# RECLAMATION RESEARCH AND MONITORING AT HIGHLAND VALLEY COPPER

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## ABSTRACT

To meet the goals of revegetating land to a self-sustaining state, using appropriate plant species and achieving levels of land productivity not less than existed prior to mining, Highland Valley Copper has undertaken over 20 years of reclamation research and monitoring. The evaluation of the results of these studies has provided important feedback that is used to modify and enhance the reclamation product. Monitoring results have also been used to determine if progress is proceeding toward the desired goals and provide early warning signs of potential problems. Benchmark values have been developed that indicate the need for remedial action and others that indicate the expected trajectory of the revegetation to an acceptable product.

Parameters that have been measured for forage areas include species composition, nutrient content and biomass production. On areas planted with trees and shrubs, parameters measured include survival, growth and stocking densities. All of these parameters have been measured systematically across the revegetated areas and over time. Initial assessments of revegetated areas are conducted two years following establishment and a second assessment is conducted three years after the withdrawal of maintenance fertilizer application. Based on the results of this monitoring and other directed research studies, Highland Valley Copper can be shown to meet their revegetation goals and satisfy the land use objectives for the property.

## INTRODUCTION

Highland Valley Copper operates one of the larger base metal mining complexes in North America, producing approximately 400 million pounds of copper an 3.6 million pounds of molybdenum annually. The mine site is located in the interior of British Columbia, approximately 80 km southwest of Kamloops. The lower elevations of the mine site are within the dry cool subzone of the Interior Douglas-fir biogeoclimatic zone (IDFdk1). Elevations

greater than 1450 meters are in the very dry cool subzone of the Montane Spruce biogeoclimatic zone (MSxk).

Revegetation in the Highland Valley began in 1983 on the Bethlehem property, and since that time over 2000 hectares have been revegetated of the 6100 hectares disturbed. Revegetation activities are guided by the mine's end land use plan. The assessment and research program provides information to assess the progress toward achieving end land use objectives on a site-specific basis. This includes routine assessment of indicators of vegetation establishment and sustainability.

## METHODS

Revegetation monitoring at Highland Valley Copper includes repeated measurements of biomass production, species composition and foliar nutrient status of forages, and of tree and shrub survival, stocking densities and growth. The first monitoring of forage sites is conducted two years after seeding and then repeated three years after the maintenance fertilizer is discontinued, when the stands are six or seven years old. (Waste rock dumps are maintenance fertilized for three years and tailings are maintenance fertilized for four years after initial seeding and fertilizing.) Tree and shrub survival is monitored frequently after planting to determine when the plants achieve a steady survival rate. Growth monitoring and stocking densities are conducted on the same schedule as described for the forage sites. Discussion of results is based on statistical analysis of data using standard parametric methodology, the results of which are not presented in this paper. However, the use of the term "significant" indicates a statistically, not subjectively, identified trend or difference.

## RESULTS

The results are presented first for the areas planted with agronomic forage species, followed by the areas planted with native tree and shrub species.

### Forage Results

The results of the assessment of forage sites have been used to develop criteria for predicting the long-term success of reclaimed areas. Biomass, foliar nutrients and species cover data were used in the selection of criteria. Change in these parameters between the first and second assessment

dates were also examined to investigate trends that may indicate stability of the reclaimed vegetation.

An analysis of the first and second assessment data from thirty-four sites that were established between 1987 and 1996 was used to develop revegetation success criteria for Highland Valley Copper. This represents an area of over 800 hectares of reclaimed mine soils on all of the mine areas. The sites were initially stratified based on biomass production at the second assessment. Twenty-four of the sites, have greater than 1500 kg/ha of biomass production and were classed as "Good". Five sites have a biomass production of less than 1000 kg/ha and were classed as "Limited". The remaining five sites have biomass production between 1000 and 1500 kg/ha and were classed as "Marginal". The separation between the "Good" and "Limited" classes is significant.

When biomass was compared to foliar nitrogen concentration in grasses, further subdivisions of these classes were observed as shown in Figure 1. A subgroup (seven) of the "Good" class sites has foliar nitrogen in grasses of less than 1.5 percent. All but one of the "Limited" class sites have foliar nitrogen in grasses of less than 1.5 percent and within the "Marginal" class there were sites with foliar nitrogen in grasses both above and below the 1.5 percent criteria. This analysis led to the subdivision of the "Good" and "Marginal" classes into high and low foliar nitrogen subclasses.

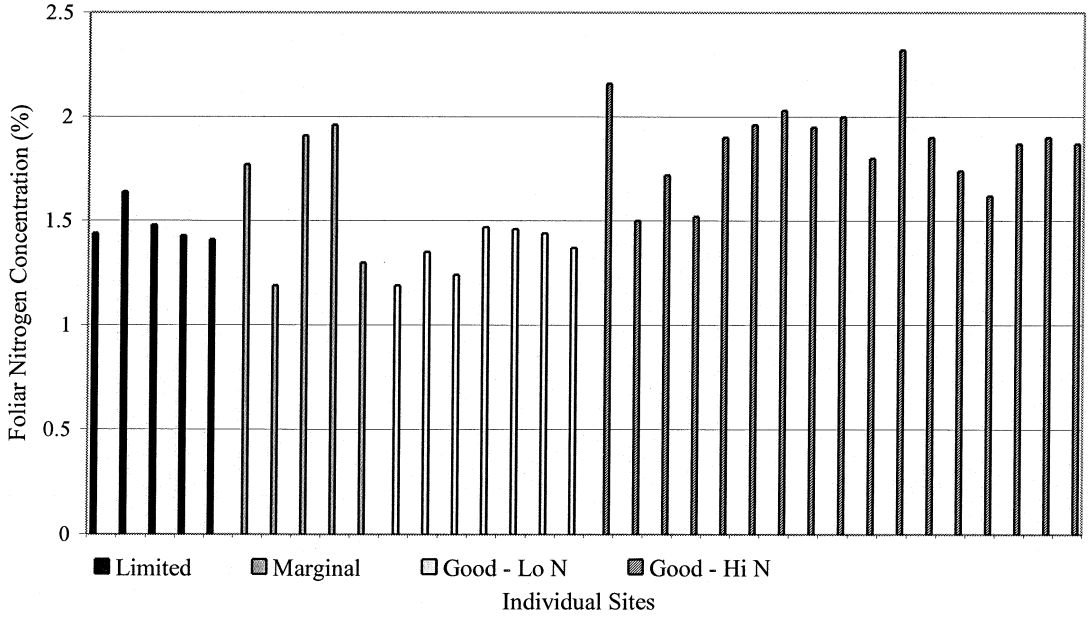



Figure 1. Second-Assessment Grass Foliar Nitrogen Concentrations by Revegetation Class

The species composition data was also assessed and total cover of legume species was found to have a strong relationship with the previously defined classes. All "Limited" sites have less than 20 percent cover of legumes, while all "Good-High N" and six of the seven "Good-Low N" sites have legume cover greater than 30 percent. Marginal sites range in legume cover between the "Good" and "Limited" classes. Figure 2 illustrates the distribution of legume cover by class.

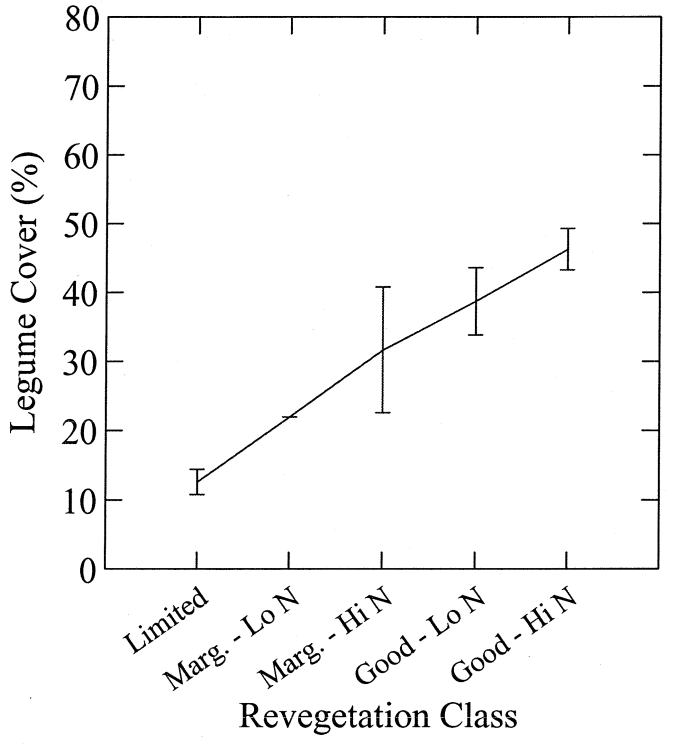



Figure 2. Legume Cover at the Second Assessment by Class

Change in various assessment parameters between the first and second assessments were evaluated using the previously defined classes. Figure 3 illustrates that sites in the "Good-High N" class show stable or aggrading biomass trajectories while the sites in the "Limited" class show degrading biomass trajectories, separated from each other by a large absolute difference. The sites in the "Good-Low N" class begin with low biomass and increase to within the range of the "Good-High N" class by the time of the second assessment. Biomass is strongly influenced by legume cover and these parameters show similar trends over time.

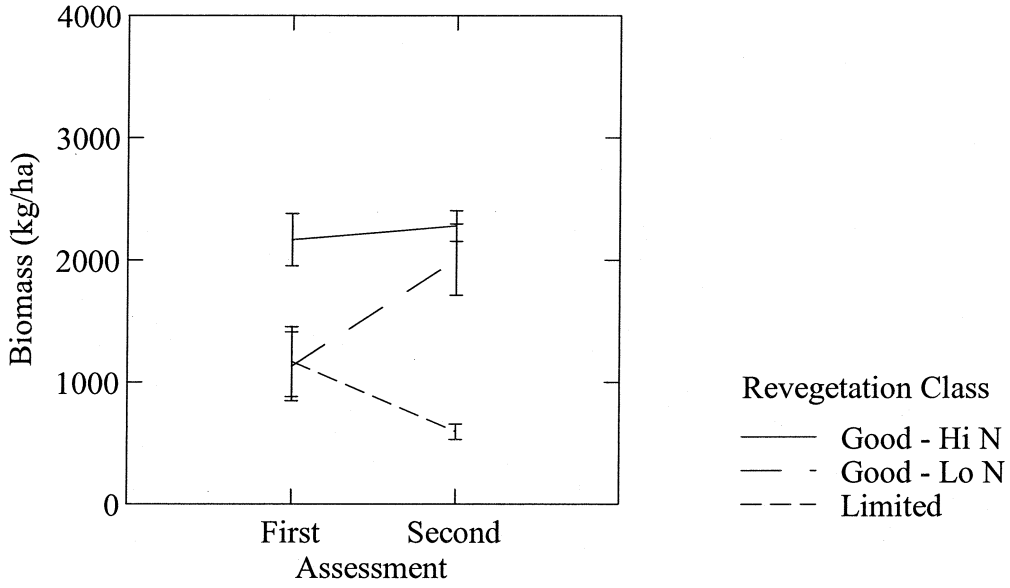
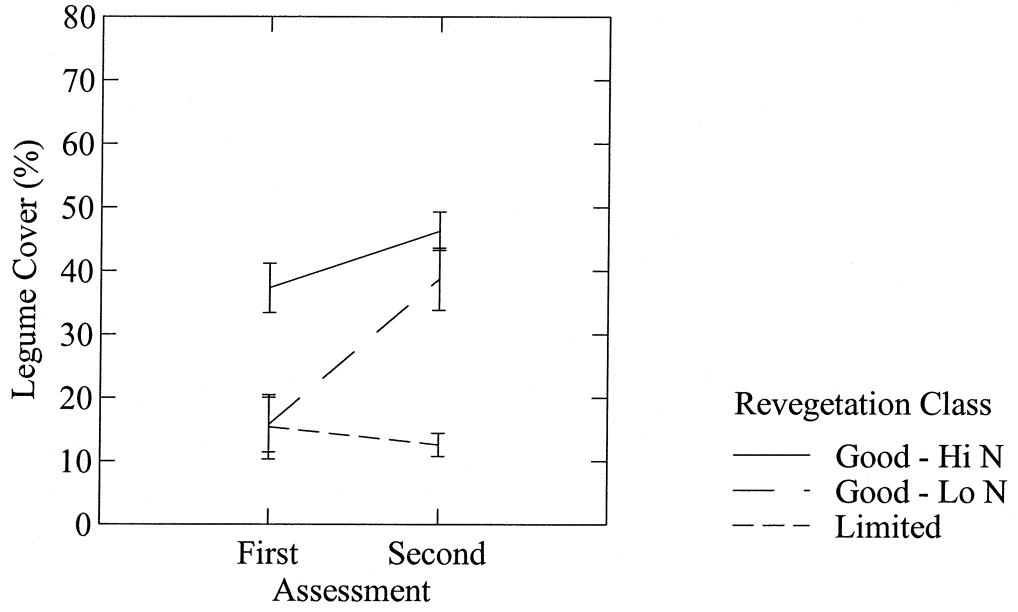



Figure 3. Change in Biomass Over Time by Class

In Figure 4, legume cover is contrasted with grass cover and it is apparent that "Good" class sites have a stable grass component of around 20 percent cover. The "Limited" class sites begin with a significantly higher grass cover and a lower legume cover and over time the grass cover decreases sharply while the legume cover decreases slightly.

When total cover is plotted in Figure 5, additional trends are apparent. "Good-High N" class sites begin with good total cover and continue to increase after fertilizer is withdrawn. "Limited" class sites start with almost the same total cover as the "Good-High N" class but the cover is composed mostly of grasses. After fertilizer is withdrawn, the total cover in the "Limited" class sites degrades significantly. In contrast, the sites in the "Good-Low N" class begin with a lower total cover than in either of the other classes, with similar legume cover and biomass to the "Limited" class but lower grass cover. Over time, sites in the "Good-Low N" class aggrade while most of the "Limited" class sites degrade.



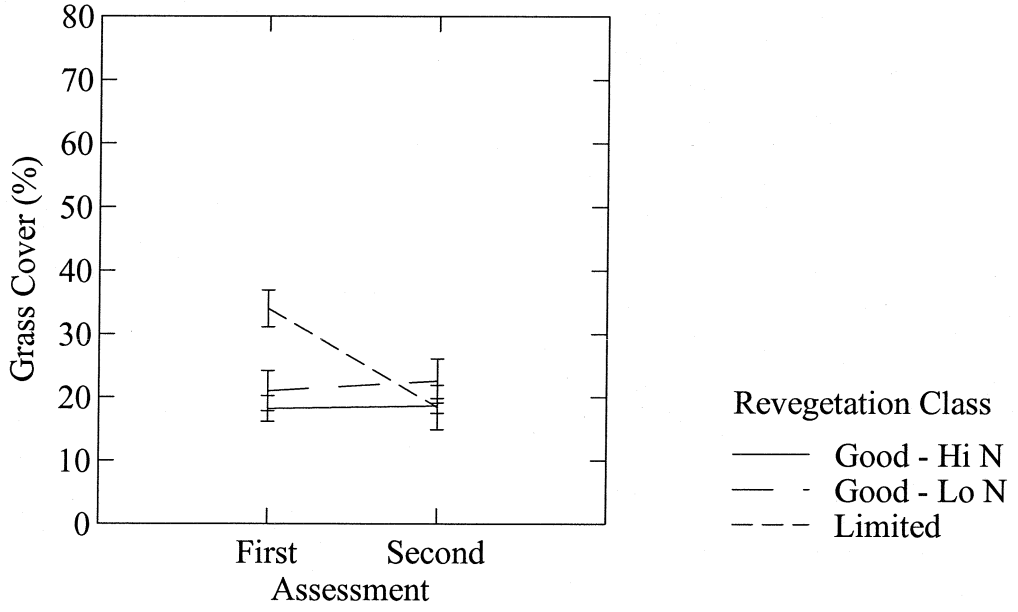




Figure 4. Legume Cover and Grass Cover Over Time by Class

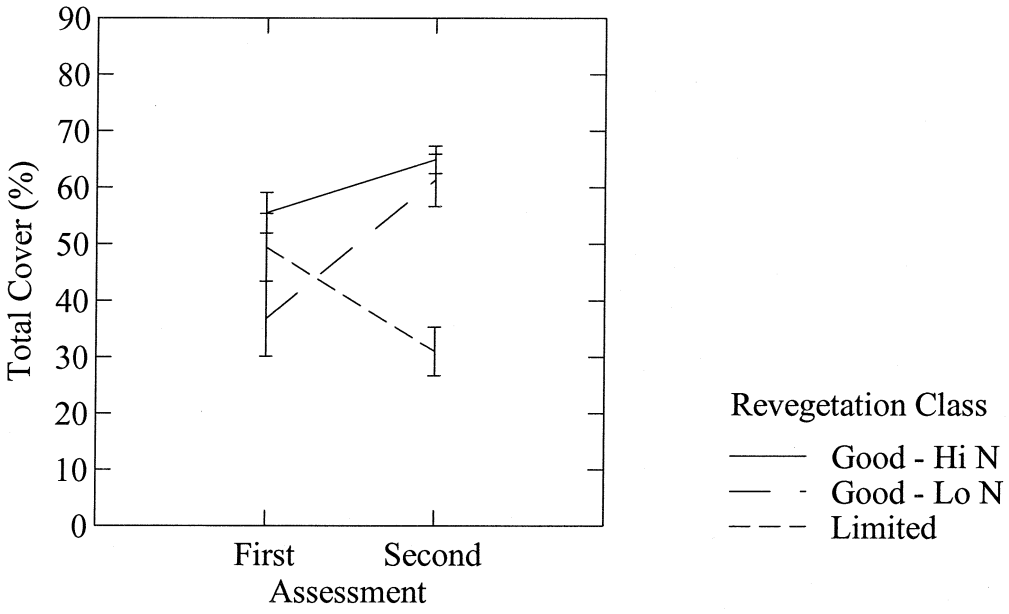



Figure 5. Total Cover Over Time by Class

There is high value in parameters that can be measured early in the establishment of a reclaimed site that may predict the long-term performance of the site. Percent grass cover at the first assessment may provide the best the predictor of revegetation success. Figure 6 illustrates the relationship between high initial grass cover and resulting "Limited" class sites.

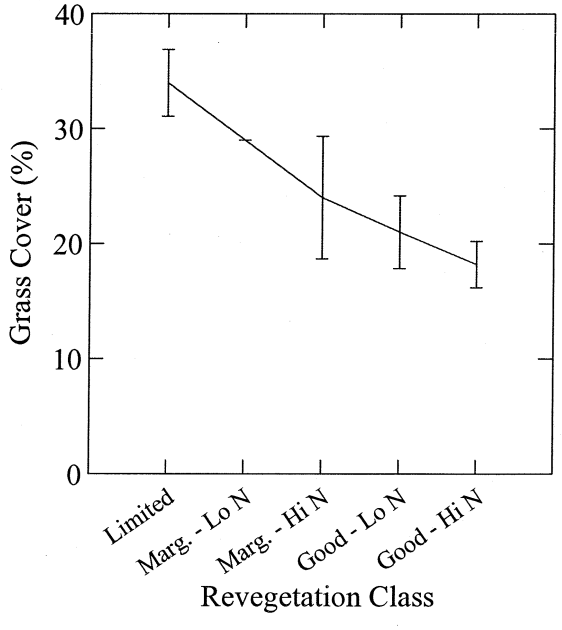



Figure 6. Grass Cover at First Assessment by Class

There is a significant difference between the first assessment grass cover on "Good-High N" and "Good-Low N" class sites and the "Limited" class sites. Mean grass cover of the two "Good" classes are 18 and 21 percent at first assessment and the mean grass cover of the "Limited" class is 34 percent. A cover of 30 percent grass at the first assessment can be used as a criterion for predicting future success. In this data set, 80 percent of the sites classed as "Limited" have greater than 30 percent grass cover at first assessment. Over 95 percent of the "Good" class sites have less than 30 percent grass cover at the time of the first assessment.

The results of the forage monitoring suggests that "Good-High N" sites are composed of a stable grass component of approximately 20 percent cover and a slightly increasing legume component to approximately 40 percent cover, six to seven years after seeding. The sites comprising this class occur on various waste material types and at both high and low elevation sites. It is believed that these sites have adequate moisture to support legume establishment and growth and that on these sites the seed and fertilizer regime favours the establishment of legume dominated stands. In contrast, the "Limited" class sites have physical properties that limit the soil water holding capacity and consequently do not have adequate moisture to support legume establishment and growth. The "Limited" sites start with a high cover of grasses during the fertilization period and this cover degrades when the fertilizer is discontinued. This trend is similar to that observed on similar sites at Highland Valley treated with biosolids and it is thought that the grasses (primarily Fescues and Wheatgrasses) are quite drought tolerant and respond to nitrogen additions with high production. When the nitrogen source is discontinued or less available, the grass production is significantly reduced (see Straker *et.al.*, this volume).

The third class, "Good-Low N" starts with lower total cover than both other classes. It has similar biomass to the "Limited" sites at the first assessment, similar legume cover and lower grass cover. However, sites in this group increase biomass and legume cover over time while the "Limited" sites degrade over time. The soil moisture and nutrient holding conditions in this class may be intermediate between the other two groups, it often occurs on tailings or shallow/poor quality overburden sites. The nitrogen content in grasses on these sites remains lower than the "Good-High N" sites throughout the monitoring period and this may limit these sites from becoming grass dominated. Legume cover on the "Good-Low N" sites begins quite low but increase over the period of monitoring to reach cover values nearing the "Good-High N" class.

When the five sites that were classed as "Marginal" were further examined, two were judged to be adequate and three sites were not. It is likely that some sites with this range of characteristics will require a further assessment before they can be reliably judged to meet the revegetation goals. All of the sites in the "Limited" class have been retreated with biosolids in an effort to improve their revegetation success. These sites are being monitored for all of the parameters discussed above and a judgement on the ability of these sites to meet the revegetation goals will be based on those assessments.

**Tree and Shrub Results**

Stocking density assessments have been conducted on approximately 330 hectares planted with native trees and shrubs. These assessments are used to document the success of planting programs in re-establishing wildlife habitat on the reclaimed mine site and to aid in planning of future planting programs. This discussion is focused primarily on planted sites over ten hectares, at these sites account for over 80 percent of the planted and assessed areas on the mine. The sites have been categorized based on waste material characteristics, climatic characteristics and designated end land use. Three representative site categories are discussed here. Stocking densities are compared to conifer and broadleaf stocking standards developed by the BC Ministry of Forest for cutblock reforestation. These standards do not have direct application to mine reclamation and are not applicable to all designated end land uses as they are stocking standards for regeneration of commercial forest. They are nevertheless useful for comparison because they provide some information on the densities of tree species required to successfully re-establish forested ecosystems in the appropriate biogeoclimatic subzones. Target broadleaf stocking is 1000-1200 (500 minimum) for the IDFdk1 and 1200-2000 (1000 minimum) for the MSxk.

Over 50 planted hectares of Shrubland have been assessed on Lornex/Highmont waste rock to date. The average stocking density on these sites is just over 1200 stems per hectare, which falls within the target range of 1200-1500 stems per hectare for the MSxk. The most successful species on this waste material have been willows, wax currant, penstemon, prickly rose and trembling aspen. Due to their good survival and originally high planting densities, willows, prickly rose and trembling aspen currently account for approximately 1000 of the 1200 total stems per hectare recorded in this area. Eight other species including black cottonwood, wolf-willow, lodgepole pine, big sagebrush, penstemon, red raspberry, wax currant and Sitka alder make up the remainder of the stand, illustrated in Table 1.

| Table 1. Stand Components by Species and Site Category | | | |
|---|---|---|---|
| | Site | | |
| | Lornex/Highmont Waste Rock Shrubland | Valley Overburden Shrubland | Valley Overburden Wildlife Corridor |
| Species | Percentage of Total | | |
| Trembling Aspen | 16 | 28 | 20 |
| Lodgepole Pine | 3 | 7 | 18 |
| Black Cottonwood | 4 | 10 | 11 |
| Douglas-Fir | - | 3 | 8 |
| Chokecherry | - | 8 | 7 |
| Saskatoon | - | 10 | 6 |
| Willow species | 48 | 11 | 5 |
| Ponderosa Pine | - | 1 | 4 |
| Raspberry | 1 | - | 4 |
| Prickly Rose | 19 | 9 | 4 |
| Hybrid White Spruce | - | - | 3 |
| Big Sagebrush | 2 | 3 | 3 |
| Douglas Maple | - | 5 | 2 |
| Wolf-willow | 3 | 3 | 1 |
| Sitka Alder | 1 | 1 | 1 |
| Penstemon | 2 | - | 1 |
| Wax Currant | 1 | - | - |

Over 50 hectares of overburden have been planted and assessed on sites designated as Shrubland in the Valley area. The average stocking density on these sites is 1050 stems per hectare, which meets the broadleaf target for the IDFdk1. The most successful species on the Valley Shrubland sites have been willows, trembling aspen, black cottonwood, big sagebrush, Douglas maple, hybrid white spruce, prickly rose, chokecherry, and wolf-willow. Both willow and trembling aspen have shown increased densities since planting, indicating substantial natural invasion and/or self-propagation on these sites. Trembling aspen, willows, black cottonwood and Saskatoon account for 60 percent of the current stocking on these Shrubland sites with prickly rose, chokecherry and lodgepole pine accounting for an additional 24 percent. The remainder consists of Douglas maple, Douglas-fir, big sagebrush, wolf-willow, ponderosa pine and alder. Planting mixes for Valley Shrubland areas were developed to provide a mixture of tree species for cover and deciduous species for browse. The results presented in Table 1 show that these mixes have been very effective at achieving this objective.

Thirty-five hectares of overburden have been planted and assessed on sites designated as Wildlife Corridor in the Valley area. The mean stocking density on these sites is approximately 900 stems

per hectare, which is just under the target broadleaf standard, but well above the 500 stems per hectare minimum. The most successful species on these sites are similar to those in the Valley Shrubland, with the inclusion of ponderosa pine and wax currant. Planting mixes for the Corridor areas were developed to include substantial conifer and deciduous tree components, to provide visual cover for wildlife species transiting more open mine areas. The secondary goal within these areas is to provide a variety of shrubs for forage. Results presented in Table 1 show that the reclamation program has been very effective at achieving its objectives, with over 65 percent of current stocking consisting of trembling aspen, lodgepole pine, cottonwood, Douglas-fir, ponderosa pine and hybrid white spruce. The remaining 35 percent of stocking consists of chokecherry, Saskatoon, willows, red raspberry, prickly rose, big sagebrush, Douglas maple, wolf-willow, Sitka alder and penstemon.

The stocking density and species survival monitoring shows that planted areas designated as wildlife Shrubland or Corridor by Highland Valley's end land use plan are well-stocked, with stand densities that meet the standards for establishment of forested ecosystems in this area. Some recommendations for future planting arising from this data analysis are for a high proportion of ponderosa pine on sites in the IDFdk1 subzone due to this species' high drought tolerance and its good performance to date on the mine site at lower elevations. Ponderosa pine has also been planted successfully on portions of the Bethlehem area of the mine at elevations above 1450, particularly on sites with southern exposure. On these latter sites, ponderosa pine can be reduced as compared to the lower elevation planting mix, but not eliminated. Because of poorer performance by Douglas-fir, this species has been removed form current planting programs throughout the mine.

Deciduous species that should be included as basic components of planting mixes on overburden sites include trembling aspen, wolf-willow, black cottonwood, willows, prickly rose and saskatoon. Big sagebrush should also be included on overburden sites in the IDFdk1 subzone. Results from waste rock sites indicate that willows, wax currant, prickly rose, trembling aspen and black cottonwood perform well and these species should be included as basic components of future planting mixes on waste rock areas. Buffalo-berry, Sitka alder and rabbit-brush have shown consistently poor survival on waste rock sites and have been removed from planting mixes.

## CONCLUSIONS

Criteria have been established for the prediction of the trajectory of the revegetation at Highland Valley Copper to an acceptable end product. On forage areas, sites can be characterized as successful, if at six or seven years after establishment, they are determined to have a biomass of greater than 1500 kg/ha that is stable or aggrading, a legume component of greater than 30 percent and stable or aggrading grass, legume and total vegetation cover. Importantly, an assessment two years after establishment can predict this success if the cover of grasses is less than 30 percent. Sites with grass contents higher than 30 percent cover in the early establishment phase have been shown to degrade and result ultimately in limited revegetation success. It is believed that the basis for successful revegetation at Highland Valley Copper is based on the water holding capacity of the waste materials and that sites with better moisture retention can maintain good plant cover. It may also be possible to develop grass dominated stands on sites with good moisture conditions, but they will require longer periods of fertilizer application. Within the data set presented, approximately 80 percent of the forage sites have demonstrated good revegetation success. It is expected that this percentage will increase in future assessments since control of waste material deposition has improved over the past decade.

On tree and shrub areas, assessments have shown that planting programs have been successful in establishing various tree species for cover and deciduous species for browse on a range of reclaimed sites. The majority of areas designated as wildlife Shrubland or Corridor by the end land use plan are well-stocked with stand densities that meet the densities required for the establishment of forested ecosystems in the local biogeoclimatic subzones.

## ACKNOWLEGEMENTS

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