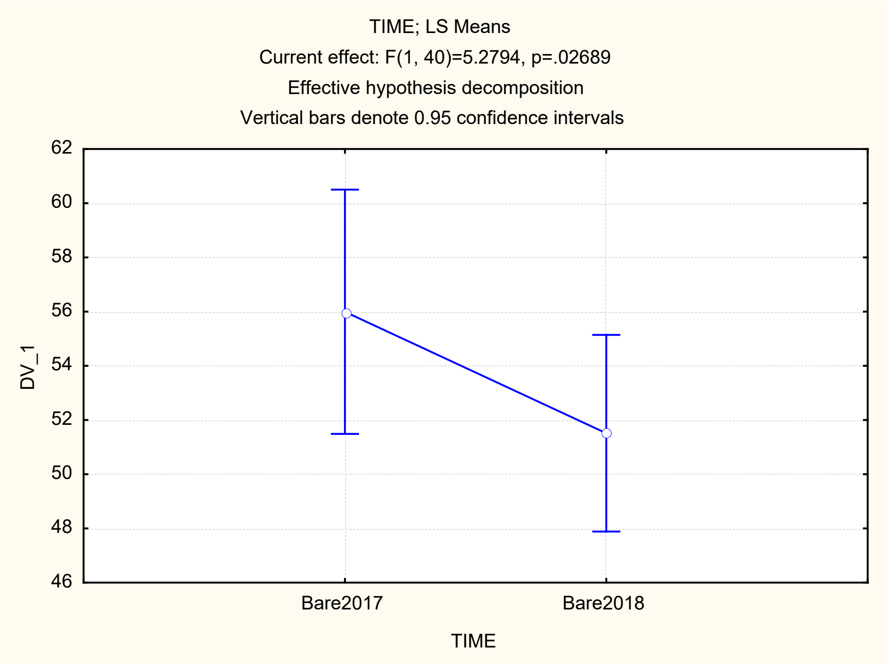

Figure 8 Change in average bare ground percentage.

in bare ground percentage over time depends on grazing. As it turns out, neither effect was significant, which means that after a year no effect of grazing on bare ground percentage or change thereof could be demonstrated. Both the factor Exclosure and the interaction of Time and Exclosure have significant effects on percentage bare ground. This, however, merely reflects the fact that the bare ground is patchily distributed, that some exclosures therefore have more bare ground than others and that the change in bare ground percentage is different between exclosures. This is visualized in Figure 9.

3.4 Veld assessment and grazing pressure

The species composition and biomass as measured with a disc pasture meter were used to determine the grazing capacity of the rehabilitated area. We used the scoring system described in Van Oudtshoorn [17]. This system bases scores on ecological categories as follows:

Decreaser	10
Increaser I	7

Increaser II	3
Increaser III	1

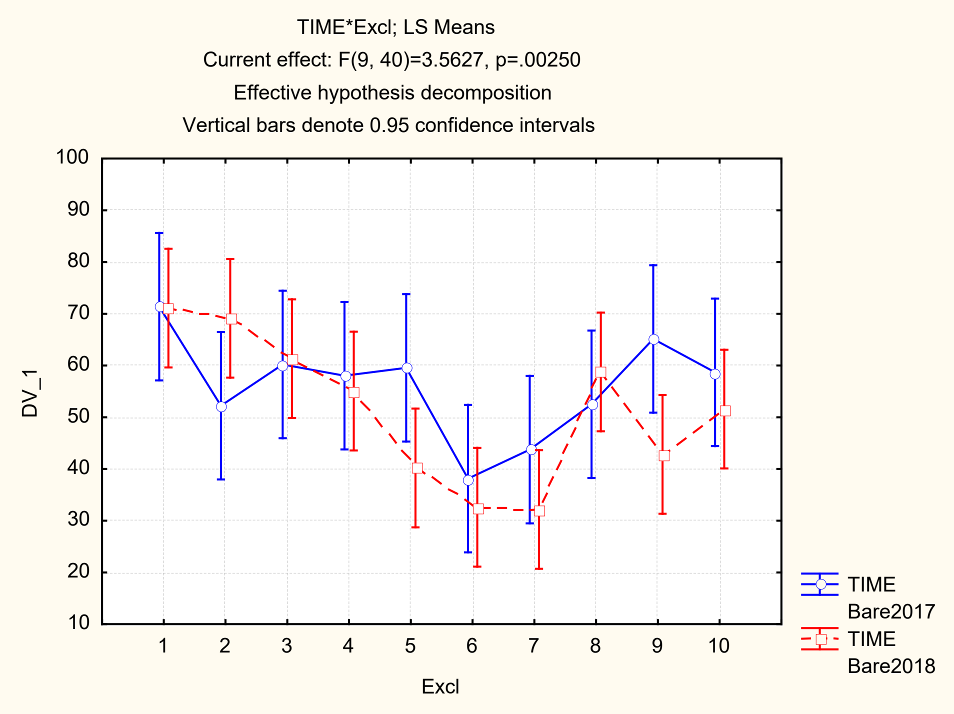

Figure 9 Interaction of time and exclosure.

These values are multiplied with relative abundances of the species in the respective categories. This yielded a score of 262 for 2017. According to the benchmark method [17] this value is to be compared to a value obtained from a benchmark site in good condition. Our benchmark sites 1 and 2, however, were both completely devoid of Decreaser grasses. Hence we decided to use the default score of 800 given in Van Oudtshoorn [17]. Thus the site score is 33% of the benchmark score. This value, in combination with the biomass (dry weight) was used in the following equation to determine the grazing capacity:

$$y = \frac{d \cdot r}{DM \cdot f}$$

where

> y = grazing capacity in ha/animal unit (AU)
> d = number of days in a year when grazing takes place
> r = daily dry mass requirement per AU (kg/day)
> DM = dry mass (kg/ha)
> f = utilization factor based on veld condition score

The average biomass in 2017 was 2992 kg/ha and the period over which the cattle was allowed to graze in the study area was 90 days. For r we used 11.25 kg/day [17] and f = 0.33. Thus we obtain:

$$y = \frac{90 \cdot 11.25}{2992 \cdot 0.33} = 1.025 \text{ ha/AU}$$

The herd of cattle grazing in the area was calculated to be the equivalent of 105 AU. Thus they would require an area of 107.6 ha. The size of the camp is 31.8 ha. Even though the calculations are based on rough estimates and somewhat arbitrary index values and are therefore not very exact, the difference between the estimated required and the actual size of the camp is so large that the conclusion that the camp is overgrazed is justified.

3.5 Soil sample analyses

The results of the nutrient analysis are shown in figure 10.

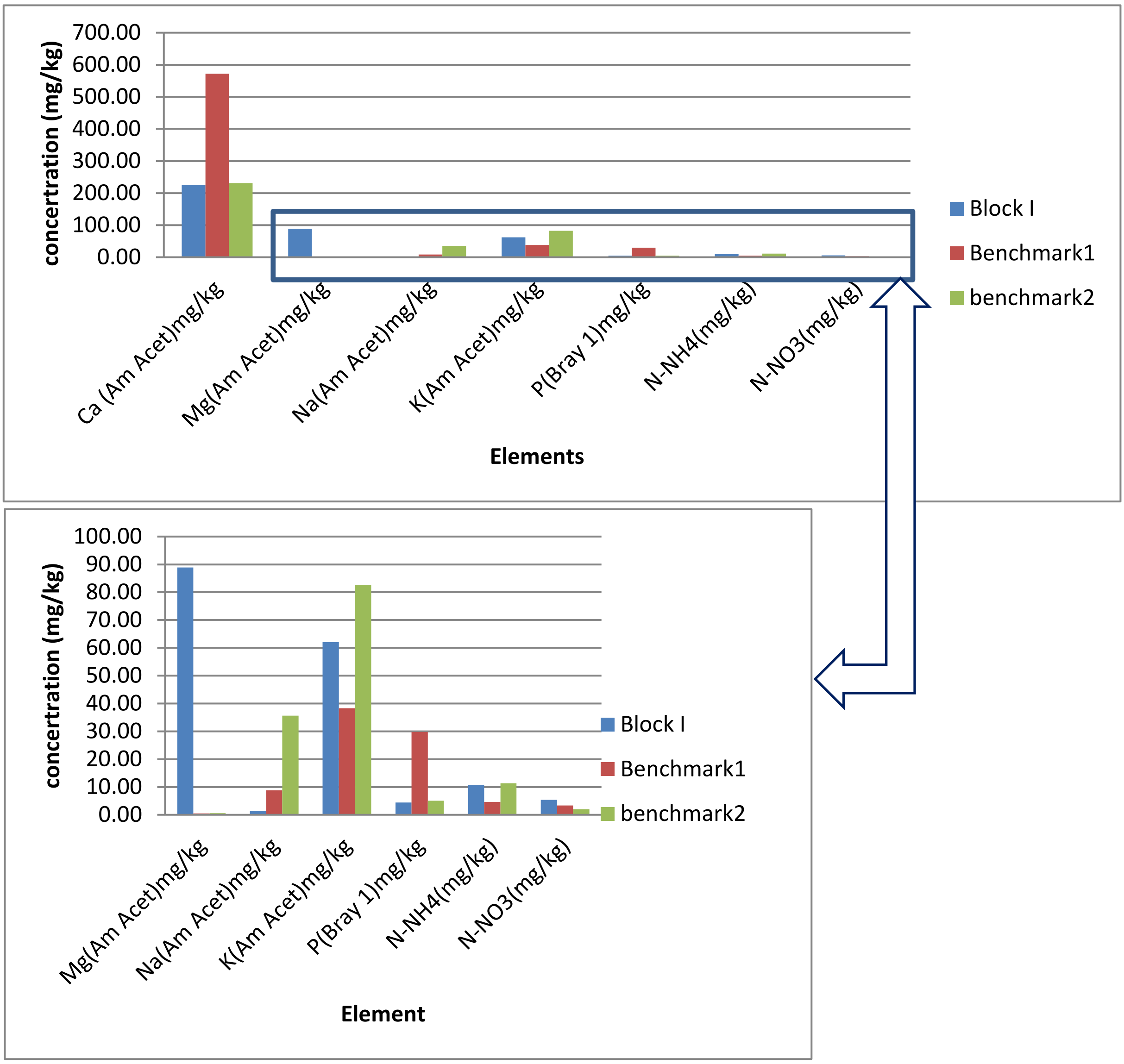

Figure 10 Soil analysis results: nutrients

Noticeable is the high concentration of Ca in benchmark site 1 which also has the highest pH value (Fig. 11). Both results suggest that the area may have undergone lime treatment. Also remarkable is the comparatively high concentration of magnesium in the Block I samples. However, this concentration falls within the normal range of 50-300 mg/kg (G Nortje, pers.

comm.), while the values for the two benchmark values are far below this range. The Bray 1 P values are very low for Block I and Benchmark 2 while at Benchmark 1 it is at an intermediate level [20]. The low concentrations of plant available N (NH_4^+ and NO_3^-) are to be expected as nitrogen is highly mobile and can leach out of the soil quickly [20].

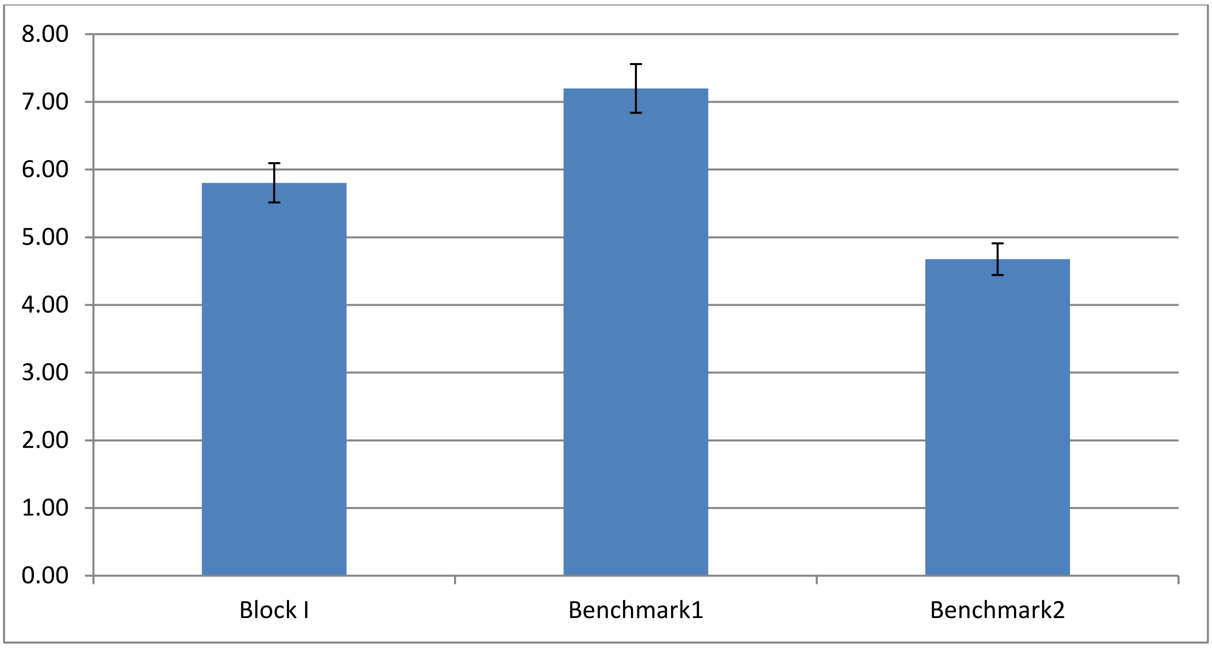

Figure 11 Soil analysis results: pH

When comparing the soil textural classes between Block I and the benchmark sites, it appears that block I is more clayey and therefore less sandy. Benchmark site 1 is sandier than benchmark site 2 which has more silt. The relatively high clay content of the Block I soil may render it more vulnerable to soil compaction and crusting.

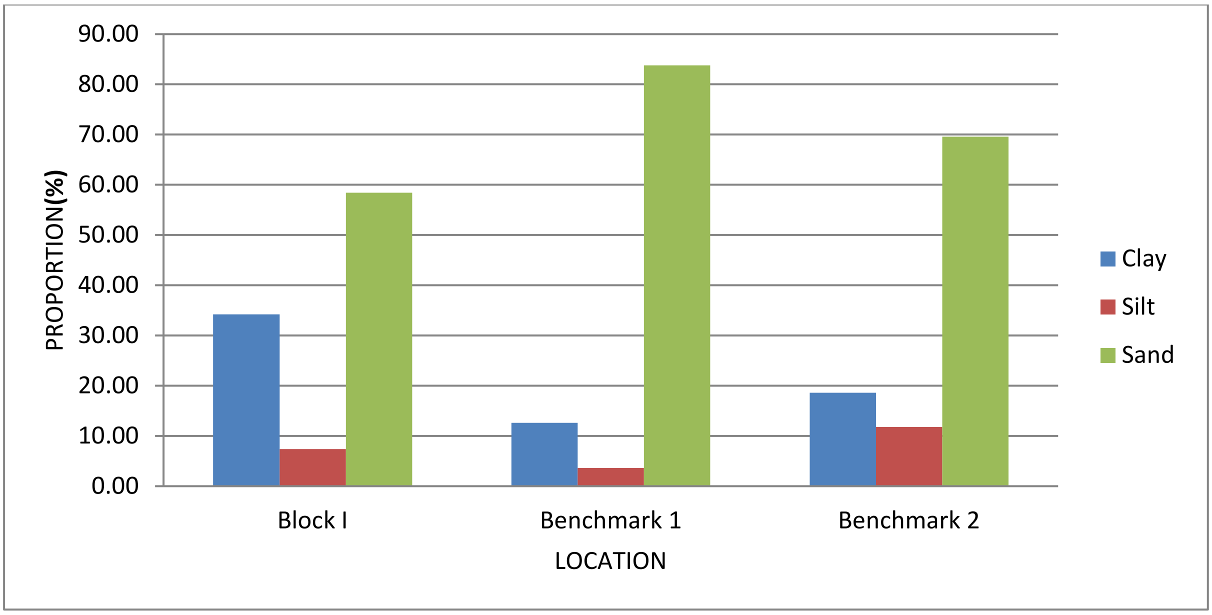

Figure 12 Soil analysis results: texture

4 Conclusions

Both the rehabilitated site and the two benchmark sites are dominated by low quality grasses. In addition, the rehabilitated site has a high percentage of bare ground which renders it vulnerable to erosion. Multivariate analysis did not show that the rehabilitated ecosystem as a whole was moving in a particular direction. Nor did it show an effect of grazing. This may be due to the short time period between surveys. Univariate analysis where the change of abundance is analysed for each species separately did show an exclosure effect, at least for a few species, in particular *Hyparrhenia hirta* and *Eragrostis curvula*. Veld assessment revealed that the veld condition and carrying capacity were low and that the current grazing regime may lead to further deterioration.

5 Recommendations

5.1 Recommendations for interventions by the mine

The study site is highly degraded and needs a strong intervention by the mine. In particular the ground cover needs urgent attention. Even the use of an exotic species like *Pennisetum clandestinum* (kikuyu) should be considered as it has been successfully applied locally to cover bare patches. Furthermore, if the area is meant to be used for grazing (planted pasture), the mine would do well to sow a few more palatable grasses, such as *Digitaria eriantha* (Smuts' finger grass), which is currently grown successfully in a neighbouring area, and/or *Themeda triandra* (red grass), which occurs naturally in the area. *Panicum maximum* (buffelsgras) could also be considered. After sowing a resting period should be applied to allow the new grasses to establish themselves. Then another veld assessment should be performed to determine whether grazing can commence and at which intensity.

5.2 Recommendation for further research

A third vegetation survey, in 2022 (after five years), may allow us to answer the question whether the inconclusive result of the multivariate analysis is explained by patchiness of the area or the short period of one year between survey 1 and 2. It will also give us more insight into the effect of grazing on the rehabilitated ecosystem.

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7 Appendix 1: Vegetation surveys

BLOCK I 2017.xlsx

BLOCK I 2018.xlsx

BENCHMARK SITE 1.xlsx

BENCHMARK SITE 2.xlsx