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Vegetation Trends on a Waste Rock Repository Cap in the Northern Black Hills

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ABSTRACT We assessed successional trends, long-term vegetation sustainability, and soil surface protection during the 2005–2007 growing seasons on the 32-ha Ruby Gulch Waste Rock Repository cap. The cap consisted of 150 cm of rock and soil covering a polyethylene membrane which in turn covered mining waste rock in order to prevent leaching of heavy metals and acidic water into streams. Following construction in 2003, a contractor applied a grass-forb seed mixture to provide soil-surface protection especially for steeply sloped portions of the cap. In 2005, we established 56, 1-m^2 plots, and 20, 20-m transects to annually measure canopy cover, basal cover, and species diversity over three growing seasons. Our results showed a decrease in species richness, including a decline in broad-leaved plants (especially clovers [*Trifolium* spp.]), near disappearance of thickspike wheatgrass (*Elymus lanceolatus*), and poor establishment of western wheatgrass (*E. smithii*). Kentucky bluegrass (*Poa pratensis*), fescue (including *Festuca brevipila* and *F. ovina*), intermediate wheatgrass (*E. hispidus*) and slender wheatgrass (*E. trachycaulus*) increased or remained stable. With declining diversity, species composition among plots and transects became more similar over the three-year period. A severe drought and grasshopper outbreak in 2006 likely accelerated the compositional shift. Increases in vegetative cover and litter appear adequate to prevent excessive erosion, and despite low diversity, the vegetation appears self-sustaining.

KEY WORDS Black Hills, erosion protection, Gilt Edge Mine, reclamation, South Dakota, succession, vegetation

In 2000, the abandoned Gilt Edge Gold Mine in the northern Black Hills of South Dakota was placed on the Environmental Protection Agency's (EPA) National Priorities List. Mine waste rock deposited in the upper reach of Ruby Gulch was a source of acid- and heavy-metal-contaminated water that threatened to contaminate the Madison Aquifer, the chief water source for the towns of Sturgis and Galena (U.S. EPA 2001). Given the task of sitewide cleanup, the EPA constructed a water treatment plant to treat acid rock drainage from Ruby Gulch. Ruby Gulch Waste Rock Repository was created to sequester the nearly 9.2 million m^3 of mine waste rock within Ruby Gulch (U.S. EPA 2006). Construction of the 32-ha repository began in 2001, and in the process, mine waste rock was covered with an 80-mil polyethylene membrane and a 283.5-g geotextile and subsequently buried beneath 46 cm of crushed drain rock, 76 cm of rocky subsoil and 15 cm of topsoil (U.S. EPA 2006). Upon completion, the Ruby Gulch cap consisted of two plateaus at its summit and 10 30-percent erodible slopes (separated by terraces) leading to the bottom of Ruby Gulch (Fig. 1).

Following cap construction, contractors applied nitrogen fertilizer (urea) to the slopes (33 kg N/ha) and plateaus (140 kg N/ha). Phosphorous (56 kg P_2O_2/ha) also was applied to both the slopes and plateaus. Supplemental organic matter from the Rapid City Landfill was added only on the plateaus at a rate of 90 metric tons/ha. Wood cellulose fiber was applied to both the slopes (2800 kg/ha) and plateaus (3400 kg/ha) with a hydromulcher and tackifier. The seedbed was prepared by raking, harrowing, clod removal, and smoothing. A grass-forb seed mixture (Table 1) was planted on the cap during spring (May–June) 2003.

Seed mixtures were designed to quickly establish soil-surface cover and prevent erosion while creating a meadow type community favorable to wildlife. Chambers et al. (1994) showed that synchronized planting of forbs and grasses could provide cover similar to that of undisturbed sites; however, aggressive introduced species often tend to reduce the number of native species that can establish and persist (DePuit et al. 1978, DePuit and Coenenberg 1979, DePuit et al. 1980). Mummey et al. (2002) and Chambers et al. (1994) found that plant diversity was lower on reclaimed mine sites compared to natural sites in the same area. Holechek et al. (1981, 1982) reported that nitrogen and phosphorous fertilizer applications increased soil stabilization and canopy cover in mine reclamation efforts. Likewise, additional seeding, ripping, and topsoiling has been shown to reduce the amount of time needed for soil development (Holechek 1982).

Our primary objectives were to monitor short-term successional trends and to determine composition and persistence of established vegetative species on the Ruby Gulch Waste Rock Repository cap. Our secondary objectives were to assess soil-surface protection by the

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extent, and relative contribution of live vegetation, litter, and rock cover.

STUDY AREA

We conducted our study at the Gilt Edge Mine National Priorities List site (EPA ID No. SDD987673985) in Lawrence County, South Dakota, located 8 km east of Lead in the northern Black Hills (Fig. 1). Topography of the area was mountainous and elevation ranged from 1730 m at Anchor Hill on the north side of the site to 1490 m near the base of Ruby and Bear Butte gulches (Fig. 1). Down slope from the Gilt Edge site are the headwaters of the ephemeral (upper reach) and intermittent (lower reach) Ruby Gulch and the perennial Strawberry Creek, both tributaries of Bear Butte Creek that flows northeastward. Vegetation of the area was dominated by Ponderosa pine (*Pinus ponderosa*) in the overstory and coralberry (*Symphoricarpos albus*) in the understory (Hoffman and Alexander 1987). Climate in the area was characterized by cold, dry winters and warm, moist summers (Johnson 1949). The month with the highest monthly average temperature was July (18.9° C), and January had the lowest monthly average temperature (0.56° C). Average annual temperature was 6.7° C. Average total annual precipitation was 68 cm with the greatest amount occurring in May (7.8 cm) and the least in January (2.5 cm). The growing season for the area was approximately 130 to 145 days (Bender 2000).

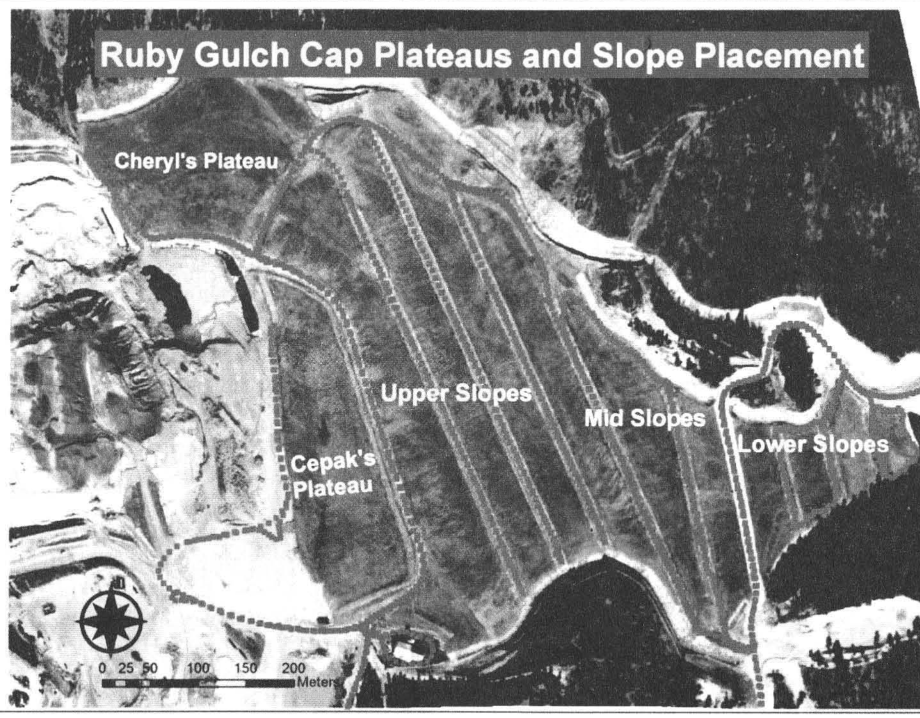

Figure 1. Location of plateaus and slopes on the Ruby Gulch Waste Rock Repository cap following construction in the northern Black Hills, South Dakota, 2001.

METHODS

We established 56, 1-m^2 permanent plots and 20, 20-m permanent transects on the slopes and plateaus. We stratified and randomly distributed plots and transects on 3 terraced portions (upper, mid, and lower slopes) and 2 plateaus (Cepak's and Cheryl's plateaus). We ocularly estimated cover by species in each 1-m^2 permanent plot and photographed each plot during the annual sampling period. Likewise, we measured species cover in 10, 0.25-m^2 plots along the 20-m transects at 2-m intervals. We used a modified Daubenmire (1959) cover scale to assign cover values to species and litter. Using an 8-pin point frame, we also measured ground-level cover in 2006 and 2007. We recorded basal hits on individual species, litter, rock, and bare soil at 80-cm intervals along the 20-m transects for a total of 200 points per transect.

Table 1. Component species in seed mixtures applied to the Ruby Gulch Waste Rock Repository cap in the northern Black Hills, South Dakota, 2003.

Ruby Gulch cap slopes and terraces	Native forbs seeded on Cepak's and Cheryl's plateaus only
Canada wildrye (*Elymus canadensis*)[a]	American vetch (*Vicia americana*)
Hard fescue (*Festuca brevipila*)	Black-eyed Susan (*Rudbeckia hirta*)
Intermediate wheatgrass (*Elymus hispidus*)	Blanket flower (*Gaillardia aristata*)
Kentucky bluegrass (*Poa pratensis*)	Lewis blue flax (*Linum lewisii*)
Little bluestem (*Schizachyrium scoparium*)[a]	Prairie coneflower (*Ratibida columnifera*)
Mountain bromegrass (*Bromus carinatus*)[a]	Purple prairie-clover (*Dalea purpurea*)
Red clover (*Trifolium pratense*)	
Sheep fescue (*Festuca ovina*)	
Sideoats grama (*Bouteloua curtipendula*)[a]	
Slender wheatgrass (*Elymus trachycaulus*)[a]	
Regreen triticale (*x Triticosecale rimpauii*)	
Thickspike wheatgrass (*Elymus lanceolatus*)[a]	
Western wheatgrass (*Elymus smithii*)[a]	
White clover (*Trifolium repens*)	

[a] native grasses

We used Nonmetric Multidimensional Scaling (NMS; Mather 1976, Kruskal 1964) in the program PC-ORD® Version 4 (McCune and Mefford 1999) to ordinate permanent transect data using the Relative Sorensen distance measure. We conducted all NMS tests using 50 iterations and with the final plot containing 44 iterations. We tested stability by plotting stress versus iterations. NMS allowed us to create a successional vector overlay to depict successional trends over the 3 years.

Using SPSS® version 11.0 (SPSS 2006), we performed Friedman two-way analysis of variance by ranks (Friedman 1937, 1940) to test for differences in cover for individual species among years as measured in permanent plots. If significant differences ($P < 0.05$) were detected between years, we conducted follow up Wilcoxon paired-sample tests (Wilcoxon 1945) to determine which years' cover values differed from one another.

We compared basal cover values (based on number of point hits per transect) between years using ANOVA. For each permanent plot and sampling year, we used the Shannon-Wiener index (H'; Shannon and Weaver 1949) to calculate species diversity, and Pielou's index (J'; Pielou 1966) to calculate species evenness. We compared diversity and evenness indices among years using ANOVA in JMP® version 7.0 (JMP 2007).

RESULTS

We detected 49 vascular plant species in our sampling between 2005 and 2007, of which only 16 were included in seed mixtures. We were unable to document presence of 3 species present in the seed mixes using our sampling protocol, including sideoats grama (*Bouteloua curtipendula*), prairie coneflower (*Ratibida columnifera*), and triticale (x *Triticosecale rimpauii*). The latter species was planted as an annual nurse crop and was present in 2005 only as sparse, standing, dead plants. We observed prairie coneflower only as widely scattered plants on the plateaus, however, it was never included in a sample. Thus, we documented 33 nonseeded species on the cap but never observed sideoats grama on site during our study.

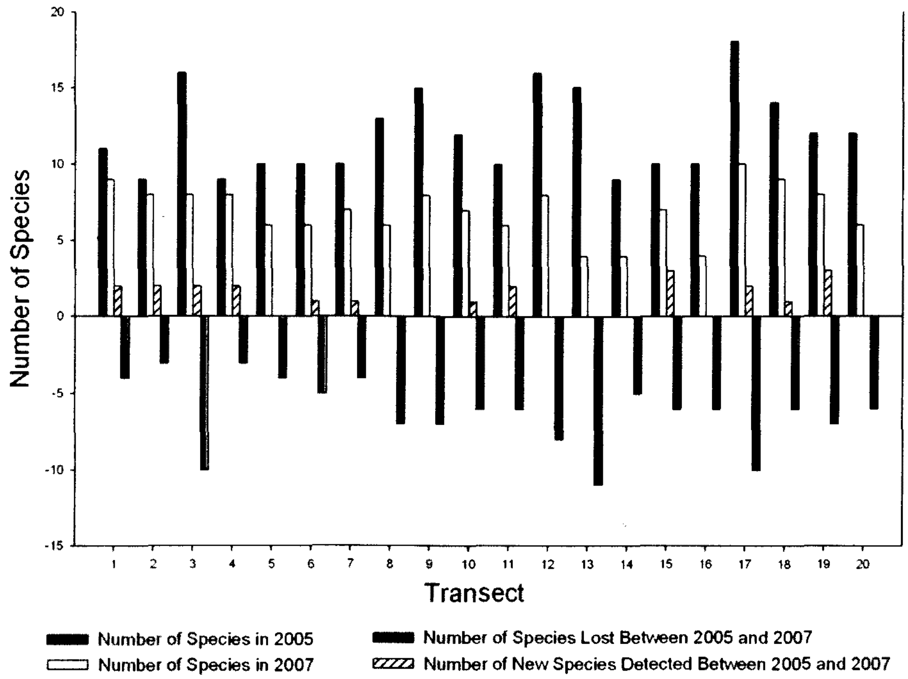

Figure 2. Total number of species detected per transect and number of species gained and lost per transect on the Ruby Gulch Waste Rock Repository cap in the northern Black Hills, South Dakota, 2005–2007.

Number of species per transect declined from 34 in 2005 to 21 in 2007 (Fig. 2). The number of broad-leaved plants decreased from 22 species in 2005 to 8 in 2007, whereas the number of grass species was 12 in 2005 and 13 in 2007. Mean species diversity (H′) decreased ($P < 0.05$) between 2005 (1.37) and 2007 (0.99), and between 2006 (1.23) and 2007 (0.99). Evenness (J') across the permanent plots remained relatively stable for the entire sampling period (2005, 0.67; 2006, 0.64; and 2007, 0.60).

Only intermediate wheatgrass (*Elymus hispidus*) and fescue (including sheep fescue [*Festuca ovina*] and hard fescue [*F. brevipila*]) significantly increased ($P < 0.05$) in canopy cover (Fig. 3). Canada wildrye (*E. canadensis*) and slender wheatgrass (*E. trachycaulus*) cover declined in 2006 and showed recovery in 2007 (Fig. 3). Kentucky bluegrass (*Poa pratensis*) cover remained relatively stable over the duration of our study, whereas western wheatgrass (*E. smithii*) and thickspike wheatgrass (*E. lanceolatus*; not shown) had low levels of incidence from the initiation of our study (2005) and were nearly absent in 2007 (Fig. 3). Red and white clover (*Trifolium pratense* and *T. repens*, respectively) cover decreased ($P < 0.05$) between years and disappeared completely by 2007 (Fig. 3). In contrast, litter cover increased ($P < 0.05$) between years (Fig. 3).

The NMS ordination revealed a temporal compositional shift where most data points tended to merge to the left near the vertical axis (Fig. 4). The final vector overlay reflects increasing similarity in species composition over the study duration, with the greatest change occurring between 2005 and 2006 (Fig. 4). Our final NMS ordination had the best fit as a 2-dimensional solution as determined by a Monte Carlo randomized test ($P < 0.01$). The two axes accounted for 92.6% of the data variability (axis 1 = 37.5%, axis 2 = 55.1%) with a final stress of 12.5 and final instability of 0.07.

We noted vegetative ground cover increased ($P < 0.05$) between 2006 (13.9%) and 2007 (20.03%; Table 2). We also detected an increase ($P < 0.05$) in overall surface protection (total ground cover) from 2005 (52.5%) to 2007 (72.0%) as litter cover accumulated (Table 2).

DISCUSSION

Weather was a major factor in accelerating vegetation change on the Ruby Gulch Waste Rock Repository cap. We saw forb richness decline sharply between 2005 and 2006 mainly as a result of severe drought during the 2006 growing season; May through August 2006 precipitation at nearby Lead was 19.7 cm compared to an average of 32.7 cm for the same period (South Dakota Office of Climatology 2006). Red and white clovers were especially impacted by drought conditions. These species are commonly used in restoration projects because of their ability to establish quickly, to provide nitrogen fixation, and to supply high quality forage for wild and domestic grazers. However, they are normally associated with areas of reliable soil moisture (Johnson and Larson 1999). Our sampling showed that both clover species were nearly absent in 2006, and completely absent by 2007. We observed white-tailed deer (*Odocoileus virginianus*) frequently grazing on Ruby Gulch cap during 2005, however, we never observed them on the cap during 2006 and 2007 sampling periods when red and white clover had dried up and subsequently disappeared. We observed no clover seedlings in 2007 despite a return to more normal precipitation. Though uncertain, it is possible that Ruby Gulch cap may be too well drained and thus too xeric for clovers to reestablish.

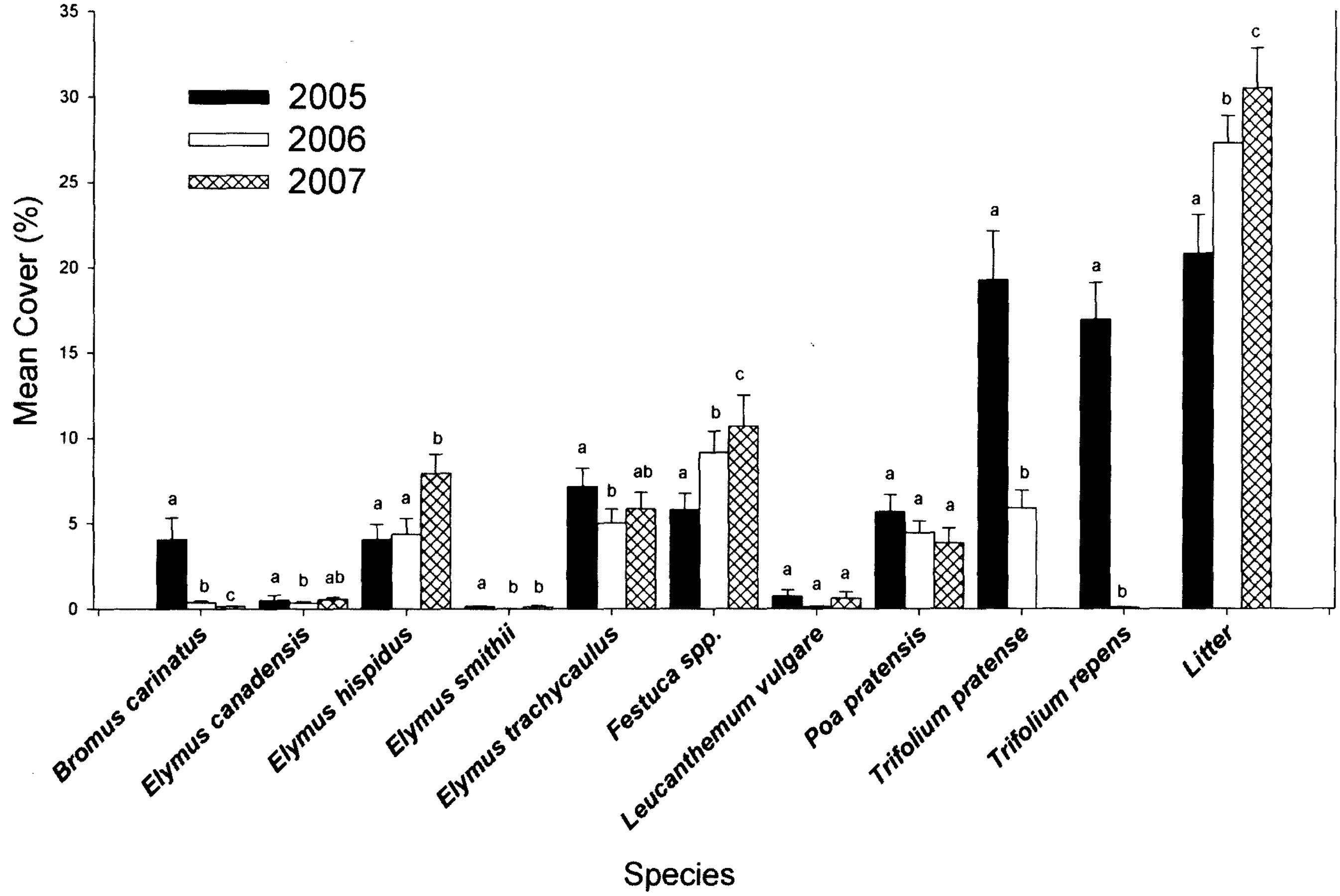

Figure 3. Mean cover (±1 SE) of common species and litter in the permanent plots on the Ruby Gulch Waste Rock Repository cap in the northern Black Hills, South Dakota, 2004–2007. Means with different letters for each category are significantly different ($P < 0.05$).

Decline in species richness and increased dominance of slender wheatgrass, intermediate wheatgrass, fescue, and Kentucky bluegrass was reflected in our NMS ordination, as points representing transects coalesced from right to left over the 3-year period. The largest change in vegetation, as indicated by vector lengths, occurred between 2005 and 2006 for most transects, and this corresponds to severe decline of red and white clovers between those years due to the 2006 drought. Coalescence of the points concomitantly reflects a decrease in overall differences in vegetation cover between transects during the 3-year period. Successional change was essentially accelerated by drought and led to simplification in the make-up and structure of vegetation on the cap.

Soil surface protection increased significantly ($P \leq 0.01$) between 2006 and 2007 due to an increase of Kentucky bluegrass, fescue, and litter, and a concomitant decrease in bare soil and rock cover. Return to near average growing season precipitation in 2007 led to increased cover by fescue and Kentucky bluegrass as these grasses responded favorably to improved moisture conditions.

Table 2. Mean ground cover (%) ± SE for the Ruby Gulch Waste Rock Repository cap in the northern Black Hills, South Dakota, 2006–2007.

Species	2006	2007
Slender wheatgrass	1.88 ± 0.21	1.60 ± 0.26
Fescue	6.13 ± 0.88	9.28 ± 1.03[c]
Kentucky bluegrass	2.20 ± 0.52	5.75 ± 2.47[c]
Other vegetation	3.70 ± 0.42	3.40 ± 0.69
Vegetative ground cover[a]	13.90 ± 1.13	20.03 ± 1.28[c]
Litter	38.58 ± 2.66	51.95 ± 2.04[c]
Rock	16.47 ± 1.33	12.68 ± 1.24[c]
Soil	31.05 ± 2.32	15.35 ± 1.79[c]
Total ground cover[b]	52.75 ± 2.72	72.00 ± 2.00[c]

[a] Vegetative ground cover was calculated by the addition of percentages of slender wheatgrass, fescue, Kentucky bluegrass, and other vegetation; [b] Total ground cover was calculated by the addition of total vegetation cover and litter cover; [c] Denotes statistically significant ($P < 0.05$) differences in mean ground cover percentages between 2006 and 2007.

Canada wildrye, slender wheatgrass, intermediate wheatgrass, fescue, and Kentucky bluegrass appeared to be self sustaining on Ruby Gulch cap. In contrast, the decline of forbs during our study was consistent with findings by Mummey et al. (2002), who found that overall cover and diversity of forbs was lower than grasses on reclaimed sites. We expect species diversity to remain low relative to natural communities, as observed in the reclamation studies of Mummey et al. (2002) and Chambers et al. (1994). The near disappearance of thickspike wheatgrass that we found on Ruby Gulch cap is contrary to findings of Holechek et al. (1982) who described thickspike wheatgrass as a highly successful reclamation species on coal mines in southeastern Montana. However, the much higher seeding rate for thickspike wheatgrass (538 seeds/m^2) and heavier fertilizer applications together with less competition from other grasses in the latter study likely account for the differing results for this species.

Even though we detected cicer milkvetch (*Astragalus cicer*) in only a few samples, the plant appeared to be spreading at a rapid rate on the upper slopes of Ruby Gulch cap. This introduced legume was planted on older reclaimed areas of Gilt Edge Mine and also was observed spreading along roadsides away from the mine. Cicer milkvetch has been described as a high quality forage for livestock (e.g., Acharya et al. 2006, Townsend et al. 1978), but we saw no evidence of plants being grazed by wildlife during this study. We suggest that the species needs to be monitored as a potential weed problem and that it may need to be treated with herbicide to aid in control efforts.

With ground cover steadily increasing, we believe soil surface protection is adequate and assured for the future. Vegetation on the cap is expected to remain dominated by fescue, Kentucky bluegrass, and intermediate wheatgrass with little forb diversity. Most importantly, we found that the vegetation appears to be self-sustaining and capable of providing surface protection over the long term.

MANAGEMENT IMPLICATIONS

Our results indicated that a protective self sustaining and durable vegetative cover can be established in relatively short time to protect erodible substrates of reclamation projects in the northern Black Hills. While using strictly native plant materials would have been more desirable, native grasses seeded on Ruby Gulch cap provided much less soil surface cover than exotic grasses, i.e., Kentucky bluegrass, fescue, and intermediate wheatgrass. Rapid establishment of protective cover is mandatory in mountainous areas, and consequently, use of fast-growing exotic grasses is virtually unavoidable. How to obtain long term establishment of forbs in plantings remains enigmatic, especially when herbicides must be used to control noxious weeds. The decline of native forbs seeded on the plateaus was pronounced although it appeared to have no relation to spot spraying for noxious weeds. After 3 years the vegetation on Ruby Gulch cap closely resembled that of much older restored (though unstudied) mining areas in the Black Hills, suggesting that low species diversity and dominance by exotic grasses are long term characteristics of these plantings.

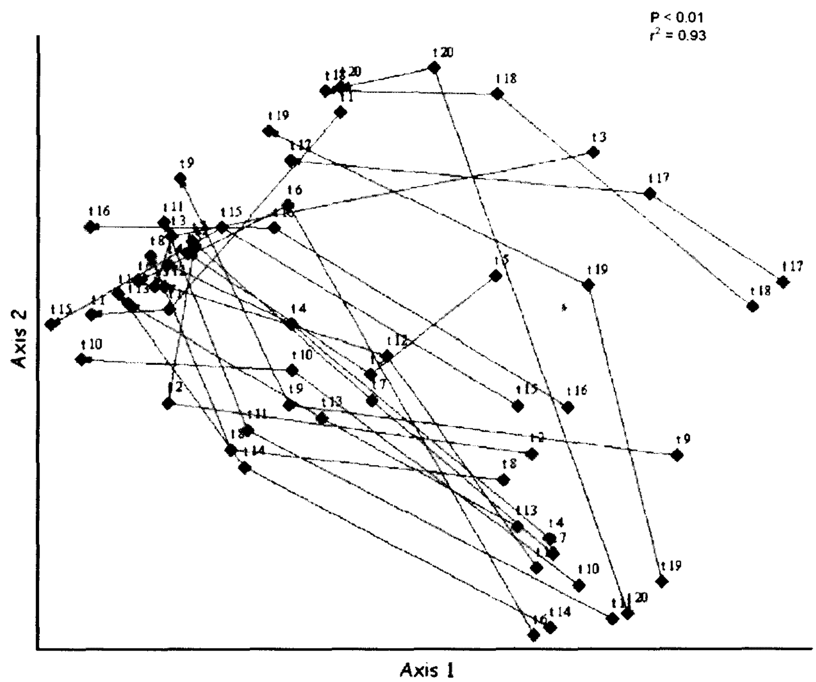

Figure 4. Nonmetric multidimensional scaling ordination with successional vectors showing compositional shift in the permanent transects (numbered points) on the Ruby Gulch Waste Rock Repository cap in the northern Black Hills, South Dakota, 2005–2007. Note how transect data lead to a coalescing of points (movement from right to left) near Axis 2 reflecting increased similarity among transects.

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