VEGETATION DEVELOPMENT AND NATIVE SPECIES ESTABLISHMENT IN RECLAIMED COAL MINE LANDS IN ALBERTA: DIRECTIONS FOR RECLAMATION PLANNING

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ABSTRACT

This study evaluates the reclamation vegetation at Coal Valley Mine (CVM) in Alberta with respect to a series of expected vegetation changes, establishes a successional model of the vegetation development, and examines factors contributing to the observed patterns. Recommendations are developed that will improve convergence of reclamation effort with established reclamation goals.

A study area of reclamation vegetation was initiated at CVM based on year of reclamation and the vegetation in these areas assessed with respect to expected changes in vegetation patterns over time. Results indicate that most expected trends were evident (lower graminoid cover and height, lower legume cover, higher native species richness, and the establishment of woody species). Four vegetation communities were identified and a successional model constructed. The cause of the increased native species diversity and cover with time since reclamation was deemed uncertain but may have been positively influenced by CVM's planting program that operated in the early years of the reclamation at the mine.

The research highlights the need for a monitoring program to inform future reclamation efforts.

Key Words: Succession, agronomic.

INTRODUCTION

This study evaluates the reclamation vegetation at Coal Valley Mine in Alberta with respect to a series of expected vegetation changes, establishes a successional model of the vegetation development, and examines factors contributing to the observed patterns. Recommendations are developed that will improve convergence with established reclamation goals.

Coal Valley Mine (CVM) is located 90 km southwest of Edson, Alberta, via Highways 47 and 40. It has been in operation for more than 30 years, and detailed reclamation information exists for most of the those years. Primary end land uses are forestry and wildlife habitat. The mine exists within a Forest Management Agreement area (FMA) which is an agreement between the Province of Alberta (the landowner) and forest companies. The FMA gives the forest company the right to grow, harvest, and remove timber from the area covered by the agreement. All forested areas within the permitted area of the FMA must be returned to viable commercial timber after mining.

CVM's reclamation strategy is based on the expectation of a number of key changes in the reclamation vegetation over time. The initial seeded legumes and grasses planted to improve and protect the soil should decrease in cover and height over time allowing volunteer species to establish. Woody plants such as the reforestation conifers should become established over time, and these changes will facilitate the establishment of more native species with higher cover (CVRI 2008).

The establishment of native species in reclaimed areas is a goal of many reclamation plans, but research on reclamation vegetation at CVM indicates that although richness and native cover do increase with time, native species remain a small component of the vegetation communities (Strong 1998, Geographic Dynamics 2008). A literature review of the interaction between native species colonization and commonly used aggressive agronomic species used to rapidly establish ground cover reveals that in general the use of the agronomics, while efficient for short term goals on ground cover and erosion control, probably interferes with the establishment of native species (Davis et al 2005, Elliot et al 1987, Halofsky and McCormick 2005, Williams and Crone 2006).

This study examines the patterns of agronomic and native species over time in CVM's reclamation vegetation and compares these patterns to the expected patterns. This provides information on the successional patterns of the vegetation, which in turn informs recommendations on improvements to reclamation practices.

MATERIALS AND METHODS

Reclamation has been on-going at CVM since 1979. The reclaimed areas of the mine considered for analysis had been reclaimed between 1979 and 2003. The potential study area was divided into polygons based on similarity of reclamation activities such as the occurrence of reforestation and the year of reclamation (YoR), defined as the year in which the area was seeded. Study polygons that met these criteria were selected based on the completeness of the reclamation information and the absence of reseeding events and wetland areas. This process resulted in 72 valid polygons. Each polygon was assigned a YoR and assigned 40 sample points. Sample points were distributed evenly between all valid polygons in the YoR group. Field sampling occurred during the summers of 2007 and 2008. At each of the 732 sample points a 1x1 m sample grid was established and the percent foliar cover of each taxon visually established. Average taxa height and the percent cover of moss and lichen were also estimated.

Species richness was calculated at various scales by counting the number of unique taxa present in the analysis unit. The total cover of various species was calculated by summing the individual cover values for all relevant taxa; summed cover values may therefore exceed 100%. Simple linear regression techniques with scatterplots were used to establish trends in species occurrence and abundance over time. TWINSPAN (Hill 1979) was used to establish vegetation community assemblages which were then verified with Indicator Species Analyses (Dufrene and Legendre 1997) and Nonmetric Multidimensional Scaling (Kruskal 1964). Analyses of differences within and between groups was accomplished with non-parametric statistics. The Mann-Whitney U-test was used for two groups and the Kruskall-Wallis (KW) test for k groups where $k>2$. Post hoc Scheffé tests based on the KW ranks were used to identify differing groups where indicated by the KW tests.

RESULTS

General Vegetation Characteristics

The field sampling yielded 118 species, of which 87 were native and 31 were non-native . There were 18 species seeded at some point of the reclamation program, two planted conifer species, and 23 exotics that became established in the study area. Species richness ranged from 56 in 1979 to 11 in 2003, averaging 22 for the study time period. Total cover averaged 110% and varied from a high of 204% in 1979 to a low of 42% in 1998. Richness of native species was highest in 1979 at 42 species, and lowest in 1991 at 1 species, averaging 12 species. The mean native cover was 34% and ranged from 183% in 1979 to 1% in the 1990-1992 time frame.

The most common species was Red Fescue (*Festuca rubra* L.) which had a constancy of 100% in the polygons studied. Alsike Clover (*Trifolium hybridum* L.) was the next most frequent species at 93. The most common native species was Lodgepole Pine (*Pinus contorta* L.), found in 57% of the polygons, and Fireweed (*Epilobium angustifolium* L.) was found in 35% of the polygons and was the most common native species not part of the reclamation program.

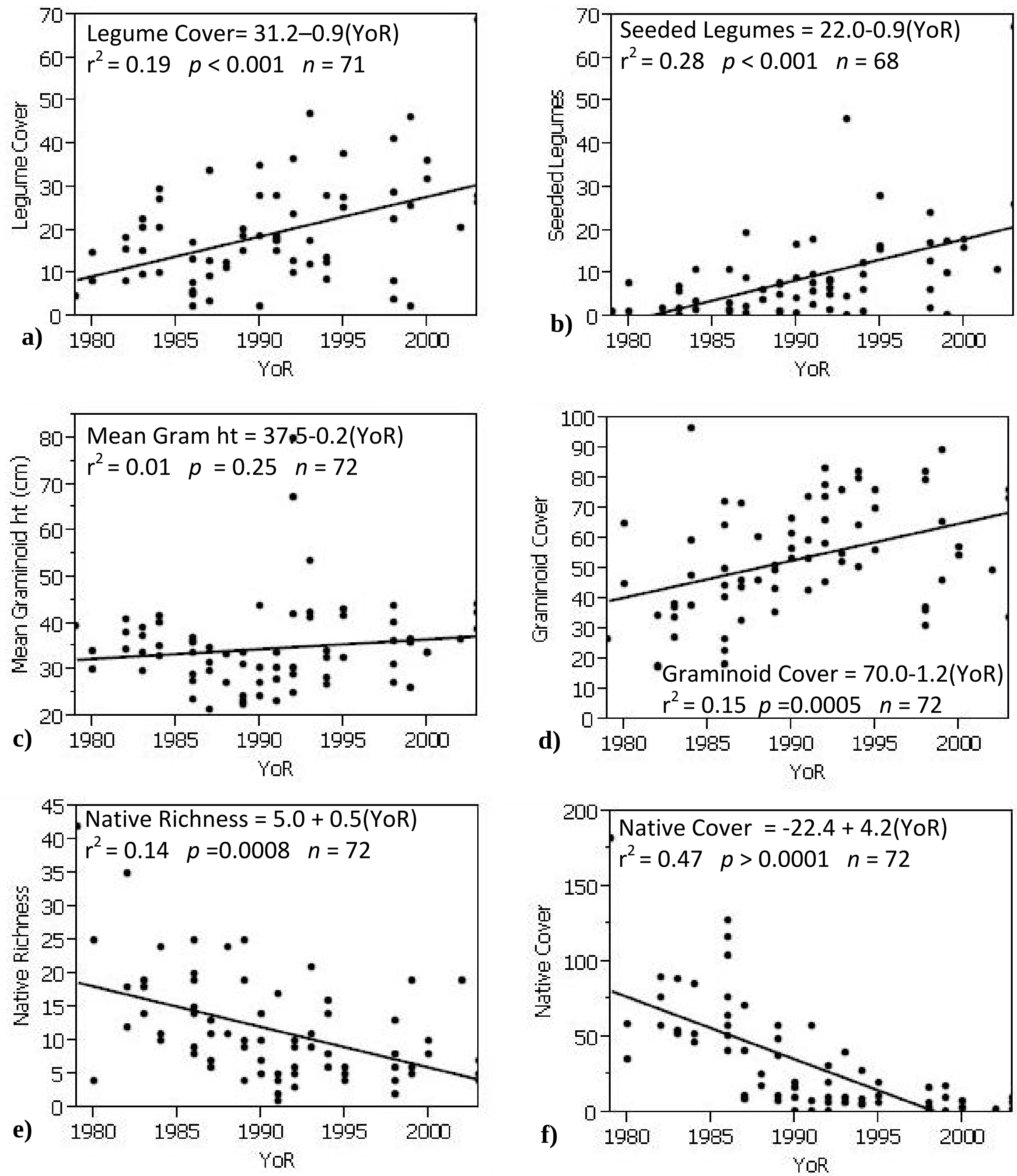
Figure 1 shows the results of the regression analyses. Seeded legumes (Figure 1b) showed a more marked decline than Total Legume Cover (Figure 1a) due to the presence of unseeded legumes such as Alsike Clover, Red Clover and Birdvetch (*Vicia cracca* L.). The dominant grass Red Fescue did decrease in height over the time period even though the average of all graminoid species did not (Figure 1c). All graminoid species decreased in cover except for Smooth Brome (*Bromus inermis* Leyss.). The majority of native species increased in cover in older areas. Lodgepole Pine was planted as part of the reclamation program and in many areas has very high cover values so to remove the influence of this species, its cover was removed from the total of native species cover. Even under these conditions there is still a strong correlation (r^2=0.36) between YoR and total native species cover (no Lodgepole Pine), suggesting that the high abundance of Lodgepole Pine in the older areas is not skewing the native cover values and there are other native species contributing to this increase. The mean tree cover (Figure 1g) increases in older areas, but if Lodgepole pine is removed this variable is no longer significantly correlated with year of reclamation, meaning that the establishment of woody species other than Lodgepole Pine is not higher in older areas.

Vegetation Communities

The TWINSPAN analysis identified two graminoid-dominated communities and two conifer-dominated communities in the reclamation vegetation at CVM, and these results were borne out by the Nonmetric Multidimensional Scaling (NMS) ordination (Figure 2). The graminoid communities are dominated by Red Fescue (cover 30%) and the conifer communities are dominated by Lodgepole Pine.

The graminoid-dominated Legume-Fescue communities have a higher legume cover, tend to be younger and have little to no native cover. The graminoid-dominated Fescue-Timothy areas have shorter grasses and some native cover in the form of sedges (*Carex* sp) and horsetails (*Equisetum* sp). These communities account for almost half of the study area.

Forested communities in the study area are dominated by the species planted as part of the reclamation program, namely Lodgepole Pine with some White Spruce. In total, these areas account for less than a quarter of the study area. These communities can be divided based on the nature of the understory. The Pine-Fescue association has a graminoid-dominated understory and a lower species richness whereas the Pine-Forb association has a herb understory and has a high native and total species richness and cover. This last community type accounts for less than one percent of the study area. Figure 2 is axis 1 and 2 of the NMS ordination, showing the separation of the communities.



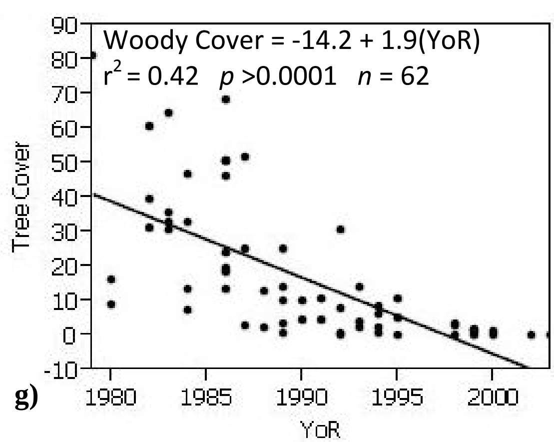


Figure 1. Scatter diagram and regression model for YoR and percent cover of a)Total Legume Cover, b)Seeded Legumes, c)Mean Graminoid Height, d)Total Graminoid Cover , e)Native Species Richness, f)Total Native Cover, and g)Total Woody Species Cover.

DISCUSSION

The Legume-Fescue association represents the youngest successional stage of the vegetation development, as this most closely resembles the initial seeding mixes and is found in the most recently reclaimed areas. The Pine-Fescue and Pine-Forb areas are likely to be later successional stages; time is required for the planted tree species to attain the observed height.

The Fescue-Timothy may represent a successional stage between the Legume-Fescue and the later forested communities, but it may also be a successional endpoint. The ages of these communities are very varied; only the very young and the very old areas are not represented (Table 1). It may be an intermediate stage, but the existence of this community type in 20 year old reclamation vegetation is evidence that progression past this stage into a tree-dominated community type is not a given. One of CVM's end land uses is wildlife habitat, and the reclamation areas are used by ungulates. This community type is both valuable for ungulates and may also be maintained in the grassland stage by grazing.

Table 1 Differences in ages of the four vegetation types

	1979	1980	1982	1983	1984	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1998	1999	2000	2002	2003
Legume-Fescue									•		•	•	•	•		•		•	•	•
Fescue-Timothy					•		•	•	•	•	•	•	•	•	•	•	•	•		
Pine-Fescue		•	•	•	•	•	•		•											
Pine-Forb	•		•			•														

Whether there is a successional relationship between the Pine-Fescue and the Pine-Forb is difficult to interpret. On one hand, the ages of the plots in these two groups did not differ significantly (Table 2) but there is a clear separation of the Pine-Forb from the other three types with respect to seeded, graminoid and native covers (Table 2). Further study on changes in vegetation composition over time need to be conducted to confirm whether or not the reclamation vegetation evolves in a linear fashion from the Legume-Fescue communities through to the Pine-Forb type. A controlled, medium to long-term replicated experiment where specific site are sampled over a period of time, such as those set up in monitoring programs, will enable the quantitative assessment of these changes. This is discussed further in the recommendations.

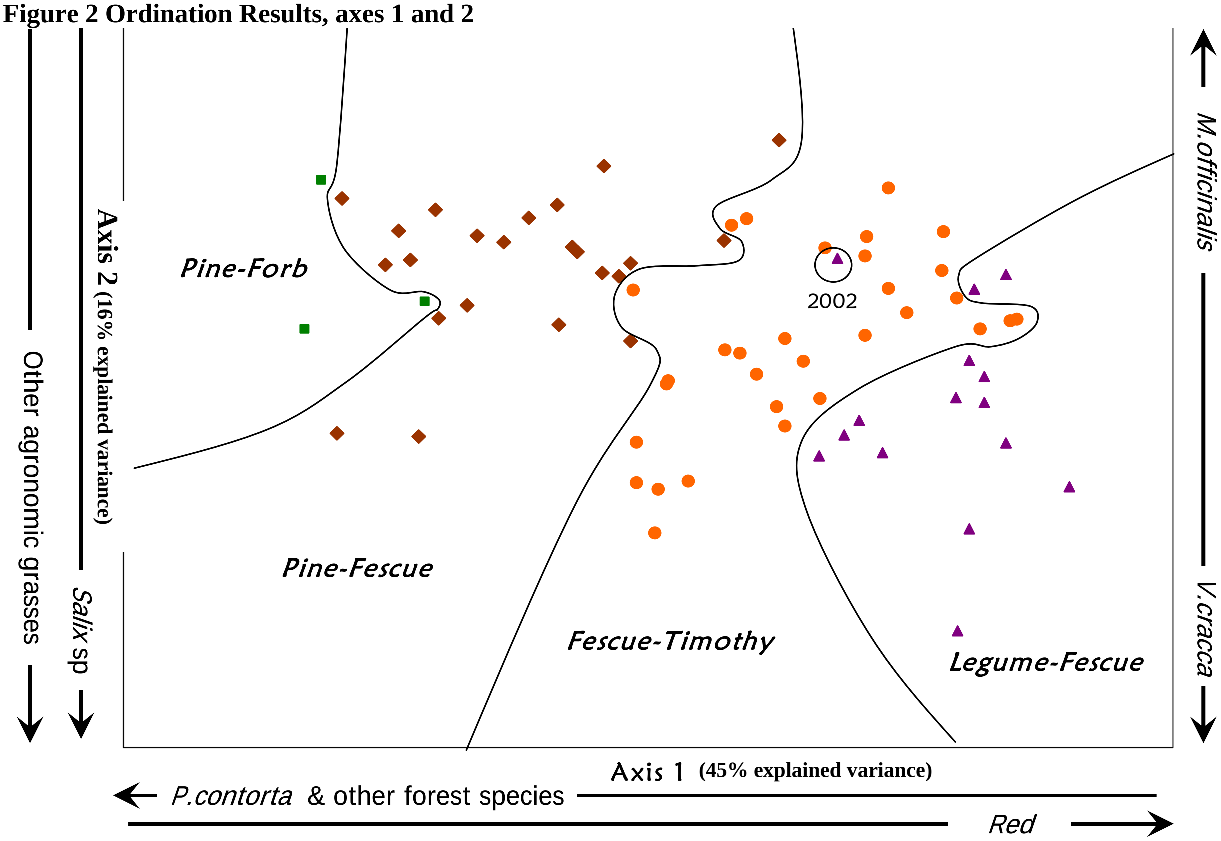
Table 2 Differences between Pine-dominated communities. Data presented as Mean(Std Dev), Mann-Whitney U-test.

	PINE-FESCUE	PINE-FORB	*p*
H'	**1.9 (0.3)**	**2.4 (0.2)**	**0.003**
Age	19 (2)	22 (4)	0.206
Richness	**24 (6)**	**45 (12)**	**0.006**
Native Richness	**15 (6)**	**34 (9)**	**0.002**
Total Cover	115 (20)	151 (48)	0.177
Total Native Cover	**66 (24)**	**125 (54)**	**0.036**
Total Native Cover no Tree*	**35 (16)**	**76 (39)**	**0.036**
Seeded Species Cover	**51 (16)**	**17 (6)**	**0.001**
Graminoid Cover	**42 (14)**	**21 (5)**	**0.010**
Forb Cover	**40 (13)**	**75 (22)**	**0.014**
Lodgepole Pine cover	30 (19)	49 (14)	0.107
Moss Cover	**12 (5)**	**22 (5)**	**0.020**

*Tree species planted as part of the reclamation program removed from the total

Environmental and physiographic variables were collected as part of the vegetation assessment and included slope, heat load, drainage, bare ground, precipitation and distance to native vegetation. None of the variables collected proved to have any relationships with the vegetation patterns

Figure 2 Ordination Results, axes 1 and 2



Vegetation Dynamics: Agronomic Grasses

One of the most common and abundant species in this vegetation is Red Fescue. While the analysis did indicate that the cover of Red Fescue was lower in older areas of the mine, except for the very oldest areas the cover is still averaging around 30% which is far more than the average graminoid cover in surrounding undisturbed areas (Strong 2002, Beckingham 1996). Research suggests that the seeding density of Red Fescue can play a role in the long-term patterns of abundance; seed mixes determined by weight underestimate the percentage of smaller seeds such as Red Fescue and seeding at lower rates (Strong 2000, Polster 1991) can harness the benefits of agronomic species, such as quick establishment and aggressive growth, while improving the conditions for the establishment of other species.

In this study, Smooth Brome (*Bromus inermis* Leyss.) cover did not show a relationship with age or native species cover or richness although other major graminoid species did. Native species cover was however significantly higher when Smooth Brome was absent (mean native cover 57%) as opposed to present (mean native cover 23%, $p = 0.000$).

Vegetation Dynamics: Legumes

Legume cover did show a positive relationship with YoR in this study, but the cover of a number of legumes that were not directly seeded is actually higher in older areas. Alsike and Red Clover (*Trifolium pratense* L.) are both non-native legumes that were used at CVM in seed mixes other than the standard mix used on the reclamation areas. Both these species became incorporated into the flora of the study area quite quickly; both are found in even the most recently reclaimed areas and are the second and the third most common species in the vegetation as a whole. There does not appear to be any relationship between these two species and native richness or native cover variables so the long-term impact of this vegetation pattern is not clear.

The total cover of non-seeded legumes is greater than that of seeded legumes in all areas and all time frames in the study except 2003 and as such have become a significant part of the reclamation vegetation. None of these species exist in the surrounding undisturbed vegetation (Strong 2002, Beckingham et al 1996).

Vegetation Dynamics: Tree Cover

Native species richness and cover appears to be positively affected by Lodgepole Pine abundance, but all these variables are correlated with YoR. Further analysis showed that the age of an area is not significantly different depending on whether Lodgepole Pine is present or not, but native richness and native species cover are higher when Lodgepole Pine is present in an area (Table 3).

Many native and characteristic species are forest-floor species and are thus unlikely to thrive in areas without a canopy. The presence of Lodgepole Pine appears to be a more reliable indicator of higher species recruitment and establishment than the cover of Lodgepole Pine, indicating that focusing on better establishment and growth of reforested species will not only increase the likelihood of meeting Forest

Management Agreement reclamation requirements but also improving native species establishment. This study can not determine whether the presence of the conifer overstory facilitates native species establishing and flourishing, only that areas with Lodgepole Pine have higher species richness and cover.

Table 3 Differences between variables based on Lodgepole Pine presence/absence. Data presented as Mean(SD), Mann-Whitney U-test.

	ABSENCE	PRESENCE	*p*
Native Richness	**8 (6)**	**13 (8)**	**0.004**
Native Cover	**17 (23)**	**40 (39)**	**0.011**
Richness	**18 (6)**	**24 (9)**	**0.005**
Total Cover	**101 (28)**	**113 (26)**	**0.009**
Age	12 (5)	14(6)	0.268

During the years 1979-1989 plantings of native forbs and shrubs occurred along with the conifer reforestation program. A limited planting regimen occurred from 1990-1996, but since then only the conifer reforestation has occurred.

The variables native richness and native cover are significantly higher for the areas reclaimed during the planting program, but the total cover is not. (Table 4). This suggests the planting program did not affect the overall vegetation development but was related to an increase in diversity and native species establishment within that vegetation.

Table 4 Differences between variables based on the existence of a planting program. Data presented as Mean(SD), Mann-Whitney U-test.

	NO PROGRAM	PROGRAM EXISTS	*p*
Native Richness	**8 (5)**	**16 (8)**	**0.000**
Native Cover	**11 (12)**	**60 (37)**	**0.000**
Richness	**20 (7)**	**25 (9)**	**0.006**
Total Cover	107 (26)	114 (28)	0.180

RECOMMENDATIONS

Improve the Establishment of a Conifer Overstory

Concomitant with an increase in Lodgepole Pine abundance is an increase in native richness and native cover. The causality of the relationship can not be determined from the data collected in this study, but either way these two develop together. In addition, the native richness and native cover in areas without any Lodgepole Pine cover are significantly less than in areas with Lodgepole Pine, regardless of height or canopy closure.

This suggests the potential benefit of establishing a well-growing conifer overstory as part of the reclamation plan. This is a regulatory requirement on the majority of CVM's lands because of the Forest Management Agreement, and improving the establishment and survival of the reforestation species will not only increase the likelihood of the area passing the Free-To-Grow standards necessary for reclamation certification but will increase the likelihood of the areas developing along the trajectories outlined in the reclamation strategy.

Investigate Changes to Seeding Mixes

Certain agronomic species currently used in the reclamation program may be detrimental to CVM’s medium and long term reclamation goals. It is recommended that CVM consider creating site-specific seed mixes depending on the end land use of an area, and that in general lower seeding rates are used.

Investigate Planting Program for Native Forbs and Shrubs

The native forb and shrub planting program that operated in the early years of the reclamation effort may have positively affected the native richness and native cover in the older areas. There are a number of reclamation techniques that could be implemented as part of a plating program, including the creation of islands of native shrubs and live staking of willows and alders.

Establish a Monitoring Program

There are a number of ad hoc studies of the reclamation vegetation at CVM but no monitoring or adaptive management program in place. Information can be gained from ad-hoc studies but long-term monitoring studies provide valuable information including successional paths of the reclamation vegetation which can only be inferred from studies such as this one.

CONCLUSION

CVM has identified a number of vegetation trends which should allow for the establishment and propagation of native species. Most of these trends are confirmed in the assessed reclamation vegetation but a review of the literature and the development of the reclamation vegetation on the mine raises concerns that the expected trends still may not supply the expected opportunities for native species establishment. Modifying the seeding mix, re-establishing a forb and shrub planting program, improving conifer establishment, and the creation of the formal monitoring/adaptive management program would allow CVM to better manage their reclamation vegetation development and facilitate the establishment of native species.

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