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Floristic composition of gold and uranium tailings dams, and adjacent polluted areas, on South Africa's deep-level mines

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ABSTRACT

Gold and uranium tailings ('slimes') dams and the adjacent polluted soils in the deep-level mining regions of South Africa (Carletonville, Klerksdorp and Welkom) were surveyed for the frequency of occurrence of naturally colonizing, actively introduced and persisting plant species. Fifty-six tailings dams with a combined area of 5864 ha, and a similar area of tailings-polluted soils, were surveyed between July 1996 and March 1997. During the survey, 376 plant species and subspecies were recorded from the dams and adjacent polluted soils, with an additional 86 records obtained between 1998 and 2003 (i.e. a total of 462 taxa: species and infraspecific species). Overall, the most commonly represented families were the Poaceae (107 species and subspecies), Asteraceae (81), Fabaceae (55) and Anacardiaceae (16), with other families represented by just one to 14 species. Only 60 species were common to all three regions, and of these 24 had been introduced during rehabilitation attempts. Most of the species found on tailings were persisters or natural colonizers (53-88%, depending on substrate), with the vast majority being indigenous and perennial taxa (76% and 85% respectively), with semi-woody to woody growth forms (66% being resprouters, forbs, shrubs and trees). Less than 4% of the naturally-colonizing taxa found during the survey had also been introduced by vegetation practitioners. The majority of introduced plants were alien herbaceous taxa. The number and frequency of annuals was only high on recently vegetated sites, whereas annuals were rarely present on old-vegetated and never-vegetated dams. This list includes a wide range of indigenous plant species that may be suitable for phytoremediation of tailings dams and polluted soils due to their apparent tolerance of acid mine drainage and salinity.

INTRODUCTION

Tailings storage facilities (TSF) containing waste rock or milled rock slurry from the gold and uranium-mining industry, cover vast areas in South Africa. Gold TSF and 'footprints' (the area of contaminated soil and residual slimes left behind after re-mining of the original TSF) cover about 400 km^2 in the Witwatersrand Basin goldfields alone, comprising about 6 billion tonnes of gold and uranium tailings (Chevrel *et al.* 2003), and contain an estimated 430 000 tons of uranium (Council for Geosciences 1998; Winde 2004a, b, c) and approximately 30 million tonnes of sulphur (Witkowski & Weiersbye 1998). The volume of waste generated by mining in South Africa increases at the rate of 315 million tonnes per annum, mostly in the form of tailings, of which 105 million tonnes per annum is generated by the gold mining industry on the Witwatersrand Basin alone, at the rate of 200 000 tonnes of waste per ton of gold (Department of Tourism, Economic and Environmental Affairs, 2002; Chamber of Mines of South Africa, 2004). Environmental degradation from gold TSF spreads far beyond the waste deposit sites in the form of air pollution (Van As *et al.* 1992; Mizelle *et al.* 1995), soil pollution (Coetzee 1995; Rosner & van Schalkwyk 2000; Rosner *et al.* 2001; Witkowski & Weiersbye 1998a) and pollution of streams, rivers, dams and sediments (Funke 1990; Pulles 1992; Hodgson *et al.* 2001; Naiker *et al.* 2003; Tutu et al. 2003; Coetzee *et al.* 2004; Winde *et al.* 2004a, b, c). Since the TSF for slurry (referred to as slimes dams) are elevated above the natural ground contours and have steep slope angles, they are particularly susceptible to erosion (Mizelle *et al.* 1995; 1996). Whereas erosion from agricultural fields may be as high as 10 to 15 tons ha^{-1} year^{-1}, losses from the slopes of gold slimes dams may exceed 500 tons ha^{-1} year^{-1} (Blight 1991). Erosion and acid mine drainage from gold slimes dams have severe impacts on nutrient cycling in polluted soils (Witkowski & Weiersbye 1998a), on the regeneration of vegetation (Witkowski & Weiersbye 1998b; Weiersbye & Witkowski 2003) and on the biogeochemical cycling of potentially toxic elements (Weiersbye *et al.*1999; Winde *et al.* 2004a, b; Weiersbye & Cukrowska 2005).

Prior to 1991, South Africa had little legislation specifically directed towards environmental protection from mining impacts, although recommendations and statutes existed for the structure and abandonment of tailings dams (James 1964; James & Mrost 1965; Chamber of Mines of South Africa 1968, 1979; Blight 1969). Mines did not have a legal obligation to prevent dust pollution until the promulgation of the Atmospheric Pollution Prevention Act 45 (1965), amended in 1973. The Chamber of Mines Guidelines (1979) recommend that wind and water erosion of dams be controlled by the most practical means possible using the BATNEEC (Best Available Technology Not Entailing Excessive Cost) concept. Erosion control included covering the surface of tailings dams with waste rock, or vegetating the tailings; the latter ('grassing') is still considered the most effective means of reducing dust by the industry. This acceptability is based on the speed with which the grass cover establishes, rather than on its long-term persistence or effective erosion control. The earliest recorded attempts at rehabilitation (dust control) of gold tailings dams on the Witwatersrand occurred in 1894, with the planting of *Ammophila* sp. (seed from Kew Gardens, UK), and have been followed by a series of vegetation trials between 1932 and the present day (Thatcher 1979; Weiersbye &

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Witkowski 1998). Slimes dams are inhospitable environments for plant growth, and various combinations of leaching, liming, fertilization and irrigation are used to facilitate the growth of a small suite of herbaceous, mostly pasture species. As predicted by Halliday (1978), the grass cover achieved is temporary and the methods have proven economically and ecologically unsustainable (Thatcher 1979; Weiersbye & Witkowski 1998; Witkowski & Weiersbye 1998a, b). The cost of grassing the steep (30°–45°) slopes of tailings dams ranged from R70 000 to R160 000 ha^{-1} in the period 1994 to 2002, whereas the cost of grassing the flat tops of dams and dam 'footprints' (polluted areas left after the dam itself has been removed for re-processing to recover residual gold) was between R10 000 and R60 000 ha^{-1} during the same period (Weiersbye & Witkowski 2002a; Weiersbye *et al.* 2002). Although grassing and irrigation of tailings dam slopes significantly abates wind-borne erosion in the short term (Blight 1991), long-term erosion control and containment of water pollution from gold TSF by grassing has been unsuccessful (Blight 1991, 1998; Weiersbye & Witkowski 1998; Rosner *et al.* 2001).

South Africa now has some of the most stringent environmental legislation in the world, with the right to a healthy environment elevated to a basic human right in the Constitution of South Africa (Act No. 108 of 1996). A number of Acts stress the responsibility of industry to prevent environmental damage, and provide for the prosecution of polluters. These include the Environment Conservation Act (ECA) No. 73 of 1989 and ECA Amendment Act 50 of 2003, the Conservation of Agricultural Resources Act No. 43 of 1983 and amendments of 2001, the National Environmental Management Act 107 of 1998 and amendments, the National Water Act 36 of 1998, the National Nuclear Regulator Act 47 of 1999, the National Environmental Management: Biodiversity Act No. 10 of 2004, the National Environmental Management: Air Quality Act No. 39 of 2004, the Minerals and Petroleum Resources Development Act 28 of 2002, the National Environmental Management: Protected Areas Act No. 57 of 2003, and the National Environmental Management Amendment Act No. 46 of 2003, which facilitated the 'Green Scorpions' unit to investigate environmental offences. In addition, the new regulatory framework for water usage renders industry liable for the cost of water used, and polluted, as a result of operations and rehabilitation under the new Waste Discharge Charge System of the Department of Water Affairs and Forestry. This environmental legislation means that novel, sustainable and cost-effective methods of containing pollution from tailings dams, have to be established.

The aim of this study was to undertake a broad-scale survey of the plant species composition on gold and uranium slimes dams, and slimes-polluted soils, in the deep-level mining regions of South Africa. The underlying rationale was to assess the feasibility of a more sustainable ecological engineering and phytoremediation approach to slimes dam rehabilitation, through identifying a greater suite of suitable species. The dams surveyed ranged in age (from 9 to 58 years since commissioning), in planted vegetation status (present or absent) and in the time elapsed since planting of vegetation (from 3 to ± 50 years). The survey objectives were: (i) to provide a systematic list of indigenous and alien plant species found on slimes dams, and slimes-polluted soils; (ii) to distinguish natural colonizers and persisters (i.e. individuals present prior to slimes deposition but still surviving despite the new conditions) from species intentionally introduced during vegetating attempts; (iii) to broadly classify species according to functional groups; (iv) to assess the number of plant species and their frequency on tailings dams differing in vegetation history at each mining locality; and (v) to assess the number of plant species and their frequency on each of the different substrates that together constitute a tailings dam. These substrates were identified in a parallel study and are characterized mainly by differences in slope angle, elevation (i.e. time since slurry deposition), texture, soil organic matter, water content, conductivity, pH and redox potential (Witkowski & Weiersbye 1998a).

THE STUDY AREA

Vegetation, soils and climate

The study was carried out at Anglo American Ltd (subsequently AngloGold, and FreeGold) mines in the Gauteng, North-West and Free State Provinces. Tailings dams situated around Carletonville (Gauteng), Klerksdorp (North-West) and Welkom (Free State) were surveyed for plant species composition. The survey covered ± 12 000 ha, situated within an overall area of 150 × 100 km over the Upper Witwatersrand Basin, on the West Wits, Vaal and Welkom Reefs (Figure 1). All tailings dams at the West Wits and Elandsrand gold mines (Gauteng), at the Vaal River and Afrikaander gold mines (North-West), and at the Free State Gold, Freddies, Western Holdings, President Brand, President Steyn, Free State Saaiplaas and Free Gold mines (Free State) were included in the survey. Most of the surveyed tailings dams occur within the Grassland Biome (Acocks 1988; Rutherford & Westfall 1994; O'Connor & Bredenkamp 1997), with one dam in the east occurring in the transition zone between grassland and savanna (Afrikaander Leases in the North-West). The Vaal River and Afrikaander dams are situated on doleritic and sandy soils within the A2 vegetation subdivision (O'Connor & Bredenkamp 1997) of the Grassland Biome at an altitude of 1 300 to 1 350 m. The Free State dams occur on clayey to sandy soils within the A2 and B3 subdivisions at 1 300 to 1 400 m. The Carletonville dams are constructed on rocky quartzite, shale and dolomitic soils in the C6+7 subdivisions at 1 600 to 1 650 m. Tailings dams in the Carletonville region are situated within various combinations of bankenveld, xeric grassland (klipveld) and *Acacia karroo* savanna (Acocks 1988). The main veld type in the Vaal River and Afrikaander mine areas is a combination of dry transitional *Cymbopogon-Themeda* veld, with some development of a mixed grassy false Karoo veld, and dry *Cymbopogon-Themeda* veld. However, most of the surveyed dams here were surrounded by xeric grassland (klipveld) and *Acacia karroo* savanna (Bredenkamp & Brown 1995a, b). In the Welkom mine lease area, most dams are surrounded by mesic to seasonally inundated hydromorphic grassland on clays, endorheic saline pans supporting halophytic grasses, sedges and *Atriplex* spe-

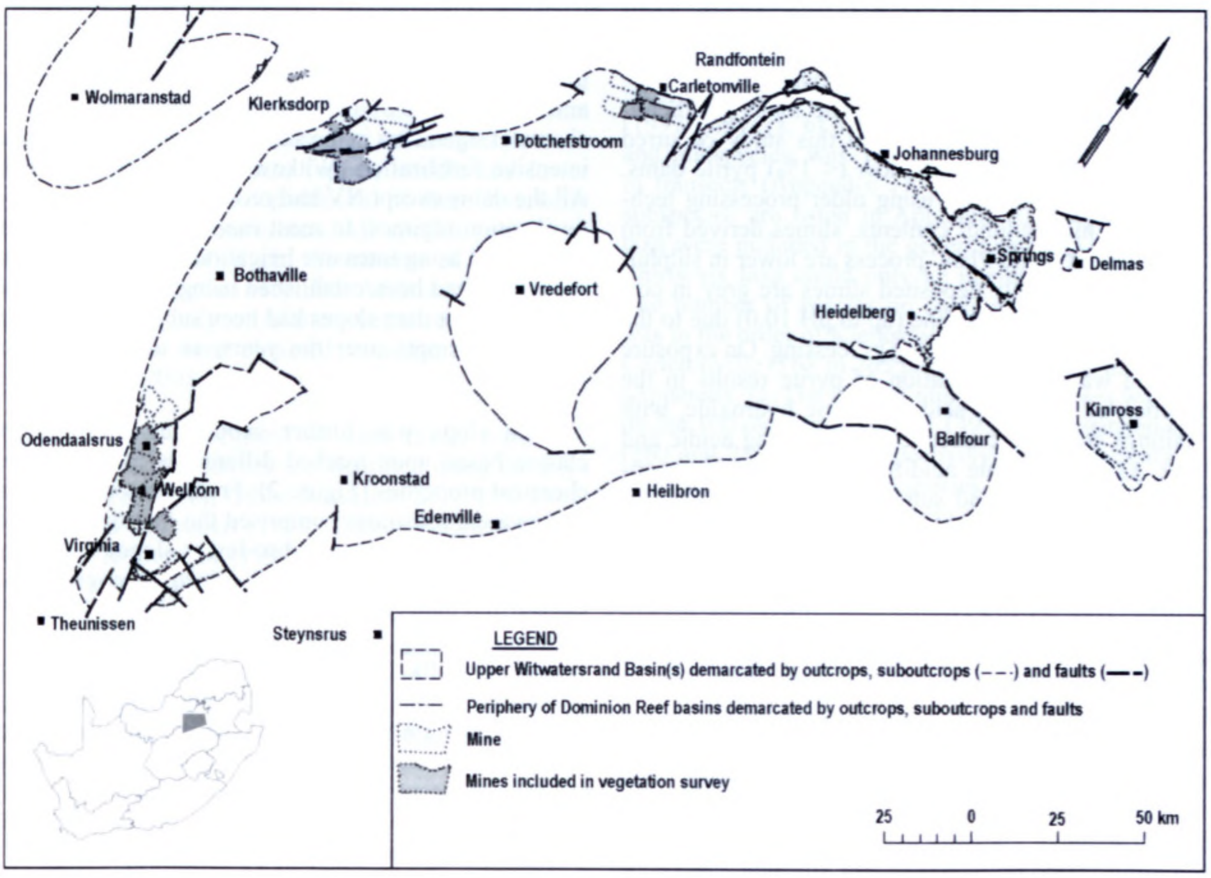

FIGURE 1.—Sketch map showing the location of the study sites (dark grey shading), in relation to the Witwatersrand Basin (light grey shading) (after Anhauser 1987).

cies, and perennial swamps dominated by *Phragmites australis* and *Tamarix* spp. Two tailings dams near Carletonville, three near Klerksdorp, and most of the Welkom dams are situated on pans, vleis or streams.

The climate of the region surveyed is highly seasonal and falls within the Austral summer rainfall belt (Schulze 1997). Mean annual precipitation is 662, 630 and 604 mm for Carletonville, Klerksdorp and Welkom respectively, with high inter-annual variability (25–30%). The regions all experience seasonal extremes of temperature. Mean daily minima (July) and maxima (January) were 0–2 °C and 25–27.5 °C respectively for Carletonville and Klerksdorp, and < 0 °C and 27.5–30 °C respectively for Welkom during the study period. Evaporation is 2–2.5× higher than rainfall, frosts occur frequently in winter (mean frost days is 150–175) (Schulze 1997), and frequent veld fires occur in winter. Regional land use includes cattle and game farming (rangelands), maize and sunflower cropping. Wastelands (derelict, degraded lands with little plant cover) and swampy lands inundated by seepage from slimes dams are common within these landscapes.

Tailings dam construction and composition

The dams were constructed using the paddock system, which involves construction of peripheral slimes dykes during the day ('day walls'), and filling of the central dam ('night pan') with slimes slurry during the night (Mcphail & Wagner 1987). Excess water is drained away during construction and the construction rate of the dam is limited by the drying rate of the day walls. Moisture content is high on the tops and upper slopes of current dams due to the deposition of fresh slurry, and decreases with distance down the slope. Moisture content increases sharply again at the base of the lower slope and in the toe-paddock due to seepage from the dam. The slopes of the dams surveyed ranged between 29° and 35°; these steep slopes result in high erosive losses (Blight 1991).

The tailings are derived from gold and uranium-bearing conglomerates associated with the sediments of the Witwatersrand Basin up to 4 000 m below surface. Pyrite is the dominant sulphide in the conglomerates, up to 3% of the ore mass, with an additional 2% of other sulphides namely, pyrrhotite, galena, cobaltite, arsenopyrite and chalcopyrite (Anhaesser 1987). The 'all sliming' process was introduced in 1921. Slimes particles are cohesionless, predominantly silicaceous and of the size range associated with clays and silts (Clausen 1973); the deposition of such fine particles in an aqueous slurry results in dense compaction and poor aeration in the rooting zone. However, the reactive clay content is negligible, with slimes consisting primarily of unreactive quartz and pyrophyllite. The virtual absence of organic matter contributes further to the negligible cation exchange capacity. The chemical composition of the slimes surveyed varied according to the parent substrate, the metallurgical recovery ('sliming') process used, the composition of the mined ore and the age of the deposits (Bosch 1987; Witkowski & Weiersbye 1998a). The main geochemical divisions of slimes deposits in this study occurred between high (up to 5%) and low (< 1%) pyrite dams. Although slimes produced using older processing techniques have high sulphur contents, slimes derived from the more recent 'Acid Plant' process are lower in sulphur (Bosch 1987). Freshly deposited slimes are grey in colour, saline, moist and alkaline (up to pH 10.0) due to the addition of liming agents during processing. On exposure to air and water, the oxidation of pyrite results in the production of sulphuric acid and ferric hydroxide, with the tailings substrate consequently becoming acidic and yellow. As the substrate acidifies, ferric iron also contributes to oxidation, and sulphur-utilizing *Thiobacillus* bacteria that occur in the tailings facilitate further ferrous oxidation (James & Mrost 1965; Bradshaw & Chadwick 1980). On the slopes of current dams there is consequently a steep pH and acidity gradient between the top (comprising recent, alkaline deposits) and the base comprising older deposits of increasing acidity (Witkowski & Weiersbye 1998a).

METHODS

Site classification

The tailings dams varied in age (from 9 to 58 years since commissioning), in planted vegetation status (vegetated or never vegetated) and in the time elapsed since planting of vegetation (from 3 to ± 50 years ago). The tailings dams were grouped according to region (Carletonville, Klerksdorp, Welkom), and slopes were classed according to their vegetation history. Vegetation history classes were: (i) recently-vegetated (RV) slopes: amelioration (liming, fertilizing, seeding and irrigation) had ceased >1 to < 4 years previous to 1996; (ii) old-vegetated (OV) slopes: amelioration had ceased > 4 < 50 years previously; and (iii) never-vegetated (NV) slopes: slopes on record as never having been intentionally ameliorated or vegetated. Vegetation records (dates and duration of planting, method and lists of species used) were obtained from vegetation contracts stored with the individual mines and from vegetation contractors. Most dams have had some form of vegetating attempted during the last 50 years. Distinguishing very OV slopes (> 20 years ago) from NV slopes was made difficult both by poor record-keeping prior to the 1980s, and the rapid reversal of vegetated slopes to eroded, seemingly never-vegetated conditions. This necessitated a forensic approach to determining whether or not a dam had previously been vegetated. Previously vegetated areas were identified from old photographs (including aerial survey), and the remains of old plantings, irrigation pipes and chemical signatures in the slimes as a result of liming and intensive fertilization (Witkowski & Weiersbye 1998a). All the dams except NV had received similar liming and fertilization regimes. In most cases vegetation had been established using intensive irrigation, and in seven cases, vegetation had been established using dry-land methods. In many cases dam slopes had been subjected to repeated grassing attempts over the years, as each attempt had failed.

Each slope was further subdivided into substrate classes based upon marked differences in physical and chemical properties (Figure 2). From the top of the dam downwards, substrates comprised the flat tops, upper-to-mid slopes and berms, mid-to-lower slopes and berms, retaining walls (rock and soil mixed or overlaid with slimes) and toepaddocks (a strip of veld from 20 to 60 m wide surrounding the base of the dam and bordered by an earthen wall). The toepaddocks are heavily inundated by slimes, strongly acidic and often damp (Witkowski & Weiersbye 1998a). The tops, berms and slopes were further categorized according to whether they comprised younger or recently ameliorated and marginally acidic to alkaline (pH > 6.0) slimes deposits, or older and more acidic (pH < 5.9) slimes deposits.

Sampling methods

Lists of species planted on each tailings dam, and planting methods, were obtained from vegetation contracts and assessments archived with Anglo American Mines and from individual contractors, from unpublished theses and reports (including those lodged with individual mines and the Chamber of Mines of South Africa; Thatcher 1979 (and references therein); Wiegenhagen 1996) and from publications (James & Mrost 1965; Wild & Wiltshire 1971; Cresswell 1973; Grove 1974; Clausen 1976; Bradshaw & Chadwick 1980). Two replicate surveys were carried out on the same dams within a nine-month period, in winter (June to September, 1996; Witkowski & Weiersbye 1996) and subsequently in summer (December 1996 to March 1997; Weiersbye & Witkowski 1997). Fifty-six tailings dams comprising 738 different slopes with the same number of toepaddocks were assessed. Intensive searches were carried out on dams, retaining walls and toepaddocks. These comprised (i) large-scale assessments of vegetation cover (data not

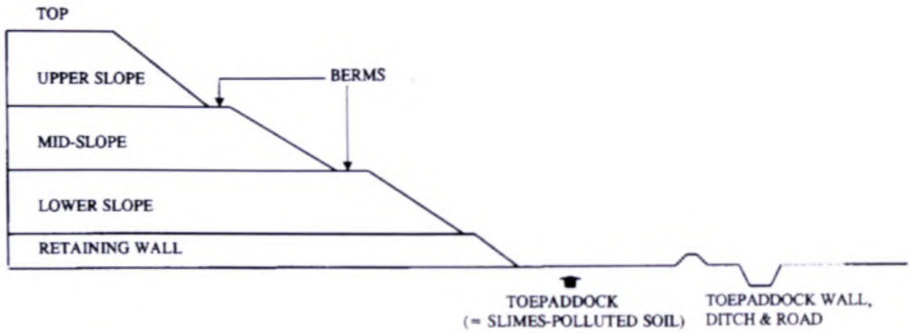

FIGURE 2.—Aspect of a gold slimes dam divided into the substrate classes.

shown, Weiersbye & Witkowski 1998), vegetation structure (proportions of trees and shrubs, forbs and herbs, and grasses) and species presence on all 738 slopes, retaining walls and toepaddocks; and (ii) 254 one hundred metre wide belt transect surveys on a sub-suite of dams (those which had > 0.5% aerial vegetation cover). Data from these 100 m belt transects were then subdivided for each substrate on the slimes dam (upper, middle and lower slopes, tops, berms and toepaddocks) as these invariably differed in species composition. All species present on transects were identified and the number of individuals present for most species recorded. Additional records of species presence only on slimes dams, retaining walls and toepaddocks were obtained from the same mines during 1998 to 2003.

Representative specimens of each taxon were collected and pressed. Plants were identified using the keys of Dyer (1975, 1976), Gibbs Russell *et al.* (1985, 1987, 1991), Venter & Joubert (1985), Coates-Palgrave (1996) and Retief & Herman (1997), and by comparison with specimens at the C.E. Moss and National Herbariums (PRE) of South Africa. Taxa were named according to Arnold & De Wet (1993). A few taxa (reputedly introduced from Namibia and the Northern Cape) defied identification beyond genus. Voucher specimens have been lodged with the C.E. Moss Herbarium, University of the Witwatersrand.

Data classification

Species, subspecies and varieties found in the 100 m transect survey (n = 327) were categorized according to their % frequency of occurrence: (i) overall, (ii) in each of the three regions, (iii) on dams of different vegetation history classes, and (iv) on each substrate class. The relative contribution of each family (in terms of component species) was also calculated for each slimes dam substrate class.

Using the 1998 PRECIS database and vegetation distribution records (Arnold & De Wet 1993; Retief & Herman 1997), all species, subspecies and varieties found during the 1996–1997 survey (n = 376) were categorized for each dam substrate and overall according to: (i) whether they were indigenous to South Africa or alien (including naturalized species), and (ii) whether they were indigenous to each of the three regions surveyed. Species were also grouped on the basis of: (iii) annual or perennial habit; (iv) broad growth habit (shrubs and trees, forbs and perennial herbs, annual herbs, annual and perennial grasses); and (v) whether they were persisters or naturally colonizing species, or intentionally planted on dams, or combinations. Persisters were generally considered to be plants that pre-dated slimes dam construction. These were categorized as old woody plants present on toepaddocks and/or growing through retaining walls, but usually not present on other substrates. Naturally colonizing species were those present on other substrates (berms and/or slopes and/or tops), either solely or in addition to being present on toepaddocks and/or retaining walls. All non-woody species present on retaining walls were categorized as natural colonizers. Species found subsequent to the survey in 1998 to 2003 (n = 86) were not included in the frequency analysis or categorization.

RESULTS

Broad species-compositional patterns

A total of 376 species, subspecies and varieties were recorded during the intensive winter (1996) and summer (1997) surveys, of which the frequency of 327 species and subspecies was recorded using the detailed 100 m transects (Appendix 1). The other (49) species and subspecies are listed in Appendix 2. However, all 376 taxa were included in the general analyses (Tables 1–5). Thirty-six taxa could only be identified to genus level. The number of species on dams in the three provinces was in the order of Klerksdorp (216 species in 1 488 ha), Carletonville (168 in 765 ha), Welkom (120 in 3 611 ha) (Appendix 1). The highest number of species was found on the 100 old-vegetated and 139 never-vegetated slopes (260 and 231 species respectively). The 15 recently-vegetated slopes contained 86 species, of which 21 had been intentionally introduced during grassing, with another 18 weedy annuals and short-lived perennials.

Most species occurred on toepaddocks and retaining walls (287 and 264 species respectively, of which 246 and 231 respectively were natural colonizers and persisters), followed by the acidic slopes (149 species of which 106 were natural colonizers) and acidic tops and berms (137 species of which 103 were natural colonizers). Species composition differed markedly between substrates (Appendix 1). Only 32 species (14 of which had been introduced) were common to more than five substrates, and 161 (16 of which had been introduced) occurred on just one or two substrates. When considering species common to tops and berms and slopes, only six species were common to both acidic (pH < 6.0) and marginally acidic to alkaline substrates (pH ≥ 6.0), whereas for tops and berms only, 12 species were common to both acidic and marginally acidic to alkaline substrates. For slopes, 28 species were common to both acidic and marginally acidic to alkaline substrates. Sixty species were common to flat and sloped acidic substrates, and just eight were common to flat and sloped marginally acidic to alkaline substrates. Of the 376 taxa recorded during the survey, only 60 were common to all three mining regions, and of these, 24 were introduced during vegetating attempts (Appendix 1). Only 10% of taxa overall (including < 4% of those which were natural colonizers and persisters) are known to have been introduced during vegetating attempts (Table 1; Appendix 1).

In addition to the 376 taxa, 86 taxa (species, subspecies and varieties) were recorded from 1998 to 2003 (Appendix 3), but were not included in the general analyses (Tables 1–4) or frequency survey (Appendix 1). Of the 86 taxa listed in Appendix 3, 40 were introduced species (three were indigenous trees), and 46 natural colonizers and persisters (39 were indigenous). Thus a grand total of 462 taxa (species, subspecies and varieties) have been identified on gold mine tailings and tailings-polluted soils in the three regions.

Plant families and higher taxa

No gymnosperms were found on slimes during the survey (two species were found post-survey). Dicotyledons dominated the vegetation on all substrates. The high-

TABLE 1.—Percentages of persisting, naturally colonizing and intentionally introduced plants on each substrate class for surveyed slimes dams. Categories mutually exclusive and values in parentheses are no. taxa found (species, subspecies and varieties, $n = 376$). Note that category 'introduced and colonizing' is for those introduced species that can also colonize unaided

Substrates	Persisters	Naturally colonizing	Intentionally introduced	Introduced & colonizing	Total no. taxa
Tops & berms (pH ≥ 6)	7.0 (4)	45.6 (26)	19.3 (11)	28.1 (16)	(57)
Tops & berms (pH < 6)	0 (0)	75.2 (103)	2.2 (3)	22.6 (31)	(137)
Slopes (pH ≥ 6.0)	0 (0)	59.6 (31)	11.5 (6)	28.9 (15)	(52)
Slopes (pH < 6.0)	0 (0)	71.1 (106)	13.4 (20)	15.4 (23)	(149)
Retaining wall (pH < 6)*	29.2 (77)	58.3 (154)	3.0 (8)	9.5 (25)	(264)
Toepaddock (pH < 6)	32.8 (94)	53.0 (152)	3.8 (11)	10.5 (30)	(287)

* Twenty-one taxa included here as persisters occurred only on retaining walls and may actually be natural colonizers.

est proportion of monocot taxa was observed on the two moistest and on flat substrates (regardless of pH): 35% on tops and berms, and 31% on toepaddocks. The majority of monocots on these two substrates were grasses (up to 28%), with Asparagaceae, Hyacinthaceae, Hypoxidaceae and Juncaceae each contributing up to 1.8% of the total taxa on the former substrate, and Alliaceae, Amaryllidaceae, Asphodelaceae, Commelinaceae, Cyperaceae and Typhaceae only present on toepaddocks, with each of the latter families containing just 0.3–1.0% of the total species detected (Appendix 1 & 2).

The dominant families represented overall were the Poaceae (containing 23.4% of all species found), Asteraceae (17.2%), Fabaceae (10.5%) and Anacardiaceae (3.8%), with other plant families containing between 0.3% and 3.5% of the total (Table 2; Appendices 1 & 2). A similar pattern was observed on toepaddocks and retaining walls. On acidic (pH < 6.0) substrates (tops, berms and slopes), most species belonged (in descending order of frequency) to the Asteraceae, Poaceae, Fabaceae and Chenopodiaceae, whereas on marginally acidic to alkaline (pH ≥ 6.0) substrates (tops, berms and slopes) most species belonged to the Poaceae, Fabaceae and Asteraceae, followed by equal representation of the Anacardiaceae, Chenopodiaceae and probably the Tamaricaceae. Identification of *Tamarix* spp. was difficult due to the presence of putative hybrids between *T. usneoides*, *T. ramosissima*, *T. chinensis*, *T. gallica* and *T. aphylla*. Genera represented by ≥ 4 species on slimes dams were *Acacia* (12 spp.), *Aristida* (7), *Asparagus* (4), *Eragrostis* (8), *Felicia* (4), *Helichrysum* (6), *Hermannia* (4), *Paspalum* (5), *Rhus* (12), *Senecio* (6), *Solanum* (6) and *Sporobolus* (4) (Appendix 1). An additional two *Acacia* spp., five *Eragrostis* spp., five *Helichrysum* spp., three *Rhus* spp., three *Senecio* spp. and two *Sporobolus* spp. were recorded subsequent to the survey (Appendices 2 and 3).

Indigenous versus alien species

The survey yielded a total of 90 alien species (including naturalized species) and 286 species indigenous to the southern African region. Fifty-five alien and 152 indigenous species occurred on tailings dams (slopes, berms and tops), whereas 59 alien and 143 indigenous species occurred on retaining walls and toepaddocks (Appendix 1). Eight alien and 14 indigenous species (of which four had been introduced to dams from other regions) occurred only on dams, and not on polluted soils. Overall, the majority of species growing on slimes (76.1%), and the vast majority of natural colonizers and persisters were indigenous to southern Africa (Table 3), with most (91%) normally found in the local province (Table 4). With the exception of marginally acidic to alkaline slopes (where numbers of indigenous species only slightly exceeded those of alien species), the same pattern prevailed on all slime substrates.

Species characteristic of particular substrates

The number of naturally colonizing and persisting species was higher on acidic (pH < 6.0) substrates, in order of abundance: retaining walls and toepaddocks > slopes and tops and berms > marginally acidic to alkaline (pH ≥ 6.0) substrates (Table 1). Although species number was slightly higher on slopes than on flat substrates (tops & berms), overall vegetation cover was always much higher on flat surfaces (Weiersbye & Witkowski 1998). On marginally acidic to alkaline substrates, a relatively high proportion of introduced taxa were also natural colonizers (28–30%, Table 1). However, once the substrate became more acidic (pH < 6.0), this proportion decreased to 10–23%. Few species (8–11%) on retaining walls and toepaddocks had been introduced. These two substrates had the highest levels of vegetation cover and number of species, dominated by indigenous, naturally colonizing and persisting perennial taxa (Appendix 1).

Ecological traits of species

The vegetation of tailings was dominated by perennial species (Table 5), with most also characterized by a deciduous habit. The majority of natural colonizers and persisters were perennial plants, whereas the majority of introduced species were annual and short-lived perennials (Table 5, Appendices 1, 2 and 3). Very few indigenous, perennial species had been intentionally introduced to

TABLE 2.—Percentages of alien (including naturalized) and indigenous plants on tailings dams. Values in parentheses are no. taxa (species, subspecies and varieties) found

Substrates	Alien	Indigenous
Tops and berms (pH ≥ 6.0)	38.6 (22)	61.4 (35)
Tops and berms (pH < 6.0)	24.8 (34)	75.2 (103)
Slopes (pH ≥ 6.0)	44.2 (23)	55.8 (29)
Slopes (pH < 6.0)	28.9 (43)	71.1 (106)
Retaining wall (pH < 6.0)	18.2 (48)	81.8 (216)
Toepaddock (pH < 6.0)	20.2 (58)	79.8 (229)
All substrates combined	23.9 (90)	76.1 (286)

TABLE 3.—Percentages of taxa occurring on particular substrates within plant families (n = 65) during 1996 to 1997 survey. Values in parentheses are actual no. taxa (species, subspecies and varieties) found

	Tops and berms (pH ≥ 6.0) (n = 57)	Tops and berms (pH < 6.0) (n = 137)	Slopes (pH ≥ 6.0) (n = 52)	Slopes (pH < 6.0) (n = 149)	Retaining walls (pH < 6.0) (n = 264)	Toepaddocks (pH < 6.0) (n = 287)	All substrates combined (n = 376)
Acanthaceae					0.8 (2)	1.0 (3)	0.8 (3)
Aizoaceae	1.8 (1)	1.5 (2)	5.8 (3)	2.7 (4)	2.3 (6)	1.0 (3)	1.6 (6)
Alliaceae						0.3 (1)	0.3 (1)
Amaranthaceae		2.2 (3)	1.9 (1)	2.7 (4)	1.9 (5)	0.7 (2)	1.6 (6)
Amaryllidaceae						0.3 (1)	0.3 (1)
Anacardiaceae	7.0 (4)	2.2 (3)	1.9 (1)	3.4 (5)	4.2 (11)	3.8 (11)	3.8 (14)
Apocynaceae					0.4 (1)	0.3 (1)	0.3 (1)
Asclepiadaceae	1.8 (1)	0.7 (1)	1.9 (1)	1.3 (2)	1.1 (3)	1.0 (3)	0.8 (3)
Asparagaceae	1.8 (1)	0.7 (1)	3.8 (2)	0.7 (1)	1.5 (4)	1.4 (4)	1.1 (4)
Asphodelaceae		0.7 (1)			0.4 (1)	0.7 (2)	0.5 (2)
Asteraceae	7.0 (4)	26.3 (36)	15.4 (8)	21.5 (32)	21.6 (57)	16.4 (47)	17.2 (65)
Boraginaceae					0.4 (1)	0.3 (1)	0.3 (1)
Brassicaceae		2.2 (3)	1.9 (1)	2.0 (3)	1.1 (3)	0.7 (2)	1.1 (4)
Cactaceae				0.7 (1)		0.3 (1)	0.3 (1)
Capparaceae						0.3 (1)	0.3 (1)
Caryophyllaceae	1.8 (1)	0.7 (1)	1.9 (1)	0.7 (1)	0.4 (1)	0.3 (1)	0.3 (1)
Celastraceae	3.5 (2)			1.3 (2)	0.8 (2)	0.7 (2)	0.5 (2)
Chenopodiaceae	5.3 (3)	2.9 (4)	5.8 (3)	5.4 (8)	1.5 (4)	2.4 (7)	2.4 (9)
Commelinaceae					0.4 (1)	0.3 (1)	0.3 (1)
Convolvulaceae		1.5 (2)		1.3 (2)	1.9 (5)	1.7 (5)	1.3 (5)
Crassulaceae		0.7 (1)	1.9 (1)	0.7 (1)			0.3 (1)
Cucurbitaceae	1.8 (1)	0.7 (1)	1.9 (1)	2.0 (3)	1.9 (5)	2.1 (6)	1.6 (6)
Cyperaceae		0.7 (1)				1.0 (3)	0.8 (3)
Dichapetalaceae					0.4 (1)	0.3 (1)	0.3 (1)
Dipsacaceae					0.4 (1)	0.3 (1)	0.3 (1)
Ebenaceae	1.8 (1)			0.7 (1)	2.3 (6)	2.1 (6)	1.6 (6)
Euphorbiaceae		0.7 (1)			1.9 (5)	1.7 (5)	1.6 (6)
Fabaceae	15.8 (9)	12.4 (17)	7.7 (4)	8.7 (13)	7.6 (20)	10.8 (31)	10.5 (39)
Geraniaceae				0.7 (1)	1.1 (3)	1.0 (3)	1.1 (4)
Hyacinthaceae	1.8 (1)				0.4 (1)	1.0 (3)	0.8 (3)
Hypoxidaceae	1.8 (1)					0.7 (2)	0.5 (2)
Illecebraceae					0.4 (1)	0.3 (1)	0.3 (1)
Juncaceae	1.8 (1)	0.7 (1)		0.7 (1)	0.4 (1)	0.3 (1)	0.3 (1)
Lamiaceae		2.2 (3)	1.9 (1)	1.3 (2)	2.3 (6)	1.4 (4)	1.6 (6)
Malvaceae		0.7 (1)			1.2 (3)	0.7 (2)	0.8 (3)
Meliaceae	1.8 (1)					0.3 (1)	0.3 (1)
Menispermaceae				0.7 (1)	0.4 (1)	0.3 (1)	0.3 (1)
Mesembryanthemaceae		1.5 (2)	1.9 (1)	4.7 (7)	0.8 (2)	0.7 (2)	2.2 (8)
Moraceae					0.4 (1)		0.3 (1)
Myrtaceae				2.0 (3)	0.8 (2)	1.0 (3)	1.1 (4)
Oleaceae	1.8 (1)	0.7 (1)			0.4 (1)	0.3 (1)	0.5 (2)
Onagraceae		0.7 (1)			0.4 (1)		0.3 (1)
Papaveraceae				0.7 (1)	0.4 (1)		0.3 (1)
Pedaliaceae					0.4 (1)	0.3 (1)	0.3 (1)
Phytolaccaceae		0.7 (1)	1.9 (1)	0.7 (1)	0.4 (1)	0.3 (1)	0.3 (1)
Poaceae	28.1 (16)	24.1 (33)	23.1 (12)	21.5 (32)	20.1 (53)	24.0 (69)	23.4 (87)
Polygalaceae					0.4 (1)	0.3 (1)	0.3 (1)
Polygonaceae				0.7 (1)	0.4 (1)	0.3 (1)	0.3 (1)
Proteaceae					0.4 (1)	0.3 (1)	0.3 (1)
Ranunculaceae		0.7 (1)		0.7 (1)	0.4 (1)	0.3 (1)	0.3 (1)
Resedaceae			1.9 (1)	0.7 (1)		0.3 (1)	0.3 (1)
Rhamnaceae	1.8 (1)			0.7 (1)	0.8 (2)	0.7 (2)	0.5 (2)
Rosaceae						0.3 (1)	0.3 (1)
Rubiaceae		1.5 (2)		1.3 (2)	1.1 (3)	2.1 (6)	2.2 (8)
Santalaceae					0.4 (1)	0.3 (1)	0.3 (1)
Sapindaceae					0.4 (1)	0.3 (1)	0.3 (1)
Scrophulariaceae		0.7 (1)			0.4 (1)	0.3 (1)	0.3 (1)
Selaginaceae	1.8 (1)				0.8 (2)	0.3 (1)	0.5 (2)
Solanaceae	3.5 (2)	2.9 (4)	7.7 (4)	2.0 (3)	3.8 (10)	2.4 (7)	3.5 (13)
Sterculiaceae		0.7 (1)		0.7 (1)	1.5 (4)	1.4 (4)	1.1 (4)
Tamaricaceae	* (3–5)	*(3–5)	* (3–5)	* (3–5)	* (3–5)	* (3–5)	1.3 (5)
Tiliaceae	1.8 (1)	0.7 (1)		1.3 (2)	1.1 (3)	1.0 (3)	0.8 (3)
Typhaceae						0.3 (1)	0.3 (1)
Ulmaceae	1.8 (1)		1.9 (1)	0.7 (1)	0.4 (1)	0.7 (2)	0.5 (2)
Verbenaceae		2.2 (3)	1.9 (1)	0.7 (1)	1.9 (5)	1.0 (3)	1.3 (5)

*Percentages could not be calculated for Tamaricaceae as some of the 5 species were not always distinguishable in the field.

TABLE 4.—Percentages of occurrence of plant species found on tailings dams (based on PRECIS database). Values in parentheses are no. taxa (species, subspecies and varieties) found

Substrates	Not found in region	Found in region
Tops and berms (pH ≥ 6.0)	14.0 (8)	86.0 (49)
Tops and berms (pH < 6.0)	10.9 (15)	89.1 (122)
Slopes (pH ≥ 6.0)	17.3 (9)	82.7 (43)
Slopes (pH < 6.0)	12.7 (19)	87.3 (130)
Retaining wall (pH < 6.0)	6.4 (17)	93.6 (247)
Toepaddock (pH < 6.0)	6.6 (19)	93.4 (268)
All substrates combined	9.3 (35)	90.7 (341)

slimes. Overall, 84.6% of species were perennials versus 15.4% for annuals and short-lived perennials. The vast majority of species found on slimes overall had semi-woody to woody growth forms: perennial forbs and herbs (47.6%), followed by perennial grasses (18.6%), and shrubs and trees (18.4%), with annual herbs (11.2%) and annual grasses (4.3%) forming minor components (Table 5). A similar pattern was seen on each substrate. The relatively high contribution of shrubs and trees to the persisting vegetation of marginally acidic to alkaline tops and berms (± 30%) was due to the low height (depth of slimes) of three current (recently commissioned) dams included in the survey. These dams contained large live trees that were rooted in the underlying soil and had survived tailings dam construction and inundation by slimes for a number of years. Islands of fertility had formed on the slimes under the canopies of these trees, and contained a number of herbaceous species that were not found on this substrate under any other conditions. Trees and shrubs were often abundant on the lowest reaches of dams (base of lower slope and retaining wall). The large size and/or morphology of many of these plants suggests that they pre-date dam construction, and had grown through the slimes. In contrast, trees and shrubs on the slopes, berms and tops appear to be rooting only within the slimes.

The naturally colonizing and/or persisting taxa comprised mostly woody and semi-woody growth forms, whereas the majority of introduced taxa were herbaceous forms (Appendix 1). The majority of naturally colonizing grasses were C_4 species, while virtually all the introduced grass taxa were pasture species comprising a mixture of C_3 and C_4 taxa (Appendix 1; Gibbs Russell *et al.* 1991). The introduced species mirror the commercial availability of grass seed in South Africa. Most of these species are intended for intensively managed pasture cultivation on agricultural lands, and not for the rehabilitation of low nutrient, saline and acidic tailings dams. In a previous survey of slimes dam tops in Johannesburg, Thatcher (1979) recorded a total of 142 species, 94 of which were also recorded in this survey. Thatcher (1979) also found that the majority of species were natural colonizers and the Asteraceae, Fabaceae and Poaceae were well represented. Woody species diversity was higher on more acidic sites, whereas grasses dominated on less acidic sites.

Few of the 376 species, subspecies and varieties found in the 1996–1997 intensive survey are known to have been intentionally introduced to slimes dams during vegetating attempts over the last 50 years. Some species were introduced to slimes dams in the surveyed region by the Chamber of Mines Vegetation Unit in the 1950s (B. Cook, B. Dawson, J. Easton, pers. comm.) However, it is not known whether existing conspecifics are remnants of the introduced populations, or individuals that have naturally colonized tailings. Some species exhibiting unusual regional distributions may be remnants of these attempts by the Chamber of Mines Vegetation Unit (e.g. *Bassia salsoloides* colonizing old slimes dams in the Welkom region), whereas other species were collected in remote regions and introduced to tailings dams by mine personnel (e.g. *Ruschia* spp. in the Welkom region).

DISCUSSION

This survey found a surprisingly high number of plant species growing on tailings and tailings-polluted soils. Earlier (pre-1980) attempts at vegetating slimes utilized a number of woody, alien species such as Australian acacias (wattles), eucalypts and tamarix in addition to herbaceous legumes and pasture grasses (Thatcher 1979), whereas more recent attempts utilized herbaceous (pasture) species and cultivars. On the basis of old photographs, many of these planted trees still survive on the slopes and tops of tailings dams. Although the contribution of natural colonizers and persisters to cover could be substantial on the flatter surfaces of dams (tops, berms, toepaddocks), the contribution to cover on slopes was extremely low and individual plants were transient due to the high rates of erosion (Weiersbye & Witkowski 1998). The lower number of species found on marginally acidic to alkaline (pH ≥ 6.0) tops, berms and slopes could be due to some influence of pH, but also to the much younger

TABLE 5.—Categories of plants found on gold slimes dams. Values are percentages, and values in parentheses are no. taxa (species, subspecies and varieties) found

Substrates	Annual & biennial herbs (excl. grasses)	Perennial & resprouting herbs & forbs (excl. grasses)	Annual & biennial grasses	Perennial grasses	Shrubs & trees	Total annuals	Total perennials
Tops and berms (pH > 6.0)	7.0 (4)	33.3 (19)	7.0 (4)	22.8 (13)	29.8 (17)	14.0 (8)	86.0 (49)
Tops and berms (pH < 6.0)	15.3 (21)	46.7 (64)	5.8 (8)	17.5 (24)	14.5 (20)	21.2 (29)	78.8 (108)
Slopes (pH > 6.0)	25.0 (13)	38.5 (20)	3.8 (2)	17.3 (9)	15.4 (8)	28.8 (15)	71.2 (37)
Slopes (pH < 6.0)	18.1 (27)	43.0 (64)	4.7 (7)	17.5 (26)	16.8 (25)	22.8 (34)	77.2 (115)
Retaining wall (pH < 6.0)	12.5 (33)	53.0 (140)	2.3 (6)	14.4 (38)	17.8 (47)	14.8 (39)	85.2 (225)
Toepaddock (pH < 6.0)	11.8 (34)	48.0 (138)	3.1 (9)	17.0 (49)	19.9 (57)	15.0 (43)	85.0 (244)
All substrates combined	11.2 (42)	47.6 (179)	4.3 (16)	18.6 (70)	18.4 (69)	15.4 (58)	84.6 (318)

age of these substrates in comparison to acidic (pH < 6.0; i.e. older and more oxidized) substrates, the low number of species introduced to recently ameliorated slopes by contractors, and the fact that many dams were current dams, with slurry still being deposited on the top. As a consequence, the tops of current dams only supported reeds and sedges (*Phragmites* sp. and Cyperaceae), if any vegetation. Marginally acidic to alkaline substrates are also usually further and higher (in altitude) removed from seed sources (i.e. surrounding veld) than the older, acidic substrates on the lower slopes of dams. In addition, vegetating efforts were seldom undertaken on slimes of more recent genesis as the Chamber of Mines vegetation guidelines (1979) recommended a dormant period for slimes dams prior to leaching and grassing.

According to species distributional databases, the pattern of species number found on slimes dams is similar to that for the provinces as a whole, with the North-West and Gauteng having the highest number of species, and the Free State the lowest (Arnold & De Wet 1993; Retief & Herman 1997). At the local scale, many Free State dams occur within a degraded agricultural and semi-industrial setting, with the only natural seed source emanating from wastelands, hydromorphic grasslands, perennial swamps dominated by *Phragmites australis*, and alkaline pans. This landscape context limits the diversity and availability of natural colonizers. Most dams in the North-West and Gauteng region were in close proximity to natural, albeit degraded veld and private (mine) nature reserves, and this environmental setting provides a wider diversity of suitable species for natural colonization.

Of the species identified, < 5% had been actively introduced during grassing. Despite the high species diversity of natural colonizers and persisters, most individuals were detected on toepaddocks, retaining walls and on the flatter surfaces of the dams (berms and tops), with the actual contribution to cover on slopes being extremely low. In contrast, the number of species introduced during vegetating efforts was extremely low, despite the high cover achieved on recently grassed dam slopes. However, most introduced species are herbaceous and weedy, and both cover and number of species declines rapidly once liming, fertilization and supplemental watering has ceased. Watering occurs either in the form of irrigation on dormant dams (slimes are no longer deposited) or water from slurry deposition on current dams. Less than five species remained on any particular tailings slope by four years after amelioration had ceased (Weiersbye & Witkowski 1998). Although we recorded an additional 14 introduced pasture species in 1998–2003 from the same slimes dam slopes surveyed in 1996–1997, these plants occurred on dams that were undergoing grassing. These same species had not been detected in the previous survey on post-amelioration grassed sites (despite having been originally planted), which suggests that they lack persistence.

Although introduced species on dams were predominantly pasture grasses, the naturally colonizing species were predominantly perennials with woody and semi-woody growth forms. In the case of tailings dams in the Carletonville and Klerksdorp regions, the predominance of indigenous, woody growth forms as natural colonizers and persisters is expected as these growth forms are common in the localities surrounding the dams (Arnold & De Wet 1993; Bredenkamp & Brown 1995a,b; Retief & Herman 1997). However, tailings dams in the Free State are surrounded by hydromorphic grasslands, degraded wetlands and alkaline pans, with woody and semi-woody plants largely restricted to low, dry rocky outcrops (Fuls *et al.* 1992, 1993; Malan *et al.* 1998). The colonization of tailings in this latter region by semi-woody/woody species despite their restricted availability strongly suggests that these are suitable growth forms for tailings dam rehabilitation.

The dominance of Poaceae, Asteraceae, Fabaceae and Anacardiaceae on acid slimes suggests an inherent tolerance to the prevailing conditions in species of these families. These results are further reinforced by seed biology studies (Witkowski & Weiersbye 1998b; Weiersbye & Witkowski 2002b, 2003) and by plant growth and water-use trials in acid slimes and AMD conditions in which hard-seeded legumes and *Rhus* spp. perform especially well (Weiersbye *et al.* 1998; Dharamraj *et al.* 1999; Dye *et al.* 2005). More recently, the use of AFLP analysis has demonstrated that there is genetic evidence for local adaptation of some woody species to the slimes-polluted soils around tailings dams (Angus 2005). Some species examined during this survey showed no signs of physiological stress despite growth on slimes, e.g. *Tamarix* spp., *Acacia* spp., *Lessertia* spp. (= *Sutherlandia* spp.), *Rhus* spp., *Asparagus* spp. and perennial *Eragrostis* spp. Seed production and seed viability levels in these taxa approaches that of conspecifics growing in unpolluted veld, and seed production and viability in *Asparagus* spp., woody legumes and *Rhus* spp. on tailings is high, with seedlings establishing around parent plants. In contrast, seed production and viability in most grasses and Asteraceae growing on tailings is low and regeneration on tailings would therefore be dependent on seed dispersal from beyond the dam (Witkowski & Weiersbye 1998b). A parallel survey found that the majority of plants persisting on tailings were infected by arbuscular mycorrhizal (AM) fungi (Straker *et al.* 2006a, b). In addition, plant growth experiments have demonstrated that slimes-tolerant AM fungi, and, for most indigenous hard-seeded legumes, compatible tolerant rhizobia, contribute significantly to host plant survival and growth in acidic slimes (Weiersbye *et al.* 1998; Straker *et al.* 2006c).

The dominant plant functional growth forms (i.e. woody and semi-woody perennials, resprouters) of slimes dams are typical of stressful environments (Grime 1979), whereas many of the grass and forb species are characteristic of nutrient-poor (especially nitrogen), low competition environments in the Grassland Biome (O'Connor & Bredenkamp 1997). The distribution of species on particular tailings substrates appears to be associated with known physiological tolerances to moisture and nutrient availability regimes. For example, species of *Eragrostis* and *Sporobolus* that were prevalent on the arid substrates typical of old vegetated and never vegetated tailings can tolerate dehydration of foliage to the point of air dryness (Gaff 1971; Gaff & Ellis 1974). The grass *Cenchrus ciliaris* is tolerant of high nitrogen and phosphorus availability (O'Connor & Bredenkamp 1997) and is an indicator of nutrient enrichment in natural ecosystems, being characteristic of environments such as iron-age kraal sites (Blackmore *et al.* 1990). *C. ciliaris* was only prevalent on recently vegetated sites, with few individuals surviving the transition to old vegetated sites and the concomitant decline in nutrient availability. In contrast, *Stoebe vulgaris* and some dominant indigenous grasses on tailings are inhibited by high nitrogen availability (Roux 1969), and these species were abundant only on the low nutrient substrates typical of the oldest vegetated and never vegetated sites. Populations of *S. vulgaris* and similar species present on never vegetated sites that were subsequently grassed and fertilized have died out.

Tailings solution extracts have extremely high conductivity and salinity (Witkowski & Weiersbye 1998a). Halophytic plants such as *Tamarix* spp. and *Atriplex* spp. naturally colonize, and may form dense cover, on the moist and marginally acidic to alkaline slopes and tops of tailings dams. However, there is no analogous natural environment to the combination of acidity, salinity, high heavy metal availability and low macronutrient (N, P, K, Ca and Mg) availability that is found on the lower reaches of dams. Plants that naturally colonize gold tailings, or persist on tailings-polluted substrates are therefore exhibiting a remarkable combination of adaptive or constitutive physiological tolerances and are being subjected to massive selection pressures (Bradshaw 1952; 1970; Mehary 1994). For example, the majority of species growing on slimes dams and polluted substrates in the goldfields have depressed seed production and viability levels in comparison to conspecifics on unpolluted substrates (Weiersbye & Witkowski 2002b). However, those species that occur frequently on slimes and slimes-polluted soils are also the species that maintain regeneration potential on these same substrates (Witkowski & Weiersbye 1998). Tree species such as *Acacia karroo, A. hereroensis, A. hebeclada* and *Rhus lancea* maintain relatively high levels of seed viability and germination despite elevated inorganic contents, and high frequencies of seedling abnormalities (Weiersbye & Witkowski 2003). *Rhus lancea* is also capable of vigorous growth in acid mine drainage, maintaining high evapotranspiration rates (Dye *et al.* 2005). Salinity and acid-tolerant land-races of the grass *Cynodon dactylon*, and local ecotypes of *Hyparrhenia hirta* are now used in slimes dam rehabilitation (B. Dawson, EMPR Services, pers. comm.). Apparently healthy *C. dactylon* growing in gold tailings can contain 30 mg g^{-1} dry mass of iron in the root epidermis and cortex, and 3 mg g^{-1} dry mass of uranium within the root stele, with even higher Fe and U concentrations associated with arbuscular mycorrhizal structures (Weiersbye *et al.* 1999).

Some indigenous, naturally-colonizing or persisting species that were frequently encountered on slimes dams, have also been recorded from gold tailings in Zimbabwe and Botswana (Wild 1974a, b), and from andalusite, asbestos, gold, platinum and base metal tailings in the Limpopo and Mpumulanga Provinces (I.M. Weiersbye, K. Balkwill & E.T.F. Witkowski unpublished). Land-races that persist and colonize gold tailings and acid mine drainage-polluted soils can be expected to have phytoremediation potential for the gold mining industry in South Africa.

CONCLUSIONS

Of the 376 species found in the intensive survey, only 60 were common to all three regions, and of these 24 had been introduced during rehabilitation attempts. Most of the species found on tailings were persisters or natural colonizers (53–88%, depending on substrate), with the vast majority being indigenous and perennial taxa (76% and 85% respectively) with semi-woody to woody growth forms (66% being resprouters, forbs, shrubs and trees). The present rehabilitation aims of mine management (i.e. the requirement for rapid green cover) forces vegetation contractors to expend massive effort and expense in modifying tailings dams to become temporarily suitable substrates for high basal cover pastures. In contrast, those species actually persisting on, and naturally colonizing tailings and tailings-polluted soils, are non-pasture species, of which < 5% have also been introduced during vegetating efforts. Naturally colonizing and persisting species are predominantly indigenous perennials comprised of resprouting, semi-woody and woody plants and C_4 tussock grasses, which, by virtue of the comparatively longer life-span of individuals and apparent tolerance to native slimes conditions are more likely to assist in the establishment of self-sustaining cover and rehabilitation of gold tailings. Finally, only multi-stemmed/shrubby or ground-covering woody plants and other growth forms with high basal cover are suitable for planting on the slopes of the dams due to erosion foci that may develop around large, single-stemmed-trees. However, plantings of shrubs and trees are suitable for the berms and tops of slimes dams, providing that planting densities are optimized in order to survive on incoming rainfall alone in an increasingly arid environment as the dam dries out. Woody plantings on the berms and tops of dams could minimize recharge of the phreatic surface within the dam, and thus limit the potential for seepage, as well as lowering the risk of fire that is ever-present in highveld winter grasslands, provide large canopies in order to abate wind and dust generation, and facilitate nutrient cycling processes and 'safe-sites' for seedling establishment more effectively than grasses (Cresswell 1973). The results of this broad-scale survey show conclusively that the rehabilitation industry needs to pay much greater attention to the use of indigenous plant species and growth forms on TSF that have a higher probability of contributing to sustainable cover, dust control and hydrological containment than the currently used pasture species.

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APPENDIX 1.—Percentage frequency of species and subspecies within each substrate, vegetation class and region for plants found in the 100 m transects. Although 327 species and subspecies were identified, for the purposes of this frequency analysis the 5 *Tamarix* spp. and putative hybrids were combined due to difficulty in telling them apart in the field (i.e. n = 323)

	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Acanthaceae (n = 3)													
Barleria macrostegia *Nees*	0.0	0.0	0.0	0.0	4.3	3.8	0.0	1.0	2.2	0.0	3.6	0.0	1.6
Crabbea angustifolia *Nees*	0.0	0.0	0.0	0.0	4.3	1.9	0.0	2.0	0.7	3.6	0.0	1.1	1.2
Justicia anagalloides *(Nees) T.Anderson*	0.0	0.0	0.0	0.0	0.0	3.8	0.0	1.0	0.7	0.0	0.0	2.3	0.8
Aizoaceae (n = 6)													
Aizoaceae sp. 1	0.0	0.0	0.0	0.0	4.3	0.0	0.0	2.0	0.0	0.0	1.8	0.0	0.8
Aizoaceae sp. 2	0.0	12.5	2.1	2.7	4.3	0.0	0.0	5.0	1.4	12.7	0.0	0.0	2.8
*Aizoaceae sp. 3	6.3	12.5	2.1	2.7	6.4	3.8	33.3	4.0	1.4	0.0	0.0	12.6	4.3
Aizoaceae sp. 4	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.7	0.0	0.0	1.1	0.4
Hypertelis salsoloides *(Burch.) Adamson* var. salsoloides	0.0	0.0	0.0	2.7	10.6	5.8	0.0	7.0	2.2	0.0	7.1	2.3	3.9
Suessenguthiella scleranthoides *(Sond.) Friedrich*	0.0	0.0	4.2	4.0	6.4	7.7	6.7	1.0	7.2	0.0	8.0	3.4	4.7
Alliaceae (n = 1)													
Agapanthus campanulatus *F.M. Leight.* subsp. patens *(F.M.Leight.) F.M.Leight.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.0	0.0	0.0	0.9	0.0	0.4
Amaranthaceae (n = 6)													
Achyranthes aspera *L.* var. aspera	0.0	6.3	0.0	2.7	6.4	1.9	6.7	4.0	1.4	1.8	0.0	6.9	2.8
Alternathera pungens *Kunth*	0.0	6.3	8.3	2.7	4.3	0.0	6.7	5.0	2.2	5.5	5.4	0.0	3.5
*Amaranthus hybridus *L.* subsp. hybridus	0.0	0.0	0.0	1.3	2.1	0.0	13.3	0.0	0.0	0.0	0.0	2.3	0.8
*Amaranthus sp.	0.0	0.0	0.0	1.3	4.3	5.8	0.0	0.0	4.3	0.0	5.4	0.0	2.4
*Amaranthus thunbergii *Moq.*	0.0	6.3	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0	1.1	0.4
Gomphrena celosioides *Mart.*	0.0	0.0	0.0	0.0	2.1	0.0	0.0	1.0	0.0	1.8	0.0	0.0	0.4
Amaryllidaceae (n = 1)													
Boophane disticha *(L.f.) Herb.*	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	1.4	0.0	1.8	0.0	0.8
Anacardiaceae (n = 13)													
Rhus burchellii *Sond. ex Engl.*	0.0	6.3	0.0	0.0	2.1	1.9	0.0	3.0	0.0	5.5	0.0	0.0	1.2
Rhus dentata *Thunb.*	6.3	0.0	0.0	1.3	17.0	13.5	20.0	8.0	4.3	12.7	8.9	0.0	6.7
Rhus discolor *E.Mey. ex Sond.*	0.0	0.0	0.0	0.0	6.4	3.8	0.0	3.0	1.4	5.5	1.8	0.0	2.0
Rhus gracillima *Engl.* var. gracillima	6.3	0.0	0.0	0.0	0.0	1.9	0.0	0.0	1.4	3.6	0.0	0.0	0.8
+Rhus lancea *L.f.*	6.3	12.5	4.2	9.3	42.6	40.4	6.7	22.0	21.6	20.0	34.8	3.4	20.9
Rhus leptodictya *Diels*	0.0	0.0	0.0	1.3	10.6	5.8	6.7	5.0	2.2	9.1	3.6	0.0	3.5
Rhus magalismontana *Sond.* subsp. magalismontana	0.0	0.0	0.0	1.3	2.1	1.9	0.0	0.0	2.2	5.5	0.0	0.0	1.2
+Rhus pendulina *Jacq.*	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.7	1.8	0.0	0.0	0.4
+Rhus pyroides *Burch.* var. pyroides	6.3	6.3	0.0	5.3	19.1	30.8	0.0	14.0	12.2	18.2	18.8	0.0	12.2
Rhus rigida *Mill.*	0.0	0.0	0.0	0.0	4.3	0.0	0.0	1.0	0.7	3.6	0.0	0.0	0.8
Rhus tenuinervis *Engl.*	0.0	0.0	0.0	0.0	4.3	0.0	0.0	1.0	0.7	3.6	0.0	0.0	0.8

*Taxa that were intentionally introduced at some stage during slimes dam vegetating attempts prior to survey in 1996.
+Taxa that were naturally present on slimes during this survey, and were also introduced to gold slimes dam trials subsequent to this survey (between 1996 and 2000).

APPENDIX 1.—Percentage frequency of species and subspecies within each substrate, vegetation class and region for plants found in the 100 m transects. Although 327 species and subspecies were identified, for the purposes of this frequency analysis the 5 *Tamarix* spp. and putative hybrids were combined due to difficulty in telling them apart in the field (i.e. n = 323) cont.

	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Rhus zeyheri *Sond.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.7	1.8	0.0	0.0	0.4
*Schinus molle *L.*	0.0	0.0	0.0	0.0	8.5	1.9	0.0	3.0	1.4	3.6	1.8	1.1	2.0
Apocynaceae (n = 1)													
Acokanthera oppositifolia *(Lam.) Codd*	0.0	0.0	0.0	0.0	2.1	3.8	0.0	2.0	0.7	5.5	0.0	0.0	1.2
Asclepiadaceae (n = 3)													
Asclepias fruticosa *L.*	6.3	43.8	14.6	17.3	53.2	63.5	40.0	37.0	30.9	25.5	45.5	24.1	33.9
Asclepias physocarpa *(E.Mey.) Schltr.*	0.0	0.0	0.0	0.0	2.1	1.9	0.0	1.0	0.7	1.8	0.9	0.0	0.8
Pentarrhinum insipidum *E.Mey.*	0.0	0.0	0.0	5.3	19.1	19.2	13.3	6.0	10.8	0.0	20.5	0.0	9.1
Asparagaceae (n = 4)													
Asparagus cooperi *Baker*	0.0	0.0	0.0	0.0	4.3	13.5	0.0	3.0	4.3	5.5	5.4	0.0	3.5
+Asparagus laricinus *Burch.*	6.3	50.0	27.1	34.7	61.7	63.5	26.7	56.0	36.0	47.3	60.7	18.4	43.3
Asparagus setaceus *(Kunth) Jessop*	0.0	0.0	0.0	0.0	2.1	5.8	0.0	2.0	1.4	0.0	3.6	0.0	1.6
Asparagus suaveolens *Burch.*	0.0	0.0	2.1	0.0	2.1	9.6	0.0	2.0	3.6	1.8	5.4	0.0	2.8
Asphodelaceae (n = 2)													
*Aloe greatheadii *Schönland* var. davyana *(Schönland) Glen & D.S.Hardy*	0.0	6.3	0.0	0.0	6.4	21.2	0.0	4.0	7.9	3.6	8.9	3.4	5.9
Kniphofia ensifolia *Baker.* subsp. ensifolia	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	1.4	0.0	1.8	0.0	0.8
Asteraceae (n = 61)													
Acanthospermum australe *(Loefl.) Kuntze*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.0	0.0	1.8	0.0	0.0	0.4
Acanthospermum hispidum *DC.*	0.0	0.0	0.0	0.0	0.0	1.9	6.7	0.0	0.0	0.0	0.0	1.1	0.4
Arctotis venusta *Norl.*	0.0	0.0	0.0	0.0	6.4	0.0	0.0	1.0	1.4	0.0	0.0	3.4	1.2
Aster harveyanus *Kuntze*	0.0	12.5	0.0	0.0	4.3	7.7	6.7	6.0	0.7	5.5	4.5	0.0	3.1
Aster squamatus *(Spreng.) Hiern*	0.0	6.3	2.1	1.3	10.6	3.8	0.0	7.0	2.2	5.5	4.5	2.3	3.9
Athrixia elata *Sond.*	0.0	12.5	0.0	0.0	4.3	1.9	0.0	4.0	0.7	9.1	0.0	0.0	2.0
Berkheya sp. 1	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.7	0.0	0.0	1.1	0.4
Berkheya insignis *(Harv.)Thell.*	0.0	6.3	0.0	1.3	4.3	0.0	0.0	3.0	0.7	5.5	0.9	0.0	1.6
Berkheya setifera *DC.*	0.0	0.0	0.0	1.3	8.5	9.6	0.0	7.0	2.2	3.6	5.4	2.3	3.9
Bidens pilosa *L.*	0.0	0.0	0.0	0.0	0.0	5.8	0.0	3.0	0.0	1.8	0.9	1.1	1.2
Brachylaena rotundata *S.Moore*	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.8	0.0	0.0	0.4
Callilepsis laureola *DC.*	0.0	6.3	0.0	0.0	2.1	1.9	0.0	3.0	0.0	5.5	0.0	0.0	1.2
Cirsium vulgare *(Savi) Ten.*	0.0	0.0	0.0	2.7	8.5	5.8	13.3	4.0	2.2	1.8	6.3	1.1	3.5
Conyza albida *Spreng.*	0.0	12.5	2.1	4.0	8.5	5.8	13.3	7.0	2.9	5.5	0.9	10.3	5.1
Conyza bonariensis *(L.) Cronquist*	0.0	12.5	0.0	1.3	2.1	7.7	6.7	7.0	0.0	5.5	0.0	5.7	3.1
Conyza podocephala *DC.*	0.0	6.3	0.0	0.0	4.3	3.8	0.0	3.0	1.4	0.0	1.8	3.4	2.0
Conyza sp.	0.0	0.0	2.1	1.3	6.4	9.6	20.0	2.0	3.6	0.0	7.1	2.3	3.9

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APPENDIX 1.—Percentage frequency of species and subspecies within each substrate, vegetation class and region for plants found in the 100 m transects. Although 327 species and subspecies were identified, for the purposes of this frequency analysis the 5 *Tamarix* spp. and putative hybrids were combined due to difficulty in telling them apart in the field (i.e. n = 323) cont.

	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Asteraceae (cont.)													
Corymbium sp.	0.0	0.0	0.0	0.0	2.1	1.9	0.0	2.0	0.0	0.0	1.8	0.0	0.8
Dicoma anomala *Sond.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.0	0.0	0.0	0.9	0.0	0.4
Dicoma zeyheri *Sond.*subsp. zeyheri	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.0	0.0	1.8	0.0	0.0	0.4
Erigeron sp.	0.0	0.0	2.1	4.0	8.5	9.6	20.0	5.0	3.6	0.0	11.6	0.0	5.1
Felicia fascicularis *DC.*	0.0	0.0	0.0	1.3	12.8	5.8	0.0	6.0	2.9	0.0	7.1	2.3	3.9
Felicia filifolia *(Vent.) Burtt Davy* subsp. filifolia	0.0	6.3	0.0	0.0	6.4	0.0	0.0	2.0	1.4	1.8	1.8	1.1	1.6
Felicia mossamedensis *(Hier) Mendonça*	6.3	12.5	0.0	0.0	2.1	0.0	0.0	3.0	0.7	5.5	0.9	0.0	1.6
Felicia muricata (*Thunb.*) *Nees* subsp. muricata	0.0	6.3	0.0	1.3	8.5	1.9	0.0	5.0	1.4	9.1	0.0	2.3	2.8
Flaveria bidentis *(L.) Kuntze*	6.3	0.0	0.0	8.0	4.3	19.2	26.7	14.0	0.7	0.0	6.3	13.8	7.5
Gazania krebsiana *Less.* subsp. serrulata *(DC.) Roessler*	0.0	0.0	0.0	4.0	6.4	1.9	0.0	3.0	2.9	0.0	4.5	2.3	2.8
Geigeria brevifolia *(DC.) Harv.*	0.0	6.3	0.0	0.0	6.4	3.8	0.0	1.0	3.6	0.0	5.4	0.0	2.4
Geigeria burkei *Harv.* subsp. burkei	0.0	12.5	0.0	0.0	2.1	1.9	0.0	4.0	0.0	7.3	0.0	0.0	1.6
Helichrysum argyrosphaerum *DC.*	0.0	6.3	0.0	8.0	6.4	7.7	0.0	9.0	3.6	0.0	12.5	0.0	5.5
Helichrysum caespititium *(DC.) Harv.*	0.0	12.5	0.0	0.0	4.3	0.0	6.7	2.0	0.7	1.8	2.7	0.0	1.6
Helichrysum dasymallum *Hilliard*	0.0	0.0	0.0	1.3	12.8	5.8	6.7	4.0	3.6	0.0	8.0	1.1	3.9
Helichrysum kraussii *Sch. Bip.*	0.0	6.3	0.0	1.3	2.1	1.9	0.0	4.0	0.0	1.8	0.0	3.4	1.6
Helichrysum melanacme *DC.*	0.0	0.0	0.0	0.0	2.1	3.8	0.0	0.0	2.2	5.5	0.0	0.0	1.2
Helichrysum rugulosum *Less.*	0.0	25.0	0.0	10.7	29.8	9.6	6.7	21.0	6.5	16.4	13.4	8.0	12.2
Lopholaena coriifolia *(Sond.) E.Phillips & C.A.Sm.*	0.0	6.3	0.0	1.3	6.4	3.8	0.0	3.0	2.9	12.7	0.0	0.0	2.8
Nidorella anomala *Steetz*	0.0	6.3	0.0	2.7	2.1	7.7	0.0	2.0	4.3	5.5	4.5	0.0	3.1
Nidorella hottentotica *DC.*	0.0	18.8	0.0	4.0	17.0	13.5	0.0	11.0	7.2	12.7	10.7	2.3	8.3
Nolletia rarifolia *(Turcz.) Steetz*	6.3	6.3	0.0	2.7	4.3	0.0	0.0	3.0	2.2	0.0	0.9	5.7	2.4
Oncosiphon pululiferum *(L.f.) Källersjö*	0.0	6.3	0.0	0.0	2.1	0.0	0.0	2.0	0.0	3.6	0.0	0.0	0.8
Osteospermum leptolobium *(Harv.) Norl.*	0.0	0.0	0.0	0.0	2.1	0.0	0.0	1.0	0.0	1.8	0.0	0.0	0.4
Pentzia incana *(Thunb.) Kuntze*	0.0	18.8	2.1	2.7	17.0	13.5	6.7	6.0	10.1	7.3	15.2	0.0	8.3
Phymaspermum athanasioides *(S. Moore) Källersjö*	0.0	0.0	0.0	0.0	4.3	0.0	0.0	1.0	0.7	0.0	1.8	0.0	0.8
Pseudognaphalium luteo-album *(L.) Hilliard & B.L.Burtt*	0.0	12.5	0.0	6.7	10.6	15.4	0.0	11.0	6.5	3.6	10.7	6.9	7.9
Pseudognaphalium undulatum *(L.) Hilliard & B.L.Burtt*	0.0	6.3	2.1	8.0	6.4	9.6	0.0	13.0	2.2	0.0	14.3	0.0	6.3
Schkuria pinnata *(Lam.) Cabrera*	0.0	0.0	0.0	1.3	4.3	0.0	0.0	2.0	0.7	0.0	0.0	3.4	1.2
Senecio consanguinensis *DC.*	0.0	31.3	2.1	10.7	23.4	9.6	0.0	19.0	7.9	16.4	8.0	13.8	11.8
Senecio coronatus *(Thunb.) Harv.*	0.0	12.5	0.0	4.0	6.4	5.8	0.0	7.0	2.9	3.6	0.9	9.2	4.3
Senecio erubescens *Aiton.* sens. lat.	0.0	18.8	0.0	0.0	6.4	5.8	0.0	7.0	1.4	10.9	0.9	2.3	3.5
Senecio isatideus *DC.*	0.0	0.0	0.0	0.0	2.1	1.9	0.0	2.0	0.0	1.8	0.9	0.0	0.8
Senecio latifolius *DC.*	0.0	6.3	0.0	0.0	2.1	1.9	0.0	2.0	0.7	0.0	1.8	1.1	1.2
Senecio scitus *Hutch. & Burtt Davy*	0.0	6.3	0.0	0.0	4.3	3.8	0.0	4.0	0.7	9.1	0.0	0.0	2.0
Sonchus oleracerus *L.*	0.0	6.3	0.0	4.0	12.8	3.8	6.7	7.0	2.9	0.0	2.7	10.3	4.7
Sonchus wilmsii *R.E.Fr.*	0.0	6.3	0.0	1.3	4.3	0.0	0.0	2.0	1.4	1.8	0.0	3.4	1.6

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	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Asteraceae (cont.)													
Stoebe vulgaris *Levyns*	0.0	18.8	0.0	12.0	14.9	25.0	20.0	16.0	9.4	16.4	20.5	0.0	12.6
Tagetes minuta *L.*	0.0	12.5	4.2	6.7	14.9	15.4	0.0	17.0	5.0	7.3	13.4	5.7	9.4
Taraxacum officinale complex *Weber* sens. lat.	0.0	0.0	0.0	0.0	2.1	0.0	0.0	1.0	0.0	0.0	0.0	1.1	0.4
Tarchonanthus camphoratus *L.*	0.0	0.0	0.0	0.0	0.0	9.6	0.0	2.0	2.2	0.0	4.5	0.0	2.0
Ursinia nana *DC.* subsp. nana	0.0	12.5	0.0	1.3	4.3	1.9	0.0	4.0	1.4	10.9	0.0	0.0	2.4
Vernonia oligocephala *(DC.) Sch.Bip. ex Walp.*	0.0	0.0	0.0	0.0	6.4	5.8	0.0	4.0	1.4	0.0	5.4	0.0	2.4
Vernonia sp.	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.7	0.0	0.0	1.1	0.4
Boraginaceae (n = 1)													
Ehretia rigida *(Thunb.) Druce*	0.0	0.0	0.0	0.0	10.6	19.2	13.3	3.0	7.2	3.6	11.6	0.0	5.9
Brassicaceae (n = 3)													
Lepidium africanum *(Burm.f.) DC.*	0.0	6.3	0.0	1.3	2.1	1.9	0.0	3.0	0.7	5.5	0.9	0.0	1.6
Lepidium bonariense *L.*	0.0	6.3	2.1	0.0	0.0	0.0	0.0	2.0	0.0	0.0	1.8	0.0	0.8
Sisymbrium thellungii *O.E.Schulz*	0.0	0.0	0.0	2.7	4.3	0.0	0.0	3.0	0.7	0.0	0.0	4.6	1.6
Cactaceae (n = 1)													
*Opuntia ficus-indica *(L.) Mill.*	0.0	0.0	0.0	4.0	0.0	1.9	0.0	4.0	0.0	0.0	2.7	1.1	1.6
Capparaceae (n = 1)													
Boscia albitrunca *(Burch.) Gilg & Gilg-Ben.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.7	0.0	0.9	0.0	0.4
Caryophyllaceae (n = 1)													
Spergularia sp *L.*	12.5	6.3	4.2	2.7	2.1	3.8	33.3	2.0	2.2	1.8	0.0	10.3	3.9
Celastraceae (n = 2)													
Gymnosporia buxifolia *(L.) Szyszyl.*	6.3	0.0	0.0	1.3	4.3	15.4	13.3	2.0	5.8	0.0	10.7	0.0	4.7
Gymnosporia polyacantha *(Sond.) Marais*	6.3	0.0	0.0	1.3	6.4	23.1	6.7	3.0	9.4	0.0	15.2	0.0	6.7
Chenopodiaceae (n = 8)													
*Atriplex semibaccata *R. Br.var* typica *Aellen*	25.0	43.8	54.2	49.3	46.8	32.7	33.3	56.0	37.4	40.0	47.3	43.7	44.5
*Atriplex lindleyi *Moq.* subsp. inflata *(F.Muell.) Paul G. Wilson*	0.0	0.0	0.0	2.7	4.3	3.8	0.0	3.0	2.2	0.0	0.9	5.7	2.4
*Atriplex suberecta *I.Verd.*	6.3	0.0	0.0	2.7	0.0	3.8	0.0	5.0	0.0	0.0	0.0	5.7	2.0
Bassia salsoloides *(Fenzl) A.J.Scott*	0.0	25.0	0.0	8.0	6.4	1.9	0.0	10.0	2.9	0.0	0.0	16.1	5.5
*Chenopodium album *L.*	0.0	12.5	6.3	2.7	4.3	1.9	26.7	3.0	2.2	0.0	1.8	9.2	3.9
*Chenopodium multifidum *L.*	0.0	6.3	0.0	1.3	0.0	0.0	13.3	0.0	0.0	0.0	0.0	2.3	0.8
*Monochlamys albicans *(Aiton) Aellen*	6.3	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.1	0.4
Salsola kali *L.*	0.0	0.0	0.0	1.3	0.0	1.9	13.3	0.0	0.0	0.0	0.0	2.3	0.8
Commelinaceae (n = 1)													
Commelina africana *L.* var. africana	0.0	0.0	0.0	0.0	6.4	13.5	13.3	2.0	4.3	3.6	7.1	0.0	3.9

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	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Convolvulaceae (n = 5)													
Convulvus sagittatus *Thunb.*	0.0	0.0	0.0	0.0	2.1	3.8	0.0	3.0	0.0	0.0	2.7	0.0	1.2
Convulvus sp.	0.0	0.0	0.0	0.0	2.1	1.9	0.0	2.0	0.0	0.0	1.8	0.0	0.8
Ipomoea crassipes *Hook.*	0.0	12.5	0.0	0.0	10.6	13.5	0.0	4.0	7.2	9.1	8.0	0.0	5.5
Ipomoea ommaneyi *Rendle*	0.0	6.3	0.0	1.3	4.3	1.9	0.0	3.0	1.4	9.1	0.0	0.0	2.0
Merremia tridentata *(L.) Hallier f.* subsp. angustifolia *(Jacq.) Van Oostr.*	0.0	0.0	0.0	2.7	6.4	3.8	0.0	3.0	2.9	0.0	3.6	3.4	2.8
Crassulaceae (n = 1)													
Crassula thunbergiana *Schult.*	0.0	6.3	2.1	2.7	0.0	0.0	0.0	4.0	0.0	0.0	3.6	0.0	1.6
Cucurbitaceae (n = 6)													
Acanthosicyos naudinianus *(Sond.) C.Jeffrey*	0.0	0.0	0.0	8.0	23.4	19.2	13.3	1.0	17.3	0.0	22.3	2.3	10.6
Citrullus lanatus *(Thunb.) Matsum. & Nakai*	6.3	0.0	0.0	0.0	6.4	1.9	0.0	2.0	2.2	0.0	2.7	2.3	2.0
Coccinia sessilifolia *(Sond.) Cogn.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.7	0.0	0.9	0.0	0.4
Cucumis anguria *L.*	0.0	0.0	2.1	1.3	2.1	1.9	0.0	0.0	2.9	0.0	3.6	0.0	1.6
Cucumis myriocarpus *Naudin* subsp. myriocarpus	0.0	6.3	0.0	1.3	2.1	3.8	0.0	3.0	1.4	0.0	4.5	0.0	2.0
+Cucumis zeyheri *Sond.*	0.0	0.0	0.0	0.0	2.1	5.8	0.0	2.0	1.4	0.0	3.6	0.0	1.6
Cyperaceae (n = 3)													
Cyperus fulgens *C.B.Clarke* var. contractus *Kük.*	0.0	0.0	0.0	0.0	0.0	1.9	6.7	0.0	0.0	0.0	0.9	0.0	0.4
Mariscus rehmannianus *C.B.Clarke*	0.0	12.5	0.0	0.0	0.0	19.2	6.7	4.0	5.0	5.5	5.4	3.4	4.7
Scirpus burkei *C.B.Clarke*	0.0	0.0	0.0	0.0	0.0	19.2	0.0	5.0	3.6	1.8	5.4	3.4	3.9
Dichapetalaceae (n = 1)													
Dichapetalum cymosum *(Hook.) Engl.*	0.0	0.0	0.0	0.0	2.1	1.9	0.0	0.0	1.4	3.6	0.0	0.0	0.8
Dipsacaceae (n = 1)													
Scabiosa columbaria *L.*	0.0	0.0	0.0	0.0	2.1	5.8	0.0	2.0	1.4	3.6	1.8	0.0	1.6
Ebenaceae (n = 4)													
Diospyros lycioides *Desf.* subsp. guerkei *(Kuntze) De Winter*	0.0	0.0	0.0	0.0	2.1	1.9	0.0	2.0	0.0	3.6	0.0	0.0	0.8
Diospyros lycioides *Desf.* subsp. lycioides	6.3	0.0	0.0	2.7	27.7	30.8	6.7	8.0	16.5	5.5	25.9	0.0	12.6
Euclea crispa *(Thunb.) Guerke* var. crispa	0.0	0.0	0.0	0.0	2.1	1.9	0.0	2.0	0.0	3.6	0.0	0.0	0.8
Euclea undulata *Thunb.* var. myrtina *(Burch.) Hiern*	0.0	0.0	0.0	0.0	2.1	5.8	0.0	1.0	2.2	0.0	3.6	0.0	1.6
Euphorbiaceae (n = 5)													
Acalypha angustata *Sond.* var. glabra *Sond.*	0.0	0.0	0.0	0.0	6.4	11.5	0.0	1.0	5.8	5.5	5.4	0.0	3.5
Acalypha ecklonii *Baill.*	0.0	0.0	0.0	0.0	2.1	5.8	0.0	1.0	2.2	1.8	2.7	0.0	1.6
Acalypha peduncularis *E.Mey. ex Meisn.*	0.0	6.3	0.0	0.0	2.1	1.9	0.0	3.0	0.0	5.5	0.0	0.0	1.2

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	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Euphorbiaceae (cont.)													
Clutia monticola *S.Moore*	0.0	0.0	0.0	0.0	2.1	3.8	0.0	0.0	2.2	5.5	0.0	0.0	1.2
Jatropha lagarinthoides *Sond.*	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.7	0.0	0.0	1.1	0.4
Fabaceae (n = 34)													
*Acacia baileyana *F.Muell.*	0.0	6.3	2.1	0.0	0.0	0.0	0.0	2.0	0.0	0.0	1.8	0.0	0.8
Acacia caffra *(Thunb.) Willd.*	0.0	0.0	0.0	0.0	2.1	1.9	0.0	1.0	0.7	0.0	1.8	0.0	0.8
*Acacia cultriformis *A.Cunn.* ex G. Don	0.0	18.8	0.0	2.7	4.3	3.8	0.0	9.0	0.0	16.4	0.0	0.0	3.5
*Acacia dealbata *Link*	0.0	6.3	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.9	0.0	0.4
+Acacia hebeclada *DC.* subsp. hebeclada	0.0	0.0	0.0	1.3	6.4	7.7	0.0	4.0	2.9	0.0	7.1	0.0	3.1
+Acacia hereroensis *Engl.*	0.0	0.0	0.0	0.0	6.4	7.7	0.0	4.0	2.2	0.0	6.3	0.0	2.8
+Acacia karroo *Hayne*	6.3	12.5	0.0	12.0	34.0	42.3	20.0	23.0	17.3	23.6	24.1	11.5	19.7
*Acacia longifolia *(Andr.) Willd.*	0.0	6.3	0.0	0.0	0.0	1.9	0.0	2.0	0.0	1.8	0.9	0.0	0.8
*Acacia mearnsii *De Wild.*	0.0	6.3	2.1	0.0	8.5	5.8	0.0	8.0	0.7	14.5	0.9	0.0	3.5
*Acacia melanoxylon *R.Br.*	0.0	6.3	0.0	0.0	2.1	1.9	0.0	3.0	0.0	5.5	0.0	0.0	1.2
*Acacia podalyriifolia *A.Cunn. ex G.Don*	0.0	6.3	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.9	0.0	0.4
Acacia robusta *Burch.* subsp. robusta	0.0	18.8	0.0	1.3	8.5	5.8	0.0	9.0	1.4	18.2	0.9	0.0	4.3
Crotalaria spartioides *DC.*	0.0	0.0	0.0	0.0	2.1	1.9	0.0	0.0	1.4	0.0	1.8	0.0	0.8
Crotalaria sphaerocarpa *Perr. ex DC* subsp. sphaerocarpa	0.0	0.0	0.0	1.3	2.1	1.9	0.0	0.0	2.2	0.0	2.7	0.0	1.2
Elephantorrhiza elephantina *(Burch.) Skeels*	6.3	0.0	0.0	0.0	0.0	21.2	6.7	1.0	7.2	5.5	8.0	0.0	4.7
Indigofera adenoides *Baker f.*	0.0	0.0	0.0	0.0	0.0	3.8	0.0	2.0	0.0	1.8	0.9	0.0	0.8
Indigofera zeyheri *Spreng. ex Eckl. & Zeyh.*	0.0	0.0	0.0	2.7	6.4	13.5	0.0	0.0	8.6	0.0	10.7	0.0	4.7
Lotononis calycina *(E.Mey.) Benth.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.0	0.0	1.8	0.0	0.0	0.4
*Medicago polymorpha *L.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.7	0.0	0.9	0.0	0.4
*Medicago sativa *L.* subsp. sativa	6.3	0.0	0.0	4.0	0.0	0.0	20.0	1.0	0.0	3.6	0.9	1.1	1.6
Mundulea sericea *(Willd.) A.Chev.*	6.3	0.0	2.1	1.3	2.1	1.9	0.0	0.0	3.6	9.1	0.0	0.0	2.0
Neorautanenia ficifolius *(Benth.) C.A.Sm*	0.0	0.0	0.0	0.0	8.5	13.5	0.0	0.0	7.9	0.0	9.8	0.0	4.3
Prosopis glandulosa *Torr.*	0.0	0.0	0.0	0.0	0.0	1.9	6.7	0.0	0.0	0.0	0.0	1.1	0.4
Rhynchosia caribea *(Jacq.) DC.*	0.0	0.0	0.0	4.0	6.4	1.9	6.7	2.0	2.9	0.0	6.3	0.0	2.8
Rhynchosia totta *(Thunb.) DC.* var. totta	0.0	0.0	0.0	0.0	2.1	3.8	0.0	0.0	2.2	0.0	0.0	3.4	1.2
Sphenostylis angustifolia *Sond.*	6.3	6.3	0.0	0.0	0.0	5.8	0.0	0.0	3.6	5.5	1.8	0.0	2.0
+Sutherlandia frutescens *(L.) R.Br.*	0.0	6.3	0.0	1.3	4.3	3.8	0.0	4.0	1.4	0.0	5.4	0.0	2.4
Tephrosia longipes *Meisn.* subsp. longipes	0.0	0.0	0.0	0.0	2.1	1.9	0.0	2.0	0.0	3.6	0.0	0.0	0.8
Tephrosia semiglabra *Sond.*	0.0	0.0	0.0	0.0	2.1	1.9	0.0	2.0	0.0	3.6	0.0	0.0	0.8
Tipuana tipu *(Benth.) Kuntze*	6.3	0.0	0.0	0.0	0.0	1.9	0.0	0.0	1.4	0.0	1.8	0.0	0.8
Trifolium africanum *Ser.* var. africanum	12.5	6.3	2.1	4.0	0.0	1.9	20.0	5.0	0.0	7.3	1.8	2.3	3.1
*Trifolium repens *L.*	6.3	0.0	0.0	0.0	0.0	1.9	6.7	1.0	0.0	1.8	0.9	0.0	0.8
*Trifolium sp.	0.0	6.3	0.0	0.0	0.0	1.9	0.0	2.0	0.0	0.0	1.8	0.0	0.8
Vigna vexillata *(L.) A.Rich.* var. vexillata	0.0	6.3	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.9	0.0	0.4

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	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Geraniaceae (n = 4)													
Monsonia angustifolia *E.Mey. ex A.Rich.*	0.0	0.0	0.0	1.3	4.3	9.6	0.0	4.0	2.9	1.8	6.3	0.0	3.1
Monsonia attenuata *Harv.*	0.0	0.0	0.0	0.0	4.3	0.0	0.0	0.0	1.4	1.8	0.9	0.0	0.8
Monsonia burkeana *Planch. ex Harv.*	0.0	0.0	0.0	0.0	6.4	1.9	0.0	0.0	2.9	0.0	2.7	1.1	1.6
Pelargonium luridum *(Andrews) Sweet*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.0	0.0	1.8	0.0	0.0	0.4
Hyacinthaceae (n = 2)													
Ledebouria ovatifolia *(Baker) Jessop*	6.3	0.0	0.0	0.0	2.1	1.9	0.0	0.0	2.2	5.5	0.0	0.0	1.2
Scilla nervosa *(Burch.) Jessop*	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	1.4	0.0	1.8	0.0	0.8
Hypoxidaceae (n = 2)													
Hypoxis hemerocallidea *Fisch. & C.A.Mey.*	0.0	0.0	0.0	0.0	0.0	5.8	0.0	0.0	2.2	0.0	2.7	0.0	1.2
Hypoxis sp.	6.3	0.0	0.0	0.0	0.0	1.9	0.0	0.0	1.4	3.6	0.0	0.0	0.8
Illecebraceae (n = 1)													
Pollichia campestris *Aiton*	0.0	0.0	0.0	0.0	12.8	1.9	0.0	0.0	5.0	0.0	6.3	0.0	2.8
Juncaceae (n = 1)													
*Juncus rigidus *Desf.*	6.3	18.8	0.0	1.3	2.1	42.3	13.3	15.0	7.9	7.3	2.7	24.1	11.0
Lamiaceae (n = 6)													
Becium grandiflorum *(Lam.) Pic.-Serm.* var. obovatum *(E.Mey. ex Benth.) Sebald*	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.7	0.0	0.0	1.1	0.4
Becium obovatum *(E.Mey. ex Benth.) N.E.Br.* var. hians *(Benth.) N.E.Br.*	0.0	6.3	0.0	0.0	4.3	3.8	6.7	3.0	0.7	5.5	1.8	0.0	2.0
Plectranthus madagascariensis *(Pers.) Benth.* var. madagascariensis	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.7	0.0	0.9	0.0	0.4
Salvia stenophylla *Burch. ex Benth.*	0.0	6.3	0.0	0.0	2.1	1.9	0.0	3.0	0.0	5.5	0.0	0.0	1.2
Salvia verbenaca *L.*	0.0	6.3	0.0	1.3	4.3	5.8	0.0	4.0	2.2	0.0	5.4	1.1	2.8
Teucrium trifidum *Retz.*	0.0	0.0	2.1	4.0	8.5	9.6	20.0	5.0	3.6	0.0	11.6	0.0	5.1
Malvaceae (n = 3)													
Hibiscus angolensis *Exell*	0.0	0.0	0.0	0.0	4.3	5.8	0.0	4.0	0.7	0.0	4.5	0.0	2.0
Pavonia burchellii *(DC.) R.A.Dyer*	0.0	0.0	0.0	0.0	2.1	7.7	0.0	3.0	1.4	1.8	3.6	0.0	2.0
Sida cordifolia *L.*	0.0	6.3	0.0	0.0	2.1	0.0	0.0	1.0	0.7	0.0	1.8	0.0	0.8
Meliaceae (n = 1)													
*Melia azedarach *L.*	6.3	0.0	0.0	0.0	0.0	1.9	0.0	0.0	1.4	0.0	1.8	0.0	0.8
Menispermaceae (n = 1)													
Antizoma angustifolia *(Burch.) Miers ex Harv.*	0.0	0.0	0.0	5.3	12.8	15.4	0.0	7.0	7.9	0.0	16.1	0.0	7.1

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	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Mesembryanthemaceae (n = 8)													
*Carpobrotus edulis *(L.) L.Bolus*	0.0	6.3	2.1	2.7	0.0	0.0	0.0	4.0	0.0	0.0	3.6	0.0	1.6
Delosperma herbeum *(N.E.Br.) N.E.Br.*	0.0	6.3	0.0	2.7	10.6	13.5	6.7	11.0	2.2	0.0	8.9	5.7	5.9
Delosperma leendertziae *N.E.Br.*	0.0	0.0	0.0	0.0	8.5	5.8	6.7	2.0	2.9	0.0	4.5	2.3	2.8
Mesembryanthemaceae sp. 1	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.1	0.4
Mesembryanthemaceae sp. 2	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.1	0.4
*Ruschia sp. 1	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.1	0.4
*Ruschia sp. 2	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.1	0.4
Leipoldtia sp.	0.0	0.0	0.0	1.3	0.0	0.0	0.0	1.0	0.0	0.0	0.0	1.1	0.4
Moraceae (n = 1)													
Morus nigra *L.*	0.0	0.0	0.0	0.0	2.1	0.0	6.7	0.0	0.0	0.0	0.9	0.0	0.4
Myrtaceae (n = 3)													
*Eucalyptus camaldulensis *Dehnh.*	0.0	0.0	0.0	1.3	0.0	5.8	0.0	4.0	0.0	0.0	2.7	1.1	1.6
*Eucalyptus maculata *Hook.*	0.0	0.0	0.0	0.0	2.1	0.0	0.0	1.0	0.0	0.0	0.0	1.1	0.4
*Eucalyptus melliodora *A.Cunn. ex Schauer*	0.0	0.0	0.0	1.3	2.1	1.9	0.0	3.0	0.0	5.5	0.0	0.0	1.2
Oleaceae (n = 1)													
Ligustrum lucidum Ait. f.	0.0	6.3	0.0	0.0	2.1	0.0	0.0	2.0	0.0	3.6	0.0	0.0	0.8
Onagraceae (n = 1)													
Oenothera stricta *Ledeb. ex Link* subsp. *stricta*	0.0	6.3	0.0	0.0	2.1	0.0	0.0	1.0	0.7	0.0	0.9	1.1	0.8
Papaveraceae (n = 1)													
*Argemone mexicana *L.*	0.0	0.0	0.0	2.7	2.1	0.0	0.0	3.0	0.0	0.0	0.0	3.4	1.2
Pedaliaceae (n = 1)													
Dicerocaryum eriocarpum *(Decne.) Abels*	0.0	0.0	0.0	0.0	2.1	3.8	0.0	1.0	1.4	0.0	2.7	0.0	1.2
Phytolaccaceae (n = 1)													
*Phytolacca octandra *L.*	0.0	18.8	12.5	26.7	29.8	23.1	13.3	27.0	18.7	21.8	38.4	0.0	21.7
Poaceae (n = 64)													
*Agrostis avenacea *C.Gmel*	6.3	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	1.8	0.0	0.0	0.4
*Agrostis tenuis *L.*	6.3	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	1.8	0.0	0.0	0.4
Anthephora pubescens *Nees*	0.0	0.0	0.0	1.3	6.4	5.8	0.0	4.0	2.2	0.0	6.3	0.0	2.8
Aristida adscensionis *L.*	0.0	6.3	0.0	0.0	6.4	5.8	0.0	2.0	3.6	5.5	3.6	0.0	2.8
Aristida congesta *Roem. & Schult.* subsp. barbicollis *(Trin. & Rupr.) De Winter*	0.0	0.0	0.0	1.3	12.8	15.4	6.7	3.0	7.9	3.6	11.6	0.0	5.9
Aristida congesta *Roem. & Schult.* subsp. congesta	6.3	6.3	2.1	2.7	17.0	11.5	0.0	9.0	7.2	5.5	9.8	5.7	7.5

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	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Poaceae (cont.)													
Aristida diffusa *Trin.* subsp. burkei *(Stapf) Melderis*	0.0	0.0	0.0	0.0	6.4	13.5	0.0	0.0	7.2	0.0	8.9	0.0	3.9
Aristida junciformis *Trin. & Rupr.* subsp. junciformis	0.0	0.0	0.0	2.7	14.9	1.9	0.0	4.0	4.3	0.0	5.4	4.6	3.9
Aristida transvaalensis *Henrard*	0.0	0.0	0.0	0.0	8.5	7.7	0.0	5.0	2.2	0.0	7.1	0.0	3.1
Aristida vestita *Thunb.*	0.0	0.0	0.0	1.3	2.1	1.9	0.0	0.0	2.2	0.0	0.0	3.4	1.2
Arundo donax *L.*	6.3	0.0	0.0	0.0	0.0	3.8	6.7	1.0	0.7	0.0	0.9	2.3	1.2
Bothriochloa insculpta *(A.Rich.) A.Camus*	0.0	0.0	0.0	0.0	8.5	11.5	6.7	4.0	3.6	0.0	8.9	0.0	3.9
*Brachiaria serrata *(Thunb.) Stapf*	0.0	0.0	0.0	1.3	2.1	3.8	0.0	2.0	1.4	0.0	1.8	2.3	1.6
*Cenchrus ciliaris *L.*	0.0	6.3	0.0	1.3	0.0	0.0	0.0	2.0	0.0	0.0	1.8	0.0	0.8
*Chloris gayana *Kunth*	12.5	25.0	2.1	14.7	14.9	3.8	46.7	18.0	1.4	10.9	9.8	11.5	10.6
Chloris pycnothrix *Trin.*	0.0	12.5	0.0	0.0	0.0	0.0	0.0	2.0	0.0	3.6	0.0	0.0	0.8
*Chloris virgata *Sw.*	0.0	6.3	2.1	1.3	10.6	7.7	0.0	6.0	4.3	0.0	8.0	3.4	4.7
*Cortaderia jubata *(Lem.) Stapf* and C. selloana *(Schult.) Asch. & Graebn.*	0.0	25.0	4.2	22.7	17.0	11.5	46.7	29.0	0.7	36.4	13.4	2.3	14.6
*Cymbopogon excavatus *(Hochst.) Stapf ex Burtt Davy*	6.3	0.0	0.0	0.0	2.1	9.6	6.7	2.0	2.9	7.3	2.7	0.0	2.8
+Cymbopogon plurinodes *(Stapf) Stapf ex Burtt Davy*	0.0	0.0	0.0	0.0	2.1	19.2	0.0	3.0	5.8	0.0	9.8	0.0	4.3
*Cynodon dactylon *(L.) Pers.*	18.8	62.5	12.5	45.3	87.2	88.5	80.0	75.0	38.1	52.7	57.1	54.0	55.1
*Cynodon nlemfuensis *Vanderyst*	0.0	6.3	2.1	2.7	4.3	3.8	26.7	4.0	0.0	0.0	1.8	6.9	3.1
Dichanthium aristatum *(Poir.) C.E.Hubb.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.0	0.0	0.0	0.0	1.1	0.4
*Digitaria eriantha *Steud.*	0.0	6.3	0.0	5.3	4.3	11.5	26.7	7.0	1.4	1.8	5.4	6.9	5.1
Diheteropogon amplectans *(Nees) Clayton*	6.3	0.0	0.0	0.0	2.1	1.9	0.0	0.0	2.2	5.5	0.0	0.0	1.2
Eleusine coracana *(L.) Gaertn.* subsp. africana *(Kenn.-O'Byrne) Hilu & De Wet*	0.0	6.3	2.1	0.0	0.0	1.9	0.0	3.0	0.0	1.8	1.8	0.0	1.2
*Elionurus muticus *(Spreng.) Kunth*	0.0	6.3	0.0	1.3	4.3	1.9	0.0	5.0	0.0	5.5	0.0	2.3	2.0
Enneapogon cenchroides *(Roem. & Schult.) C.E.Hubb.*	6.3	6.3	0.0	1.3	4.3	3.8	20.0	4.0	0.0	0.0	0.0	8.0	2.8
Eragrostis capensis *(Thunb.) Trin.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.0	0.0	1.8	0.0	0.0	0.4
Eragrostis chloromelas *Steud.*	0.0	31.3	2.1	13.3	46.8	28.8	0.0	25.0	20.1	18.2	33.0	6.9	20.9
*Eragrostis curvula *(Schrad.) Nees*	18.8	37.5	4.2	22.7	40.4	46.2	26.7	42.0	18.0	32.7	33.9	17.2	28.0
Eragrostis gummiflua *Nees*	0.0	0.0	0.0	0.0	0.0	3.8	0.0	2.0	0.0	0.0	0.9	1.1	0.8
Eragrostis heteromera *Stapf*	0.0	0.0	0.0	0.0	6.4	9.6	0.0	4.0	2.9	0.0	7.1	0.0	3.1
Eragrostis lehmanniana *Nees* var. lehmanniana	0.0	12.5	0.0	5.3	12.8	7.7	0.0	9.0	5.0	7.3	10.7	0.0	6.3
Eragrostis racemosa *(Thunb.) Steud.*	0.0	6.3	0.0	0.0	6.4	5.8	0.0	5.0	1.4	12.7	0.0	0.0	2.8
Eragrostis superba *Peyr.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.7	0.0	0.9	0.0	0.4
Heteropogon contortus *(L.) Roem. & Schult.*	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.7	0.0	0.0	1.1	0.4
+Hyparrhenia gazensis *(Rendle) Stapf*	0.0	0.0	0.0	0.0	4.3	3.8	0.0	1.0	2.2	1.8	2.7	0.0	1.6
*Hyparrhenia hirta *(L.) Stapf*	6.3	18.8	2.1	13.3	14.9	21.2	20.0	20.0	7.2	25.5	17.0	0.0	13.0
Ischaemum fasciculatum *Brongn.*	0.0	6.3	0.0	0.0	0.0	1.9	0.0	2.0	0.0	3.6	0.0	0.0	0.8
Melinis repens *(Willd.) Zizka* subsp. repens	0.0	18.8	0.0	0.0	14.9	11.5	0.0	11.0	3.6	20.0	4.5	0.0	6.3

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	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Poaceae (cont.)													
Panicum deustum *Thunb.*	0.0	6.3	0.0	2.7	6.4	3.8	0.0	4.0	2.9	1.8	4.5	2.3	3.1
Panicum maximum *Jacq.*	6.3	6.3	0.0	0.0	0.0	3.8	6.7	2.0	0.7	1.8	0.9	2.3	1.6
*Paspalum dilatatum *Poir.*	6.3	0.0	0.0	2.7	2.1	1.9	13.3	3.0	0.0	9.1	0.0	0.0	2.0
Paspalum notatum *Flüggé*	0.0	6.3	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.9	0.0	0.4
*Paspalum sp.	0.0	0.0	0.0	1.3	0.0	1.9	6.7	1.0	0.0	0.0	0.0	2.3	0.8
Paspalum urvillei *Steud.*	0.0	18.8	0.0	0.0	4.3	3.8	0.0	6.0	0.7	12.7	0.0	0.0	2.8
*Paspalum vaginatum *Sw.*	0.0	6.3	0.0	0.0	0.0	7.7	0.0	2.0	2.2	3.6	2.7	0.0	2.0
*Pennisetum clandestinum *Hochst. ex Chiov.*	0.0	6.3	0.0	2.7	14.9	1.9	13.3	6.0	2.2	12.7	0.9	3.4	4.3
*Pennisetum glaucum *(L.) R.Br.*	0.0	12.5	0.0	0.0	0.0	0.0	0.0	1.0	0.7	3.6	0.0	0.0	0.8
*Phragmites australis *(Cav.) Steud.*	50.0	25.0	12.5	13.3	12.8	53.8	46.7	34.0	15.1	23.6	23.2	26.4	24.4
Pogonarthria squarrosa *(Roem. & Schult.)Pilg.*	0.0	0.0	0.0	0.0	2.1	9.6	0.0	2.0	2.9	0.0	5.4	0.0	2.4
Setaria sphacelata *(Schumach.) Moss* var. sphacelata	0.0	0.0	0.0	0.0	2.1	3.8	0.0	3.0	0.0	0.0	2.7	0.0	1.2
Setaria sphacelata *(Schumach.) Moss* var. sericea *(Stapf) Clayton*	0.0	12.5	0.0	1.3	4.3	17.3	0.0	9.0	3.6	18.2	3.6	0.0	5.5
Setaria verticillata *(L.) P.Beauv.*	0.0	6.3	0.0	1.3	4.3	3.8	6.7	5.0	0.0	0.0	1.8	4.6	2.4
Sporobolus consimilis *Fresen.*	0.0	6.3	0.0	4.0	4.3	3.8	0.0	5.0	2.2	5.5	4.5	0.0	3.1
Sporobolus pectinatus *Hack.*	0.0	0.0	0.0	1.3	6.4	5.8	0.0	5.0	1.4	0.0	6.3	0.0	2.8
Sporobolus pyramidalis *P.Beauv.*	0.0	0.0	0.0	0.0	0.0	5.8	6.7	1.0	0.7	1.8	1.8	0.0	1.2
Sporobolus virginicus *(L.) Kunth*	0.0	6.3	0.0	1.3	0.0	1.9	6.7	2.0	0.0	0.0	0.0	3.4	1.2
Stipagrostis uniplumis *(Licht.) De Winter* var. uniplumis	0.0	0.0	0.0	0.0	6.4	15.4	6.7	3.0	5.0	0.0	9.8	0.0	4.3
Themeda triandra *Forssk.*	0.0	0.0	0.0	0.0	0.0	19.2	13.3	5.0	2.2	5.5	4.5	2.3	3.9
Tristachya leucothrix *Nees*	6.3	0.0	0.0	0.0	2.1	1.9	0.0	0.0	2.2	5.5	0.0	0.0	1.2
+Vetiveria zizanioides *(L.) Nash*	6.3	0.0	0.0	2.7	0.0	0.0	3.0	0.0	0.0	0.0	0.0	3.4	1.2
Polygalaceae (n = 1)													
Polygala hottentotta *C.Presl*	0.0	0.0	0.0	0.0	4.3	5.8	0.0	4.0	0.7	0.0	4.5	0.0	2.0
Polygonaceae (n = 1)													
Oxygonum sinuatum *(Hochst. & Steud ex Meisn.) Damm.*	0.0	0.0	0.0	1.3	6.4	1.9	0.0	3.0	1.4	0.0	3.6	1.1	2.0
Proteaceae (n = 1)													
Protea caffra *Meisn.* subsp. caffra	0.0	0.0	0.0	0.0	2.1	1.9	0.0	0.0	1.4	3.6	0.0	0.0	0.8
Ranunculaceae (n = 1)													
Clematis brachiata *Thunb.*	0.0	12.5	0.0	4.0	10.6	15.4	0.0	9.0	6.5	3.6	14.3	0.0	7.1
Resedaceae (n = 1)													
Reseda lutea *L.* subsp. lutea	0.0	0.0	2.1	1.3	0.0	5.8	0.0	3.0	1.4	0.0	4.5	0.0	2.0

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APPENDIX 1.—Percentage frequency of species and subspecies within each substrate, vegetation class and region for plants found in the 100 m transects. Although 327 species and subspecies were identified, for the purposes of this frequency analysis the 5 *Tamarix* spp. and putative hybrids were combined due to difficulty in telling them apart in the field (i.e. n = 323) cont.

	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Rhamnaceae (n = 2)													
+Ziziphus mucronata *Willd.* subsp. mucronata	0.0	0.0	0.0	0.0	14.9	21.2	0.0	5.0	9.4	3.6	11.6	3.4	7.1
Ziziphus zeyheriana *Sond.*	6.3	0.0	0.0	1.3	12.8	21.2	0.0	6.0	9.4	3.6	14.3	1.1	7.5
Rubiaceae (n = 6)													
Anthospermum hispidulum *E.Mey. ex Sond.*	0.0	0.0	0.0	0.0	2.1	0.0	0.0	1.0	0.0	1.8	0.0	0.0	0.4
Anthospermum rigidum *Eckl. & Zeyh.* subsp. pumilum *(Sond.) Puff*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.0	0.0	1.8	0.0	0.0	0.4
Galium spurium *L.* subsp. africanum *Verdc.*	0.0	6.3	0.0	2.7	8.5	1.9	26.7	2.0	1.4	0.0	0.0	9.2	3.1
Gardenia volkensii *K.Schum.* subsp. volkensii	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.7	0.0	0.9	0.0	0.4
Kohautia amatymbica *Eckl. & Zeyh.*	0.0	0.0	0.0	0.0	0.0	3.8	0.0	2.0	0.0	3.6	0.0	0.0	0.8
Pavetta zeyheri *Sond.*	0.0	0.0	0.0	2.7	4.3	3.8	0.0	3.0	2.2	0.0	5.4	0.0	2.4
Santalaceae (n = 1)													
Osyris lanceolata *Hochst. & Steud.*	0.0	0.0	0.0	0.0	2.1	1.9	0.0	2.0	0.0	3.6	0.0	0.0	0.8
Scrophulariaceae (n = 1)													
Jamebrittenia atropurpurea *(Benth.) Hilliard* subsp. atropurpurea	0.0	6.3	0.0	0.0	4.3	1.9	0.0	2.0	1.4	0.0	3.6	0.0	1.6
Selaginaceae (n = 2)													
Walafrida densiflora *(Rolfe) Rolfe*	6.3	0.0	0.0	0.0	2.1	5.8	0.0	1.0	2.9	9.1	0.0	0.0	2.0
Walafrida tenuifolia *Rolfe*	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.7	1.8	0.0	0.0	0.4
Solanaceae (n = 12)													
Datura sp.	0.0	0.0	0.0	0.0	2.1	5.8	0.0	0.0	2.9	0.0	3.6	0.0	1.6
Datura stramonium *L.*	6.3	0.0	2.1	0.0	4.3	3.8	0.0	5.0	0.7	1.8	2.7	2.3	2.4
Lycium cinereum *Thunb.* sens. lat.	0.0	12.5	0.0	0.0	4.3	0.0	0.0	4.0	0.0	0.0	0.0	4.6	1.6
Lycium oxycarpum *Dunal*	0.0	6.3	0.0	1.3	2.1	0.0	0.0	2.0	0.7	0.0	0.0	3.4	1.2
Nicotiana glauca *Graham*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.7	0.0	0.9	0.0	0.4
Solanum elaeagnifolium *Cav.*	0.0	0.0	0.0	0.0	0.0	1.9	0.0	1.0	0.0	1.8	0.0	0.0	0.4
Solanum incanum *L.*	0.0	6.3	0.0	0.0	4.3	1.9	0.0	1.0	2.2	1.8	2.7	0.0	1.6
Solanum mauritianum *Scop.*	0.0	0.0	0.0	0.0	2.1	0.0	0.0	1.0	0.0	1.8	0.0	0.0	0.4
Solanum panduriforme *E.Mey.*	0.0	0.0	0.0	0.0	4.3	0.0	0.0	1.0	0.7	0.0	1.8	0.0	0.8
Solanum retroflexum *Dunal*	0.0	6.3	6.3	6.7	12.8	9.6	6.7	14.0	3.6	7.3	11.6	3.4	7.9
Solanum sisymbriifolium *Lam.*	0.0	0.0	0.0	0.0	10.6	0.0	0.0	2.0	2.2	3.6	2.7	0.0	2.0
Withania somnifera *(L.) Dunal*	0.0	0.0	2.1	1.3	6.4	9.6	20.0	4.0	2.2	5.5	6.3	0.0	3.9
Sterculiaceae (n = 4)													
Hermannia coccocarpa *(Eckl. & Zeyh.) Kuntze*	0.0	0.0	0.0	0.0	6.4	3.8	0.0	0.0	3.6	0.0	4.5	0.0	2.0

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	Substrates						Vegetation			Region			Overall
	Tops & berms pH ≥ 6.0	Tops & berms pH < 6.0	Slopes pH ≥ 6.0	Slopes pH < 6.0	Retaining walls pH < 6.0	Toe-paddocks pH < 6.0	Recently vegetated	Old-vegetated	Never-vegetated	Carletonville	Klerksdorp	Welkom	
Sample size (no. slopes)	16	16	48	75	47	52	15	100	139	55	112	87	254
Sterculiaceae (cont.)													
Hermannia geniculata *Eckl. & Zeyh.*	0.0	6.3	0.0	0.0	2.1	1.9	0.0	3.0	0.0	5.5	0.0	0.0	1.2
Hermannia lancifolia *Szyszyl.*	0.0	0.0	0.0	0.0	4.3	3.8	0.0	3.0	0.7	3.6	1.8	0.0	1.6
Hermannia tomentosa *(Turcz.) Schinz ex Engl.*	0.0	0.0	0.0	2.7	10.6	11.5	0.0	0.0	9.4	0.0	11.6	0.0	5.1
Tamaricaceae (n = 5)													
*Tamarix spp. complex (T. usneoides *E.Mey. ex Bunge*, *T. gallica *L.*,*T. aphylla *(L.) Karst.*, *T. chinensis *Lour.*,*T. ramosissima *Ledeb.* & hybrids)	31.3	56.3	22.9	24.0	21.3	40.4	53.3	42.0	17.3	47.3	11.6	40.2	29.1
Tiliaceae (n = 3)													
Corchorus asplenifolius *Burch.*	0.0	6.3	0.0	1.3	19.1	21.2	0.0	4.0	12.9	0.0	19.6	0.0	8.7
Grewia flava *DC.*	6.3	0.0	0.0	6.7	34.0	38.5	20.0	8.0	22.3	3.6	35.7	0.0	16.5
Triumfetta sonderi *Ficalho & Hiern*	0.0	0.0	0.0	0.0	4.3	11.5	13.3	0.0	4.3	0.0	7.1	0.0	3.1
Ulmaceae (n = 2)													
+Celtis africana *Burm. f.*	0.0	0.0	2.1	2.7	19.1	25.0	13.3	9.0	10.1	0.0	22.3	0.0	9.8
Fraxinus excelsior *L.*	6.3	0.0	0.0	0.0	0.0	3.8	6.7	0.0	1.4	0.0	2.7	0.0	1.2
Verbenaceae (n = 4)													
Lippia scaberrima *Sond.*	0.0	12.5	0.0	0.0	6.4	7.7	0.0	5.0	2.9	10.9	2.7	0.0	3.5
Plexipus pinnatifidus *(L.f.) R.Fern.* var. pinnatifidus	0.0	0.0	0.0	0.0	8.5	3.8	0.0	3.0	2.2	0.0	5.4	0.0	2.4
Verbena bonariensis *L.*	0.0	6.3	2.1	1.3	4.3	0.0	0.0	5.0	0.0	1.8	0.9	3.4	2.0
Verbena brasiliensis *Vell.*	0.0	6.3	0.0	0.0	2.1	0.0	0.0	2.0	0.0	1.8	0.9	0.0	0.8
Total no. species and subspecies (5 Tamarix species combined)	53	128	47	139	242	255	86	260	231	168	216	120	323
Basal area surveyed (ha)										765	1488	3611	5864
Species density (no. species ha-1)										0.22	0.15	0.03	0.06

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+Taxa that were naturally present on slimes during this survey, and were also introduced to gold slimes dam trials subsequent to this survey (between 1996 and 2000).

APPENDIX 2.—List (in alphabetical order) of additional taxa (species, subspecies and varieties) present on gold slimes dams and adjacent slimes-polluted substrata between 1996 and 1997 (*n* = 49) and included in the general analysis (but for which frequency was not recorded). Species that were intentionally introduced during vegetation attempts are marked with an * (*n* = 12)

Anacardiaceae (n = 1)
Rhus undulata *Jacq.*

Asteraceae (n = 4)
Cotula nigellifolia *(DC.) K.Bremer & Humphries* var. nigellifolia
Gerbera piloselloides *(L.) Cass.*
Helichrysum nudifolium *(L.) Less*
Pentzia globosa *Less.*

Brassicaceae (n = 1)
* Brassica sp.

Chenopodiaceae (n = 1)
* Atriplex nummularia *Lindl.*

Ebenaceae (n = 2)
Diospyros austro-africana *De Winter* var. microphylla *(Burch.) De Winter*
Euclea crispa *(Thunb.) Gürke* var. ovata *(Burch.) F.White*

Euphorbiaceae (n = 1)
Clutia pulchella *L.* sens. lat.

Fabaceae (n = 5)
Acacia caffra *(Thunb.) Willd.*
Indigofera nigromontana *Eckl. & Zeyh.*
Lotononis divaricata *(Eckl. & Zeyh.) Benth.*
Rhynchosia nitens *Benth.*
Vigna vexillata *(L.) A.Rich.* var. angustifolia (*Schumach. & Thonn.*) *Baker*

Hyacinthaceae (n = 1)
Albuca sp.

Myrtaceae (n = 1)
* Eucalyptus sideroxylon *A.Cunn.*

Oleaceae (n = 1)
* Olea europaea *L.* subsp. africana *(Mill.) P.S.Green*

Poaceae (n = 23)
Andropogon chinensis *(Nees) Merr.*
Andropogon. sp.
Bromus inermis *Leyss.*
Cymbopogon sp.
Eragrostis bicolor *Nees.*
Eragrostis nindensis *Ficalho & Hiern*
Eragrostis sp. 1
Eragrostis sp. 2
* Festuca elatior *L.*
* Festuca rubra *L.* var. rubra
* Lolium perenne *L.*
Melinis nerviglumis *(Franch.) Zizka*
Panicum coloratum *L.* var. coloratum
* Pennisetum macrourum *Trin.*
* Pennisetum thunbergii *Kunth*
* Phalaris aquatica *L.*
* Poa annua *L.*
* Poa pratensis *L.*
Setaria pallide-fusca *(Schumach.) Stapf & C.E.Hubb.*
Setaria sphacelata *(Schumach.) Moss* var. torta *(Stapf) Clayton*
Sporobolus centrifugus *(Trin.) Nees*
Sporobolus sp.
Urochloa mosambicensis *(Hack.) Dandy*

Rosaceae (n = 1)
Cotoneaster pannosus *Franch.*

Rubiaceae (n = 2)
Pentanisia angustifolia *(Hochst.) Hochst.*
Pygmaeothamnus zeyheri *(Sond.) Robyns* var. zeyheri

Sapindaceae (n = 1)
Pappea capensis *Eckl. & Zeyh.*

Solanaceae (n = 1)
Solanum nigrum *L.*

Typhaceae (n = 1)
Typha capensis *(Rohrb.) N.E.Br.*

Verbenaceae (n = 1)
Plexipus pinnatifidus *(L.f.) R.Fern.* var. racemosa *(Schinz ex Moldenke) R.Fern.*

Zygophyllaceae (n = 1)
Tribulus terrestris *L.*

APPENDIX 3.—List (in alphabetical order) of additional taxa (species, subspecies and varieties) present on the gold slimes dams and adjacent slimes-polluted substrata subsequent to the survey (i.e. between 1998 and 2002, *n* = 86). Species that were intentionally introduced during vegetation attempts are also marked with an * (*n* = 40).

Agavaceae (n = 1)
* Agave americana *L.*

Anacardiaceae (n = 2)
Rhus erosa *Thunb.*
Schinus terebinthifolius *Raddi*

Asclepiadaceae (n = 1)
Araujia sericifera *Brot.*

Asteraceae (n = 16)
Arctotheca calendula *(L.) Levyns*
Bidens formosa (*Bonato*) *Sch.Bip.*
* Cichorum intybus *L.*
Dicoma macrocephala *DC.*
Euryops empetrifolius *DC.*
Gazania krebsiana *Less.* subsp krebsiana
Helichrysum aureonitens *Sch.Bip.*
Helichrysum callicomum *Harv.*
Helichrysum cerastioides *DC.* var. cerastioides
Helichrysum setosum *Harv.*
Senecio glanduloso-pilosus *Volkens & Muschl.*
Senecio inornatus *DC.*
Senecio laevigatus *Thunb.*
Tragopogon porrifolius *L.*
Ursinia nana *DC.* subsp. leptophylla *Prassler*
Vernonia natalensis *Oliv. & Hiern*

Casuarinaceae (n = 1)
* Casuarina equisetifolia L.

Combretaceae (n = 1)
* Combretum erythrophyllum *(Burch.) Sond.*

Cyperaceae (n = 3)
Cyperus esculentus *L.*
Mariscus congestus *(Vahl) C.B.Clarke*
Schoenoplectus corymbosus *(Roem. & Schult.) J.Raynal*

Dipsacaceae (n = 1)
Cephalaria zeyheriana *Szabó*

Fabaceae (n = 15)
Acacia mellifera *(Vahl) Benth.* subsp. detinens *(Burch.) Brenan*
*Alhagi maurorum *Medik.*
Gleditsia triacanthos *L.*
Indigofera sp.
Indigofera alternans *DC.*
Lessertia sp.
Lotononis sp.
Sesbania punicea *(Cav.) Benth.*
* Spartium junceum *L.*
Sutherlandia microphylla *Burch. ex DC.*
* Trifolium burchellianum *Ser.*
* Trifolium pratense *L.*
* Vicia sativa *L.*
* Vicia villosa *Roth*
Vigna vexillata (L.) *A.Rich.* var. davyi *(Bolus) B.J.Pienaar*

Fagaceae (n = 1)
* Quercus robur *L.*

Flacourtiaceae (n = 1)
Dovyalis caffra *(Hook. f. & Harv.) Hook. f.*

Hyacinthaceae (n = 1)
Albuca setosa *Jacq.*

Juncaceae (n = 2)
Juncus effusus *L.*
Juncus punctorius *L.f.*

Myrtaceae (n = 3)
* Callistemon sp.
* Callistemon viminalis *(Sol. ex Gaertn.) Cheel.*
* Eucalyptus grandis *W.Hill ex Maiden*

Pinaceae (n = 2)
* Pinus elliotii *Engelm.*
* Pinus halepensis *Mill.*

Poaceae (n = 20)
Avena sativa *L.*
* Cynodon aethiopicus *Clayton & Harlan*
* Dactylis glomerata *L.*
Dichanthium sp.
Digitaria abyssinica *(A.Rich.) Stapf*
Echinochloa sp.
* Eragrostis tef *(Zucc.) Trotter*
Harpochloa falx *(L.) Kuntze*
* Lolium multiflorum *Lam.*
* Pennisetum setaceum *(Forssk.) Chiov.*
* Pennisetum villosum *R.Br. ex Fresen.*
* Phalaris arundinacea *L.*
* Phalaris canariensis *L.*
* Sorghum bicolor *(L.) Moench* subsp. drummondii *(Steud.) de Wet*
* Sorghum halepense *(L.) Pers.*
* Sorghum vulgare *L.*
Stipagrostis sp.
Trachypogon spicatus *(L.f.) Kuntze*
Tragus berteronianus *Schult.*
* Triticum vulgare *L.*

Portulacaceae (n = 1)
Portulaca sp.

Rosaceae (n = 2)
* Pyracantha angustifolia *(Franch.) C.K.Schneid.*
* Pyracantha sp.

Salicaceae (n = 7)
Populus alba *L.*
Populus × canescens *(Aiton) Sm.*
* Populus deltoides *Marshall*
* Populus deltoides *Marshall* subsp. wislizenii *(S.Wats.) Sarg.*
* Populus nigra *L.*
* Populus simonii *Carrière*
* Salix babylonica *L.*

Sapindaceae (n = 1)
* Dodonaea angustifolia *L.f.*

Solanaceae (n = 1)
Lycium hirsutum *Dunal*

Ulmaceae (n = 1)
Celtis sinensis *Pers.*

Viscaceae (n = 1)
Viscum rotundifolium *L.f.*