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HERBACEOUS VEGETATION OF THE ROCK DUMP AND TAILINGS COMPLEX OF PALABORWA MINING COMPANY, 2011 to 2016

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SCOPE

SAEON has been monitoring the vegetation of the two major rehabilitation areas of PMC, Dump 4 (referred to here as the **Rock Dump**) and the Tailings Complex (**Tailings**) since 2011. This report incorporates all sampling of the **herbaceous layer** up until June 2016.

- The herbaceous layer refers to grasses, sedges and forbs.
- Changes to the woody vegetation (trees and shrubs) are not included. This will be presented in a separate report.

INTRODUCTION

Monitoring the herbaceous layer is challenging due to the dynamic nature of this component of vegetation. The growth and resulting cover of herbaceous vegetation can be very patchy, with large differences over distances less than a metre, and can vary greatly through time, due to seasonal and annual differences in rainfall. A wide a variety of methods have been developed to quantify changes to herbaceous vegetation, each focussing on a different aspect. These include measures of structure (such as Landscape Function Analysis, which is essentially a measure of cover), veld condition assessment (which focuses on the species composition of the grass component) and measures of productivity. For the purposes of monitoring the biodiversity of the Rock Dump and Tailings, as well as determining the environmental factors which affect it, there are two aspects of the herbaceous vegetation that are considered of primary interest:

1. The direct contribution to **biodiversity**, i.e. the diversity of species of the herbaceous layer.
2. **Ecological functioning**, i.e. the ability of the herbaceous layer to capture energy, prevent soil erosion, and produce biomass. The degree of functioning has a strong effect on the biodiversity of most of the faunal diversity, as it ultimately provides the food and habitat required by many invertebrates and larger animals. It is also a key determinant of hydrology, affecting how much rainfall flows over the surface of the rehabilitation areas (resulting in erosion), how much is returned to the atmosphere (through evapotranspiration), and how much infiltrates to deep layers and ultimately seeps into the groundwater below.

METHODS

Herbaceous diversity

To monitor the biodiversity of the herbaceous layer, direct measurement of species diversity was chosen as the appropriate method, with the aim of repeating this every 3 to 5 years. The abundance and detectability of herbaceous species can vary greatly from year to year, due to variations in rainfall, and ideally sampling should be done every year. However, due to the skill and time required for recording and identifying herbaceous species, annual sampling was not feasible. Surrogate measures that indirectly estimate diversity (such as only recording common grass species) that could be repeated annually were not considered too great a compromise of accuracy. However, the method used for monitoring productivity (see below) did at least allow for recording changes in the dominant species from year to year.

The exact method used for species composition was a rigorous one, involving the recording the presence and number of all species (grass and forbs) in a large number of replicate quadrats. This was done by an SAEON MSc student (Dawid Smith) during the summer of 2012-13, who sampled 85 quadrats on the Rock Dump and 89 quadrats on the Tailings. A stratified random design was used for positioning the quadrats, to include the majority of the variation in aspect, topography (slope or terrace), and rehabilitation age present.

- More details of the method and results from this study will be available from the MSc thesis of this student, which is still in preparation. Only key results are included here, but a copy of the raw data are available from SAEON if required.
- In order to benchmark these results, two additional datasets collected using the same or similar methods were used:
    - 42 quadrats sampled in Cleveland Game Reserve in 2012-13 and 2014-15 by another SAEON MSc student (Nanette van Staden, thesis available from SAEON)
    - 48 quadrats sampled by SAEON staff at a research site in the Kruger National Park (KNP), approximately 35 kilometres north-west of PMC (the SAEON Malopeni site). This site was selected as it is representative of the ecological condition of pristine herbaceous vegetation of the region, with no overgrazing due to its distance from the nearest water source (approximately 4.5km) and unrestricted movement of herbivores in the area. It does however receive slightly less rainfall than PMC.

Functioning

In order to monitor ecological functioning, the **standing crop** and **annual production** of herbaceous vegetation was measured annually since 2011. This involved clipping the above-ground parts of all grasses and forbs present in 0.5m x 0.5m quadrats. Litter (stems and leaves which had detached from the plant) were not included. The species which was estimated to contribute the most biomass in each quadrat was recorded, as well as whether the quadrat was located under a tree or in the open. This was done on approximately 30 quadrats within selected plots on the Rock Dump, and 30 on the Tailings. Approximately 24 of the quadrats (75%) were located within the same plots each year, and 6 within plots randomly selected each year. For benchmarking, a similar number of quadrats were clipped during the same years at the Malopeni site in KNP.

Clipping was done at the end of the growing season every year. The date varied between late April and early June, and depended on rainfall patterns at the end of summer, predictions of whether more rainfall was likely in late summer, and logistical constraints. From 2013 onwards, clipping was also done at a second time during the year, at the end of the dry season (late September). This was done to get an estimate of how much of herbaceous productions persists through the dry season, which is likely to have an important effect on wind erosion, as well as water erosion when the first rains fall. Clipped material was separated into current biomass, i.e. parts considered to have grown during the summer preceding sampling (green leaves, culms and stems and recently senesced parts) and previous biomass, i.e. parts that grew in the summer before that, or earlier, but were still attached to a plant at the time of sampling ("the standing dead"). Separation of current and previous senesced biomass was done on basis of colour. All parts were dried in an oven at 80^{o} C for two days and weighed.

Annual production was selected as the best measure of ecological functioning, as it provides the best estimate of the amount the herbaceous layer grows in a year. The growth of grasses (and to a lesser degree, forbs) leads to the production of biomass and litter, the cycling of water and the accumulation of organic matter in the soil, and estimating growth is therefore the most direct measure of ecological functioning. However, as with species diversity, annual production varies greatly in space and time, and requires labour intensive methods to sample it adequately. Also, where a grazing by large mammals occurs, a single measure of production at the end of the summer can lead to large underestimates, as biomass consumed by grazers is not included. Despite these short-comings, measuring annual production by clipping was considered preferable to the less intensive methods of estimating production (such as estimates of cover) as these involve even more potential errors.

Cover (by green grasses and forbs, standing dead and litter) is a key additional driver of the ecological functioning of the herbaceous layer, affecting soil temperature, infiltration of rainwater and soil organic matter and nutrient cycling. While annual production is usually the main determinant of cover, it is also determined by how much production is carried over from one year to the next, as well as the distribution of this biomass across the ground (scattered versus clumped). Measurement of the standing crop (the total biomass at a point in time, including both recent and previous production) was therefore chosen as an additional measure of ecological functioning. Furthermore, from 2013 the standing crop was measured twice a year, with a second measurement at the end of the dry season (late September or early October). This was done to investigate how much herbaceous cover persists through the dry season, and how much is present at the start of the rains when erosion potential is greatest. Finally, in order to test how well standing crop relates to cover, both variables were measured for one year. This was done at the same time as species composition was measured, by visually estimating the cover of forbs, grasses, litter, bare soil and rock in each quadrat, and clipping all biomass in 20cm x 20cm section within the quadrat.

RESULTS AND DISCUSSION

Herbaceous species diversity

Species accumulation curves indicated that the majority (>85%) of all species present were recorded during the species composition surveys. An impressive number of species were recorded for both the Rock Dump and the Tailings, comparable to one of two benchmark sites (**Table 1**). However, the majority of species found were extremely rare. Only a few species made up the vast majority of all individuals present (**Figure 1**) at each site, with more than two thirds of all individuals belonging to 7 species on the Rock Dump, and to just 6 species on the Tailings. As a result, values for evenness (a measure of the degree to which the most common species dominate over the rest) and diversity (a measure which combines both the number of species and evenness) were lower than for the benchmark sites.

Related to the differences in evenness, the composition of the Rock Dump and Tailings were very different to that of the benchmark sites (**Figure 2**). The dominant species on each are rare in the benchmark sites, and the third most common on the Tailings is an invasive alien (*Sesbania bispinosa*).

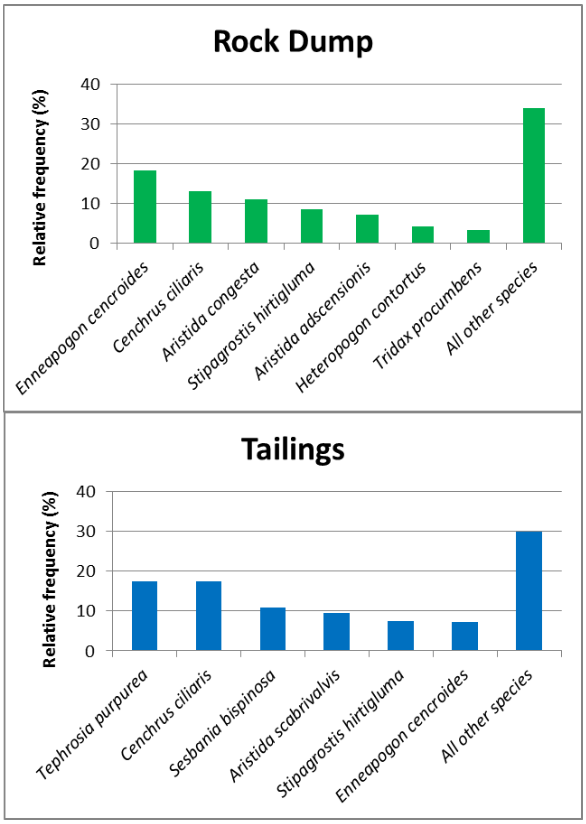

Figure 1. The relative abundance (based on the number of individuals per quadrat) for the most common species recorded in 2012-13, on the Rock Dump and Tailings.

Table 1. Diversity measures for the Rock Dump, Tailings Dam and two reference sites.

	Rock Dump	Tailings	Cleveland	KNP
Number of species	75	65	138	78
Evenness	0.6	0.6	0.75	0.7
Shannon-Weiner Diversity	1.3	1.3	1.9	3.1

Note that these differences are based on numbers of individuals, and not sizes. If the biomass or cover were measured per species, different rankings of species abundances would be found, although the overall differences in evenness and composition would probably be the similar. The productivity data indicated that *Pennisetum setaceum* (an alien grass species) and *Cenchrus ciliaris* are consistently the most dominant species, in terms of biomass, on the Rock Dump and Tailings respectively (**Figure 3**). Evenness appeared to be even lower when measured in terms of biomass, as just two species had the greatest biomass in over two thirds of all quadrats clipped, at each site. In contrast three species made up two thirds at KNP benchmark site, and these were species that were very rare on either the Rock Dump or Tailings.

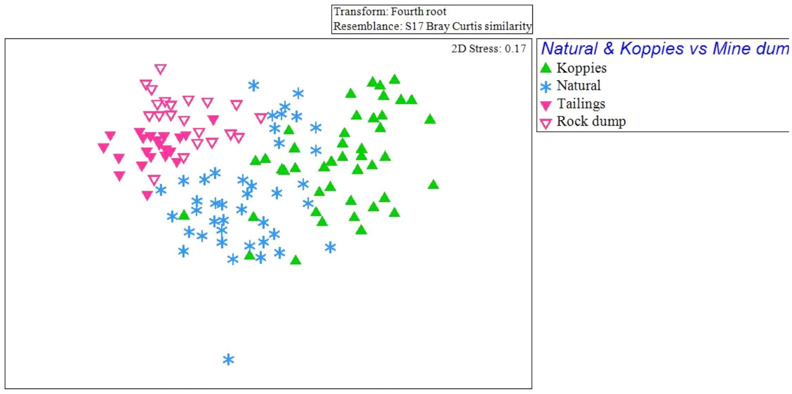

Figure 2. Ordination plot from a multi-dimensional scaling (NMDS) ordination of numbers per species in quadrats sampled on the Rock Dump, Tailings and Cleveland ("Natural" in the legend). From Fig 5.2 of Nanette van Staden's MSc thesis. Data for quadrats sampled on the koppies of Cleveland were also included in this particular analysis. The separation of the points for the Rock Dump and Tailings, from the "Natural" site, indicate large differences in composition.

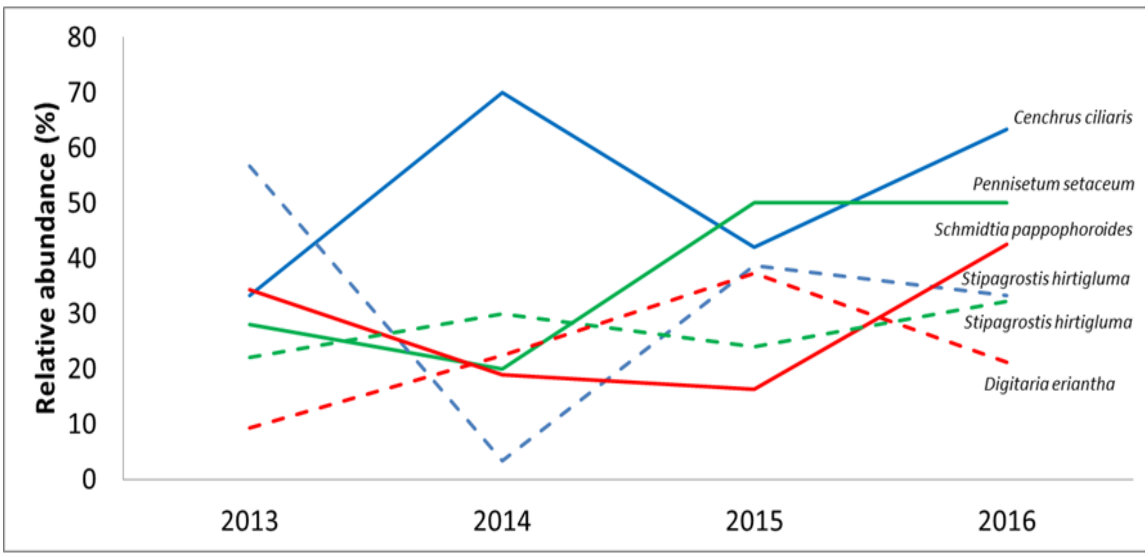

Figure 3. Abundance of the two most common species, measured as the percentage of quadrats clipped in which a species was judged to contribute the most biomass, for the 4 years in which the herbaceous layer was clipped. Solid lines show the most abundant, and dashed lines the second most abundant species, for the Rock Dump (green lines), Tailings Dam (blue lines) and the benchmark site in the KNP (red lines).

Functioning

Standing Crop

The total biomass of the herbaceous layer at the end of the growing season was similar for the Tailings and the Malopeni benchmark site in KNP, and often higher for the Rock Dump (**Figure 4**). Samples from the Rock Dump showed far greater variation, between years and within a sample. This was due to the inclusion of tufts *Pennisetum setaceum* (*Pennisetum* hereafter), which are generally far larger than tufts of the other species. Samples which by chance included more *Pennisetum* had far larger values, regardless of year or season. The steady decline in values evident for the Tailings and KNP sites is due to rainfall, which was above average in 2013 and 2014, and well below in 2015 and 2016. By 2016 the standing crop on the Tailings had become significantly lower than at the benchmark site, even though the latter had lower rainfall. The Rock Dump was less affected due to most tufts of *Pennisetum* maintaining a relatively large size even after 2 years of drought.

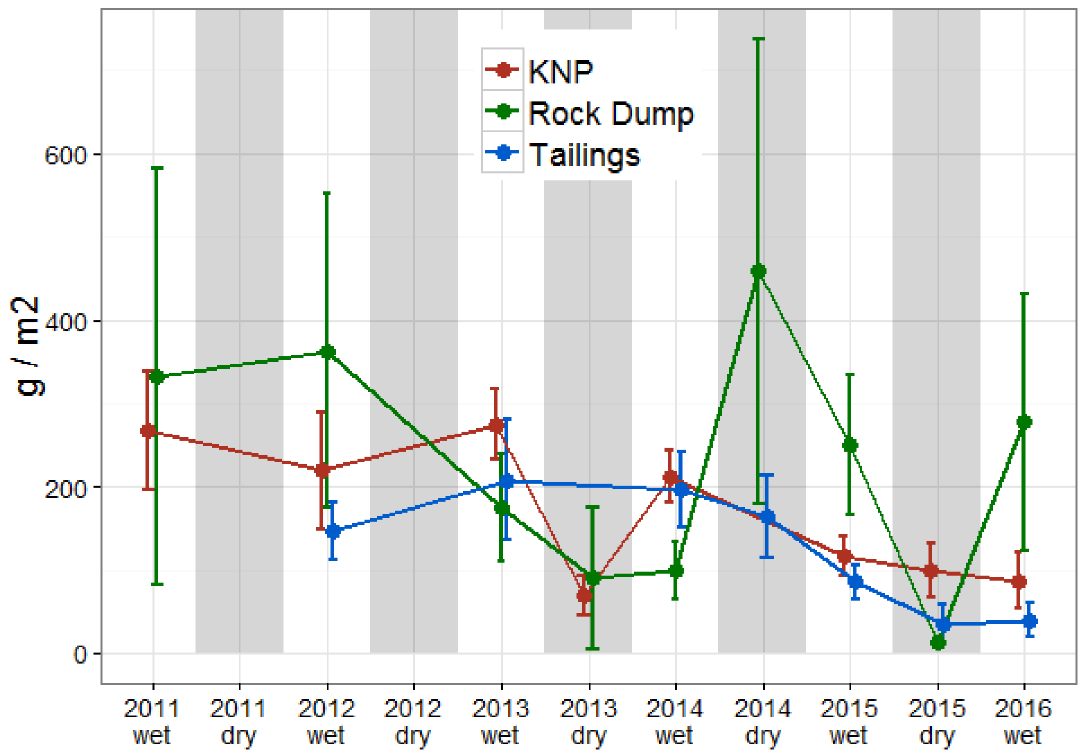

Figure 4. Mean standing crop of the herbaceous layer on the Rock Dump, Tailings and a benchmark site in the KNP, 2011 to 2016. For each year, sampling was conducted at the end of the growing season (April or May). From 2013, a second sample was conducted each year at the end of the subsequent dry season (shaded areas). Dry season values should therefore always be lower than wet season values. The large spike for the Rock Dump in 2014 is a result of inclusion of more tufts of *Pennisetum setaceum*, by chance. Error bars show the 95% confidence interval of the means (means falling outside the interval of another site indicate that the true means of the two sites are likely to be different).

Data from the 2012-13 sampling indicated that slope, aspect and age have minor effects on standing crop. On the Rock Dump, slopes tended to have a greater standing crop, but there was large variation within slopes and terraces (**Figure 5**). Differences were smaller for the Tailings, while differences between the eastern, southern and western sides of each structure were also highly variable with no clear trends. Despite the relatively high standing crop on slopes, erosion was still common, and has become particularly severe during the recent current drought (**Figure 6**). There was surprisingly little change in standing crop with changes in dump levels (**Figure 7**). While there was a trend of increasing standing crop with increasing age, for both sites, the high variability of the data makes it difficult to determine whether this is real or an artefact of sampling error. Regardless, it is clear that there is no major increase in the productivity of the herbaceous layer once a level reaches about 20 years of age.

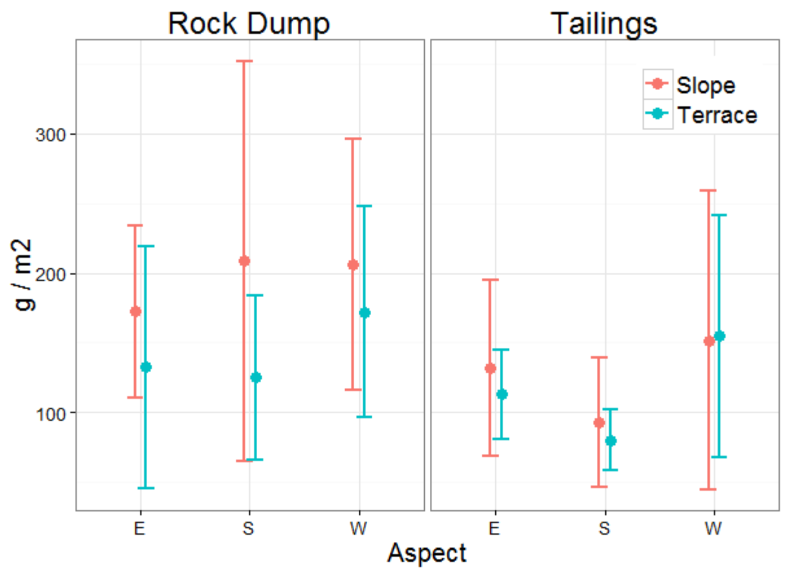

Figure 5. Mean standing crop at the end of the 2012-13 summer, on slopes versus terraces, for different aspects (east, south and west) of the Rock Dump and Tailings. Error bars show the 95% confidence interval of the means.

Figure 6. Erosion on a slope of the Rock Dump, May 2016, with gullies developing between the larger grass tufts.

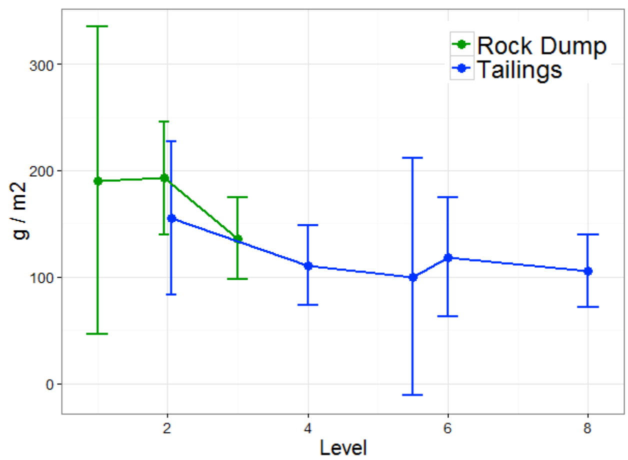

Figure 7. Mean standing crop for each level sampled on the Rock Dump and Tailings in 2012-13, averaged across all aspects and both topographic positions. Highest level numbers were created most recently, with level 1 of the Rock Dump approximately 42 years old, and level 3 approximately 28 years old. Level 2 of the Tailings is approximately 32 years old, and level 8 approximately 20.

Cover

Data from the intensive sampling conducted in 2012-13 indicated a weak relationship between the standing crop and vegetation cover when analysed per quadrat (linear regression r^2 of < 0.1). However, this was mostly due to a scale mismatch. Cover was estimated for an entire $1m^2$ quadrat, while biomass was only clipped for a $200cm^2$ subsection of the quadrat. As grass biomass can be very patchy at scales of less than $1m^2$ this creates a large amount of sampling error. To factor out some of this error, the cover and standing crop was summed for all quadrats on the same level, aspect and topography of each site. These data indicated a much stronger relationship (**Figure 8**). Relationships were similar for standing crop versus total vegetation cover (including litter), as for cover of just forbs and grasses. Relationships were also similar for the Rock Dump and Tailings, although the former had higher and more variable cover. Standing crop can therefore be considered a reasonable surrogate for direct measures of cover, at the scale of entire dump levels.

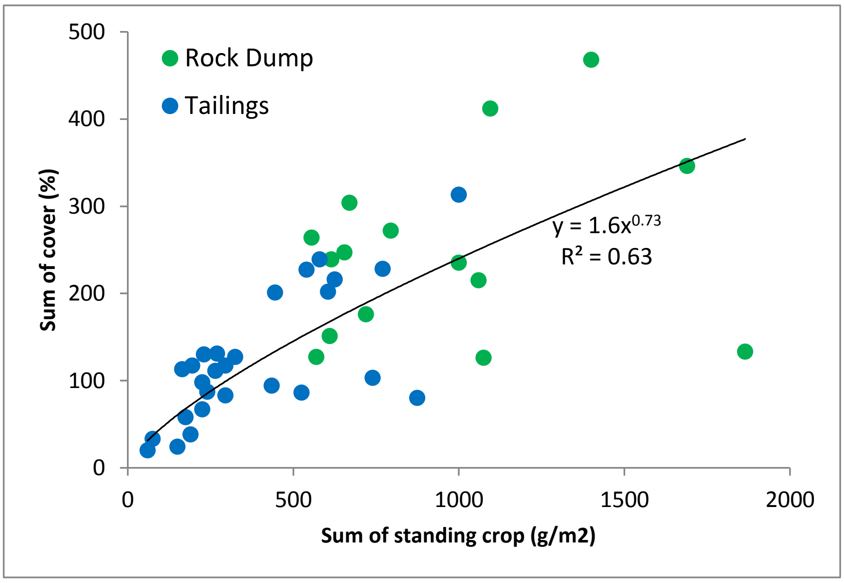

Figure 8. The cover of all vegetation (grass, forbs and litter) and biomass of a subsample of the quadrat, for the 174 quadrats sampled on the Rock Dump and Tailings in 2012-13. Results of a power function regression are shown alongside the fitted line.

Production

The annual production of grass and forb biomass showed similar trends to standing crop, with lowest values on the Tailings, and the highest (and most variable) on the Rock Dump (**Figure 9a**). Again the inclusion of *Pennisetum* in some quadrats on the Rock Dump had a large influence on the means and the variance around them. From 2013 onwards, half of all quadrats on the Rock Dump were deliberately placed to either include or exclude a tuft of *Pennisetum*, in order to control for this. Exclusion of *Pennisetum* revealed that the productivity of the remaining grasses on the Rock Dump was less that on the Tailings, and was far lower than the KNP benchmark site in 3 out of 4 years for which appropriate data were available (**Figure 9b**). As with the standing crop data, a declining trend is evident due to the drought in 2015 and 2016, except when *Pennisetum* was included. Plots of these same data against the total rainfall

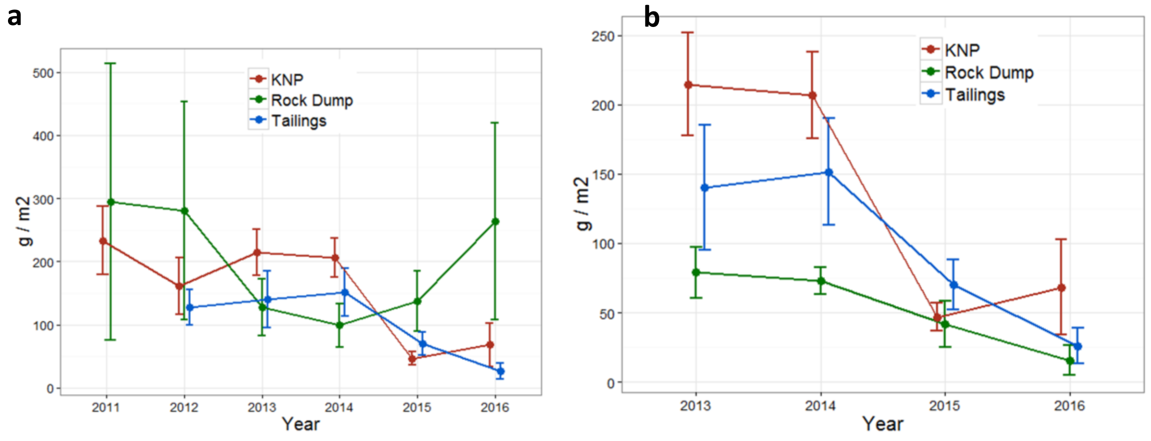

Figure 9. Mean annual biomass production of the herbaceous layer on the Rock Dump and Tailings. **a)** from 2011 to 2016, including all species, and **b)** from 2013-2016 with *Pennisetum setaceum* excluded for the Rock Dump samples. Error bars show the 95% confidence interval of the means.

per year indicated a clear effect of rainfall on production (**Figure 10**). The herbaceous layer produced more for a given amount of rainfall, particularly in higher rainfall years, while the herbaceous layer on the Rock Dump, in between tufts of *Pennisetum*, was the least productive. Much of the production on the Tailings, particular the larger amounts in the wetter years, was due to large tufts of *Cenchrus ciliaris* which dominate the herbaceous layer there (**Figure 3**) and can form swards of impressive cover.

The ability of *Pennisetum* to produce such large amounts of biomass, relative to all other species and in drought years, indicates how well adapted the species is to the substrate of the Rock Dump. In contrast the rarity of the dominants of the benchmark site indicates that these species simply cannot adapt to the Rock Dump, even after over 30 years of opportunity to colonize. The local species which have colonized successfully are either annuals (*Aristida* species) or small perennials that are not

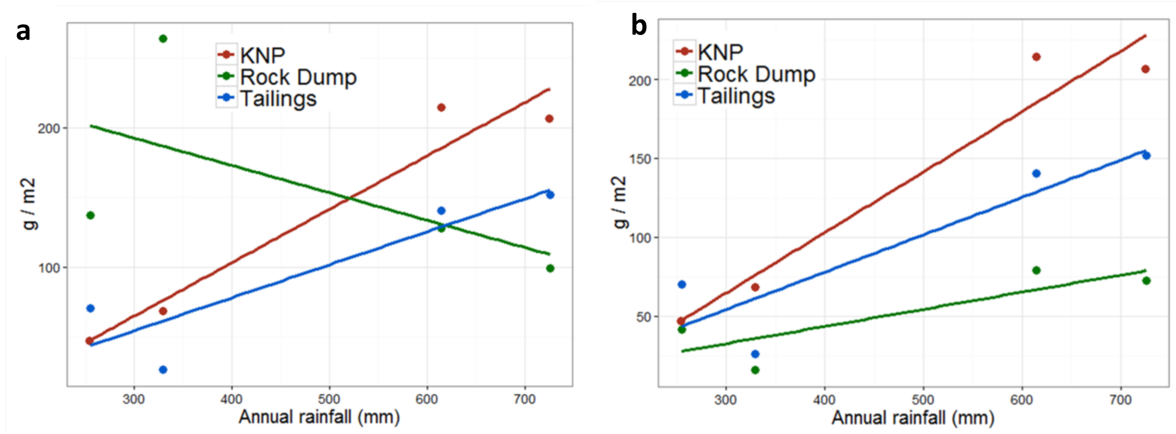

Figure 10. Mean annual biomass production of the herbaceous layer on the Rock Dump and Tailings versus annual rainfall, from 2013-2016. **a)** including all species, and **b)** with *Pennisetum setaceum* excluded for the Rock Dump samples.

capable of growing large tufts (*Enneapogon cenchroides* and *Stipagrostis hirtiglumis*).

For both the Rock Dump, and the Tailings, an additional factor that may contribute to the lower productivity, and standing crop, is greater grazing pressure. Camera trap data (presented in a separate report) show that Buffalo are recorded on the Rock Dump more frequently than in Cleveland, and likewise for Blue Wildebeest on the Tailings. It has yet to be established why these species make the effort to climb the slopes of these two structures and graze on their terraces. Together with others that frequent the dumps, such as Elephant and Kudu, these herbivores may make a positive contribution to rehabilitation, by transporting seeds from surrounding vegetation and facilitating colonization by the impressive richness of local species found on the dumps. On the other hand, widespread and frequent grazing may be preventing more productive local species from establishing.

Effects of repeated defoliation

Despite the value of *Pennisetum* for the ecological functioning of the Rock Dump, it is an alien species and should ideally be eradicated. While it has not spread from the Rock Dump, if this did occur it would have a large negative effect on the biodiversity of KNP and private reserves to the south. Furthermore, its presence may be a problem for mine closure approval.

In order to determine how easily it could be eliminated, and what the

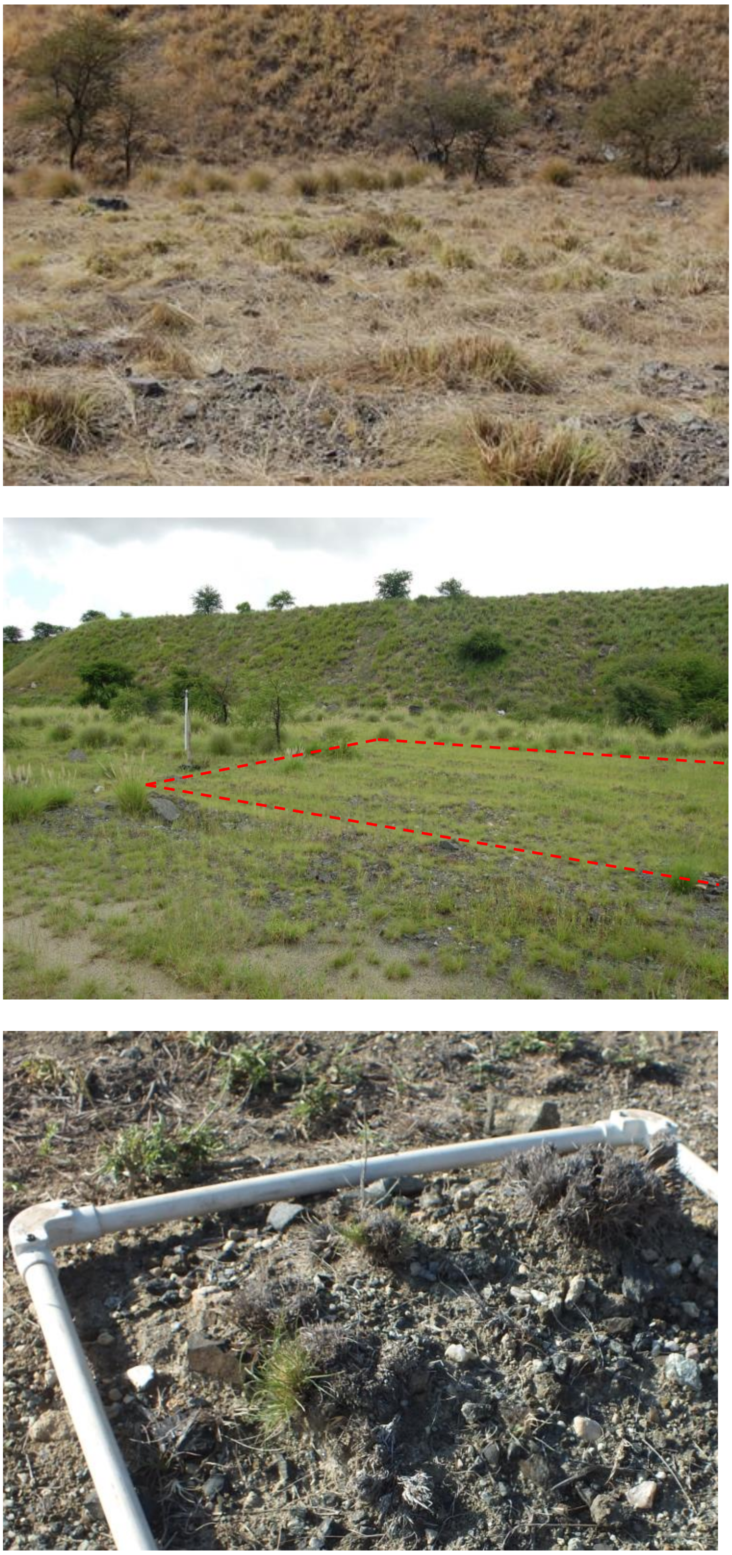

Figure 10. One of the two clipped plots on the Rock Dump, after clipping in 2012 (top), and again in 2016 (middle; red lines indicates the plot boundary). Note the absence of large tufts of *Pennisetum setaceum* within the plot. Most remaining tufts are dead or dying (bottom).

herbaceous would be like without it, two small plots were repeatedly clipped on one level of the Rock Dump since June 2011. All tufts within plots of 20m x 20m were clipped down to a height of about 5cm in the dry season, each year until June 2014. In 2015, this was not possible due to low production in these plots. The aim of this small experiment was to test whether removal of all the hard culms and old leaves of *Pennisetum* would make tufts more attractive to grazers, and whether the combined influence of clipping and grazing would eventually kill these tufts.

By 2016, this was indeed occurring, with *Pennisetum* now almost absent from these plots (**Figure 10**). Production by other grass tufts was initially not affected (**Figure 11**), perhaps because any negative effects of the clipping were compensated for by reduced competition from *Pennisetum*. However, production by these others was substantially lower in 2016, and many dead tufts were observed. Therefore the combination of clipping (as well as any extra grazing this induced) and drought were more harmful than any benefit created by the absence of *Pennisetum*. Recovery in these plots following the drought will provide more insights into the effects *Pennisetum* has on the other species present.

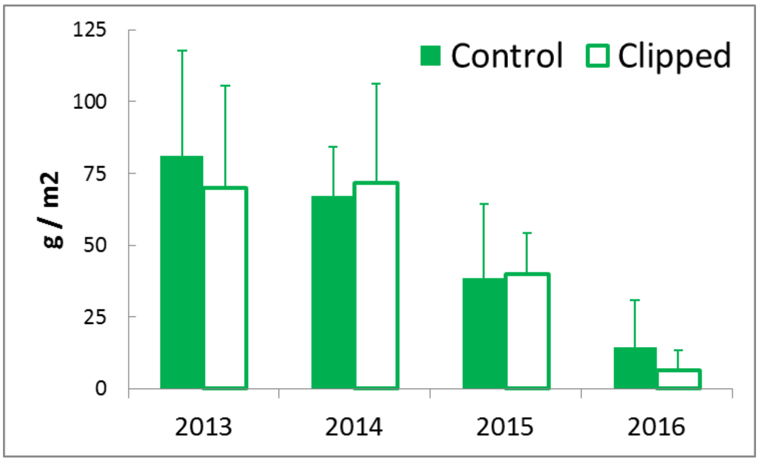

Figure 11. Mean biomass produced by grasses other than *Pennisetum setaceum* in the two control plots and two plots clipped down to 5cm every winter from 2011 to 2014. Error bars show 1 standard deviation.

The drought has also revealed that the abundance of *Pennisetum* may be regulated by grazing, in the long term, even when not manually clipped. For the first time since 2011 heavily grazed tufts of this species were seen. These were presumably grazed by buffalo, which are likely to be the only species capable of utilizing this highly unpalatable species. It remains to be seen whether the combination of drought and grazing will significantly reduce the abundance of *Pennisetum*.

Summary and recommendations

- The Rock Dump and Tailings support a large number of herbaceous plant species, but most of these are rare, while a few very abundant species dominate on each.
- The composition of the two sites is markedly different to that of the natural vegetation in the area, and is less diverse due to the relatively high abundance of the dominant species. Each site has an abundant alien plant species, but these have not spread to surrounding natural vegetation as yet.
- Composition and productivity (relative to rainfall) appears to be stable, and the spontaneous rehabilitation that occurs on both sites appears to reach a climax within 20 years.
- The productivity of the herbaceous layer on the Rock Dump is higher than that of natural vegetation in the area, due to the abundance of the alien grass *Pennisetum setaceum*. In the absence of this alien species, productivity is low and well below that of the benchmark site. An absence of more productive local species appears to be main reason for this, while heavy grazing may also contribute. The establishment of grazing exclosures on the Rock Dump would be useful for determining what excludes these species. Seeding or transplanting tufts of species that show good productivity on rocky substrates in the area (such as the nearby koppies), into both grazed and protected experimental plots, would provide a test of whether a more diverse and productive herbaceous layer is possible. Continuation and expansion of plots where *Pennisetum* has been removed will provide further insights in the ecological role of this keystone species, as well as the feasibility and consequences of eradicating it.
- The productivity of the Tailings is remarkable, considering the substrate, but still below that of the natural vegetation of the area. While a highly productive and palatable species (*Cenchrus ciliaris*) has managed to colonize much of the Tailings, it appears that this species is not increasing in abundance. Again, exclosure and transplant experiments would be useful for investigating how the diversity and productivity of the Tailings can be improved.
- The effect of tree cover on the herbaceous layer has not been investigated to date. However the dominant tree and shrub on the two sites are increasing, and the impacts of this needs to be determined.