ABSTRACT
Highland Valley Copper is a large open pit copper-molybdenum mine located in the southern interior of British Columbia. Since 1986, reclamation research conducted by C.E. Jones and Associates Ltd. at Highland Valley Copper has been designed to assess the performance of reclaimed sites by monitoring indicators of sustainability. These data are used to facilitate future reclamation planning and mine decommissioning. The reclamation research program includes monitoring activities to determine biomass production, species composition, and foliar nutrient status. This paper provides a summary of six years' monitoring data recently compiled during the preparation of Highland Valley Copper's first decommissioning application for a waste rock dump.

INTRODUCTION
Highland Valley Copper operates one of the largest base metal mining complexes in North America, producing approximately 370 million pounds of copper and 4 million pounds of molybdenum annually. The mine site is located in the southern interior of British Columbia, approximately 80 km southeast of Kamloops. The mine encompasses approximately 6200 ha of disturbance and extensive reclamation activities were initiated on the site during the 1980's. To date, approximately 1487 hectares have been revegetated with a mixture of grasses and legumes for erosion control and grazing purposes, and native shrub and tree plantings for wildlife use.

The Reclamation Permit stipulates a requirement to reclaim the land to a level of land productivity not less than that which existed prior to mining, and the land shall be revegetated to a self-sustaining state. The Permit also specifies a requirement to institute a research program to determine how the reclamation objective can best be achieved and to demonstrate site sustainability. Since 1986, reclamation research conducted by C.E. Jones and Associates Ltd. at Highland Valley Copper has been designed to assess the performance of reclaimed sites by monitoring indicators of sustainability. These data are used to facilitate future reclamation planning and mine decommissioning. The reclamation research program includes
monitoring activities to determine biomass production, species composition, and foliar nutrient status. Additional site specific investigations have been undertaken to evaluate surface and subsurface factors that may influence the sustainability of vegetation cover on reclaimed sites.

This paper provides a summary of six years' monitoring data recently compiled during the preparation of Highland Valley Copper's first decommissioning application for a waste rock dump identified as Lornex South.

The elevation of the Lornex South site is between 1615 and 1645 metres and is within the Montane Spruce biogeoclimatic zone (MSxk). Topography in the surrounding area is classed as moderately rolling to hilly. The pre-mining land uses were open range and commercial forestry. Prior to logging, forest cover on the site was characterized by a very dense stand of Pinus conferta (lodgepole pine) with a Calamagrostis rubescens (pinegrass) understory. A baseline productivity study conducted on adjacent sites indicated low forage productivity in the MSxk, from 0 to 428 kg/ha, attributed to the dense overstory canopy. Over the last fifteen years, numerous blocks have been clearcut in the vicinity. Presently, the area immediately adjacent to Lornex South is used for summer grazing with a licence issued by the Kamloops Forest District.

MINING AND RECLAMATION HISTORY

The site is a 25 hectare bench top on a waste rock dump constructed from 1980 to 1984. The waste rock is primarily comprised of Bethsaida granodiorite and was virtually barren of mineralization. A lesser component waste rock may have been derived from the subeconomic portions of the Skeena Quartz Diorite extracted during mining.

Soil capping has not been considered necessary on much of the Lornex property as the rapid weathering of the rock material has demonstrated its suitability for direct seeding. Prior to revegetation, the Lornex South site was ripped using a single tooth D8 Caterpillar dozer to an approximate depth of one metre to alleviate any compaction resulting from equipment travel. Recent soil pit excavations on the site have indicated this facilitated an active rooting depth of 52 to 93 cm in a mine soil with a pH of 8.0 to 8.5, coarse fragment content of 60%, and a sandy loam texture.

The reclamation plan for the Lornex property developed in 1984 (Runka et al, 1984) proposed an integrated forest and wildlife use for rock dumps at elevations higher than 1500 metres. Since that time, however, the
proximity of Lornex South to a cattle summer grazing area has influenced revegetation goals. The reclamation objective for Lornex South was refined to: developing a productive and self-sustaining vegetation cover using a combination of agricultural and native species to achieve a wildlife and cattle summer grazing land use.

Revegetation methods included aerial seeding in the spring of 1987 and 1988 with a mix of perennial grasses and legumes at a rate of 35 kg/ha. At the time of seeding, a fertilizer with a high phosphate composition was also aerial applied at a rate of 400 kg/ha. The revegetated areas were planted in the fall months with native tree and shrub seedlings at a rate of 1000 stems/ha. Maintenance fertilizer was applied at a rate of 250 kg/ha to the majority of the site annually until 1994.

A portion of the Lornex site was used to investigate the benefits of extended duration fertilizer application on species composition and production. Two, one hectare research exclosures were constructed in 1991 to allow biomass sampling to proceed without interference from cattle grazing. The western exclosure was eliminated from fertilizer treatments in 1991, while fertilizer application of the southeastern exclosure has continued annually.

INDICATORS OF SUSTAINABILITY

Species Composition
Assessments of species composition provide a measure of species diversity and are used to evaluate the self-sustaining capacity of vegetation on reclaimed sites. Species composition assessments utilize measurements of percent cover to provide information on the total number of species and the relative abundance of species present on a site. This information is used to assess changes in the species composition over time.

The composition of species established on a reclaimed site provides valuable information to infer the stability of the vegetation. Ideally, the vegetation cover should contain a strong component of legumes and a diversity of grasses. A diversity of grass species, particularly in the first few years after seeding suggests that the site is capable of sustaining good plant growth and is relatively stable. Species composition may change over time and often a single species will dominate the cover after a few years. Other grass species should still be present, but may occur at lower cover values.
Assessments of species composition are conducted using a grid based sampling design. Sampling densities are determined to provide adequate sampling of variations in species cover on the sites. At each sampling point, species composition is assessed along a line transect 5 metres in length.

Species composition was assessed on Lornex South in 1995. A total of 48 plots were assessed on an area of approximately 13 hectares for a sampling density of approximately 4.3 plots/ha. Results indicate the dominant species present on the site included *Medicago saliva* (alfalfa) and *Festuca rubra* (red fescue). Native shrub species including *Elaeagnus commutata* (wolf-willow), *Salix ssp.* (willow), *Amelanchier alnifolia* (saskatoon), *Alnus crispa ssp. sinuata* (Sitka alder), *Shepherdia canadensis* (buffalo-berry) and *Rosa acicularis* (wild rose) have been observed within the exclosures, but are absent or heavily browsed outside of the fenced areas. In the five growing seasons since the fencing was established, the native shrubs have grown well and many have reached heights of 60 to 80 cm.

Due to the variations in the waste rock material, vegetation density also varies across the site. Grouping of vegetation data indicated that 70 percent of the area sampled had moderate cover (20 to 50 percent total plant cover) dominated by *Medicago saliva* or mixed grasses. On 10 percent of the area sampled, vegetation cover was dense, with over 50 percent total cover represented by *Medicago saliva*. Low cover (less than 20 percent plant cover) was present on 19 percent of the area.

To assess the impact of the duration of maintenance fertilizer applications on species composition and plant cover, species composition was assessed inside the research exclosures in 1992 and 1996. In 1992, 10 plots...
per exclosure were assessed. In an attempt to overcome the variability within each site, sampling intensity was increased to 20 plots per exclosure in 1996. The results of the assessments in the exclosure fertilized for 4 years are presented in Figure 1 and of the exclosure fertilized for 10 years in Figure 2. It is apparent from these data that *Medicago saliva* density has decreased over time, in both the exclosure fertilized for 4 years and in the exclosure fertilized annually for 10 years.

![Figure 2](image_url)

Figure 2  
Species composition in exclosure fertilized from 1987 to 1990.

A decrease in legume composition is likely attributable to both grass competition and the longevity of *Medicago saliva*. *Medicago saliva/grass* hay fields in the area are commonly reseeded every five to eight years to increase the legume component of the stands. It is apparent from these data that continued fertilization has not deterred the trend towards decreased *Medicago saliva* over time.

Limiting the duration of fertilization may contribute to maintaining the legume component of the stand. The 1996 data indicate a higher *Medicago saliva* cover (31%) in the exclosure where fertilizer was discontinued than in the annually fertilized exclosure (7%). In contrast, grass cover in 1996 was higher in the annually fertilized exclosure. Total plant cover does not appear to have changed in either exclosure over time; however continued fertilizer application has impacted species diversity where a strong dominance of *Festuca rubra* has developed.

**Productivity**

Biomass production is used to assess the performance of reclaimed sites and is one measurement to determine when sites become self-sustaining. Gradual changes in productivity are expected to occur in
response to changes in species composition over time and in response to annual weather fluctuations. However, a sudden decrease in productivity following withdrawal of maintenance fertilizer may indicate a lack of ecological stability.

Productivity sampling is conducted on each reclaimed site using the same systematic grid based sampling design as species composition. Biomass data for the Lornex South waste rock dump has been collected from the research exclosures only, due to the interference from grazing. In 1992, ten permanent sample locations were randomly selected within each of the exclosures. As with species composition, due to the high variability in the biomass data collected in 1992, the sample size was increased to 20 permanent locations for sampling from 1993 to 1996.

Figures 3 and 4 illustrate mean grass and legume biomass on Lornex South as measured in both exclosures. Biomass varies year to year in both exclosures, reflecting differences in summer precipitation. Since 1992, biomass has ranged from 800 to 1800 kg/ha. Regardless of variations in total productivity from year to year, there are consistent differences in biomass noted annually between the fertilizer treatments. Higher grass biomass was observed in the continually fertilized exclosure and higher legume biomass in the exclosure were fertilizer was discontinued. With the exception of the 1992 results, total yields between the two areas have been similar.
Foliar Nutrients

Assessments of foliar nutrients are conducted on all reclaimed sites at Highland Valley Copper. These data have provided information regarding the requirements for maintenance fertilizer applications (amount and composition) and data necessary to assess the stability of vegetation on sites where maintenance fertilizer applications have been discontinued. Sampling is conducted during the middle of the growing season. Composite samples of grasses and legumes are collected from each site, and submitted for analytical determination of macronutrient and micronutrient concentrations. The foliar nutrient sampling program provides the data required to recognize possible nutrient deficiencies.

Nutrient content of the legumes and grasses on the Lornex South site have been monitored annually. Figure 5 illustrates substantial variation in foliar nitrogen content in grasses and legumes between years; however, there is little difference between the nitrogen content of the foliage from the two research exclosures indicating no benefit from long duration fertilizer on this site. Foliar nitrogen in Medicago sativa has shown an increasing trend over the seven year monitoring period. This trend has been observed in both the fertilized and unfertilized exclosures. A similar trend has been observed in grass foliar nitrogen over the study period. Foliar phosphorous content in both passes and Medicago sativa have also increased over the monitoring period (Figure 6). The fertilizer applied to the site contained a large component of phosphorous, but the annual phosphorous input did not result in higher foliar concentrations. The phosphorous demand of the plants in the unfertilized exclosure is being met by the phosphorous applied from 1987 through 1990. Although the pH of the soils is high, adequate phosphorous is available to support good plant growth without...
further additions.

![Figure 6](image6.png)

**Figure 6** Comparison of foliar phosphorus concentration in grasses and legumes on fertilized and unfertilized sites.

The foliar potassium concentrations in both grasses and *Medicago sativa* have shown an increasing trend over the monitoring period (Figure 7). There was very little variation between the fertilized and unfertilized treatments.

![Figure 7](image7.png)

**Figure 7** Comparison of foliar potassium concentration in grasses and legumes on fertilized and unfertilized sites.

Nutrient levels of the grass and legume foliage are within general ranges of B.C. grass and *Medicago saliva* hay (B.C. Ministry of Agriculture and Food), and are within ranges suitable for cattle consumption (B.C. Ministry of Agriculture, Fisheries, and Food, 1991).
RECLAIMED LAND USE

Lornex South is accessible to cattle under a grazing licence issued by the Kamloops Forest District. Cattle use of the higher elevation area surrounding Lornex South is generally from July through September. Grazing of the Lornex South waste rock dump began in 1988, immediately after revegetation. In 1995, the perimeter of Lornex South was fenced to allow better control of the cattle and grazing period. Since 1995, the licensee has allowed approximately 30 to 40 cow/calf pairs to access Lornex South for a one month period: the end of August to the end of September. This grazing period has been advantageous for both the licensee and Highland Valley Copper: late summer grazing is also desirable for sustaining the vegetation cover as plants are mature and more resistant to the annual grazing pressure.

Plants grown on mine waste may have tissue concentrations of metals that exceed background levels. At Highland Valley Copper, molybdenum and copper are the metals of concern; specifically the potential for molybdenum to produce toxicity in ruminants. Some foliage samples collected from Lornex South have had molybdenum levels above the published limit of 10 ppm (Puis, 1994). In perspective of the short grazing period available on Lornex South, development of a copper deficiency is unlikely if feed with a lower molybdenum is provided during the remainder of the grazing season. Research conducted by Agriculture Canada at Bethlehem Tailings failed to induce molybdenosis in cattle grazing for three month periods on foliage with mean molybdenum concentrations of 37 and 44 ppm in 1994 and 1995, respectively (Gardner et al. 1996).

SUMMARY

Highland Valley Copper has undertaken a reclamation research and monitoring program to support the long range reclamation and mine decommissioning activities. Lornex South is judged to meet the criteria for reclamation release as outlined in their Reclamation Permit:

- using species, productivity, and nutrient level assessments as indicators of sustainability, the site has demonstrated stability after discontinuation of fertilizer treatment;
- a successful grazing plan with range improvements, such as fencing, are in place;
- grazing has occurred annually from 1988 to 1996, and the site has demonstrated productive land use compatible with the surrounding unmined land.
REFERENCES

B.C. Ministry of Agriculture and Food. Average Analysis of B.C. Feeds 1969-1984, Victoria, BC.


