

USING MULTISPECTRAL REMOTE SENSING TO MONITOR RECLAMATION AT HIGHLAND VALLEY COPPER

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ABSTRACT

The use of airborne remote sensing is being investigated to monitor reclamation at Highland Valley Copper, a large open pit copper and molybdenum mine in the southern interior of British Columbia. The establishment of a self-sustaining vegetative cover is a central component of the mine's reclamation plan. The present vegetation-monitoring program represents a significant commitment of both financial and manpower resources, but only addresses a small portion of the reclaimed area each year. The mine is attempting to use remote sensing to increase the efficiency and expand the area monitored each year.

Airborne multispectral imagery has been acquired for the last three summers, and the results compared to the routine monitoring program. Significant progress has been made. During the first season, strong spectral separation was found between grasses and legumes with further separation due to density of vegetation. During 2002, directed ground truthing was used to associate recognisable spectral signatures with characteristic vegetation types, and the preliminary analysis of aquatic vegetation demonstrated the potential for species separation. In 2003, *in situ* and aerial data were acquired at a similar time, and the Normalized Difference Vegetation Index (NDVI)/Biomass relationship was very good ($r^2=0.81$). Further analysis of existing and new data will be the focus for 2004.

INTRODUCTION

Highland Valley Copper is a large open pit copper mining complex, situated between 1200 and 1600 m above sea level on the Thompson Plateau, near the town of Logan Lake British Columbia (BC), 220 Km northeast of Vancouver and 55 Km southwest of Kamloops (Figure 1). Principle activities in the area in addition to mining are cattle ranching and forestry.

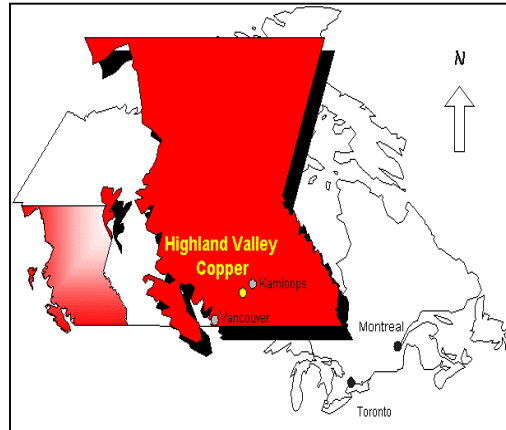


Figure 1: Location Map of Highland Valley Copper

Highland Valley Copper consists of four mining operations: Lornex, Valley, Bethlehem and Highmont. Operations at the latter two were discontinued in the mid-1980s, and decommissioning begun. Since the beginning of 2004, the mine is almost 100% owned by Teck Cominco. Current production will cease in mid-2009. The total area disturbed is currently 6000 ha.

Reclamation is an integral part of production and decommissioning. Reclamation monitoring programs are conducted annually to assess the progress toward achieving the end land use objectives, and to determine when individual sites achieve a self-sustaining state. A number of research programs investigate innovative cost-effective methods of reclamation that work towards developing self-sustaining vegetation coverage, achieving productive reclaimed land, and meeting reclamation requirements and water quality guidelines. As the area of reclaimed land expands, the monitoring program becomes increasingly complex and expensive. Beginning in 2000, remote sensing has been evaluated as a way of improving the efficiency and effectiveness of the monitoring program.

DATA ACQUISITION

Remote Sensing: Following a period of literature review and discussion, in which a number of satellite options were considered, Highland Valley Copper selected Borstad Associates Ltd of Sidney, BC to undertake aerial multispectral surveys with their Compact Airborne Spectrographic Imager (Richards *et al*, 2003). The CASI sensor was configured to acquire nine spectral channels, selected specifically for vegetation mapping. Image data were captured in a 16 bit format, in units of radiance ($\text{nW/cm}^2/\text{sr/nm}$), and areas of interest are mapped to an accuracy of 3 to 9 m before orthorectification. The entire mine was imaged each year in 2001, 2002 and 2003; however, the focus of this work is on the reclaimed areas and not all areas have been analysed every year.

Ground Data: Four different sets of *in situ* data were used to help interpret the airborne data:

- directed ground truthing - included biomass measurement and species composition, based on CE Jones Associates Ltd. standard methodology, carried out at seventy-five sites that appear to be homogeneous in the remote imaging. In addition, data from a much larger number of other sites sampled as part of the conventional reclamation operations were also available.
- qualitative data - field observations based on the 2002 thematic maps (classified by ground cover), were acquired by Borstad staff during the visit in July 2003.
- *in situ* reflectance spectra - using a hand-held spectrometer at thirty-five sites, Borstad acquired spectra of individual species and growth stages.
- photographs – acquired by Jones’ staff at the time of the ground truthing.

RESULTS

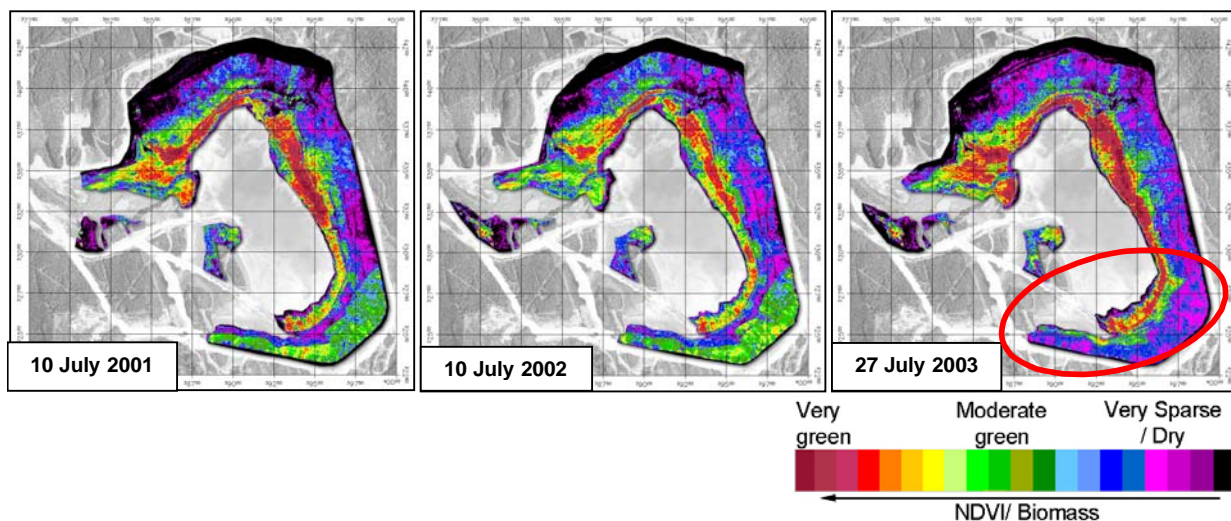
Normalized Difference Vegetative Index (NDVI)

In each of the three years, biomass has been mapped remotely using the Normalized Difference Vegetation Index (NDVI). This commonly used index (Tucker et al., 1991) is the ratio of the measured intensities in the red (665nm) and near infrared (776nm) spectral bands. Plant chlorophyll causes considerable absorption of incoming sunlight at 665nm in the red region of the electromagnetic spectrum, whereas the plant's spongy mesophyll leaf structure creates considerable reflectance at 776 nm in the near-infrared region. Consequently, vigorously growing healthy vegetation has low red-light reflectance and high near-infrared reflectance, and hence, high NDVI values. Increasing positive NDVI values indicate increasing amounts of green vegetation, while non-vegetated features such as barren surfaces (rock and soil), water and clouds exhibit NDVI values near or less than zero.

The second order regression of NDVI vs. biomass at Highmont was good ($r^2 = 0.81$), and biomass could be quantitatively mapped within an error of about ± 600 Kg/Ha across the wide range of biomass present. As expected, the legumes had the highest NDVI and contributed the most biomass, while the grasses have less.

Figure 2 shows the Highmont Tailings area over the three-year period. For most areas there was a slight overall decline in NDVI between 2001 and 2002, with a recovery in 2003 to levels similar to 2001. However, in 2003 a dramatic decrease in NDVI occurred in an area of dense grasses at the south end of the site (circled). This was due to either the later flight time and dry summer, or that the vegetation had run out of nutrients or a combination. Note that the NDVI in a narrow strip immediately above this area (blue in 2001, 2002, green in 2003) increased significantly between 2002 and 2003 due to the application of biosolids.

Figure 2: NDVI images for Highmont Tailings.



Some of these changes are recognised by biologists as related to the presence or absence of biosolids, and are certainly a point of interest for future analysis. Further analysis will involve consideration of substrate types, ages of plots and seeding times, along with information provided by biologists with local knowledge.

Vegetation Classification

Several different methods of multispectral classification have been evaluated:

Unsupervised ISOCLUS: this technique employs all of the spectral bands available. It calculates class means evenly distributed in the data space and then iteratively clusters the remaining pixels using minimum distance techniques. The user selects the number of classes to be used, and the interpretation of the classes is assigned after classification, by comparison with *in situ* observations, by spectral similarity to established classes, or from prior knowledge. This procedure is very rapid, but not very accurate. It was used to produce 50 classes, which were further grouped according to ground observations at the directed plots. Although the classes produced matched some of those established via ground control, there was a large amount of spectral overlap between classes.

Supervised Spectral Angle Mapper (SAM): this is an automated method for directly comparing image spectra to known ‘end-member’ spectra (determined in a lab, in the field with a spectrometer, or extracted from the imagery). The method treats both the unknown and reference spectra as vectors and calculates the ‘spectral angle’ between them. Because it uses only the “direction” of the spectra, and not the “length”, the method is insensitive to the unknown gain factor, and all possible illuminations are treated equally. This technique shows more promise, and was used in two different ways to produce more accurate maps: ‘rule’ or ‘probability’ images of grasses and legumes, and thematic maps using the classes established by the ground survey.

Rule images: were created using two generalized spectra selected for each area, representing spectral end members for dense dry grass and dense green legumes. The result was a map of the probability of finding one or the other at any given spot. The correlation coefficient between the dense legume rule and the linear measure of legumes on ground transects at each sample plot was 0.75. This method provides a measure of legumes, but does not separate ‘dense grasses and legumes’ and ‘dense legumes’. However, the rule image produced a useable map of the actual amount of legumes at Highmont Tailings (Figure 3 left) with an error of about 40% at low abundance, and about 20% in more dense populations. There is a suggestion that this relationship is actually made up of two populations - one dry, and the other wet and green, but this has not yet been analysed.

The rule image for grasses successfully identified the ‘dense grasses’, but confused these with ‘moderate legumes and grasses’ and ‘low cover’. This is because SAM does not take brightness into account, and looks only at the shape of the spectra. Since the substrates at Highmont Tailings are bright, it will be possible to separate the low cover, and perhaps the moderate cover areas based on brightness. Therefore, Figure 3 (right) represents only a partial classification - this analysis is not complete, and requires more effort to unravel these relationships.

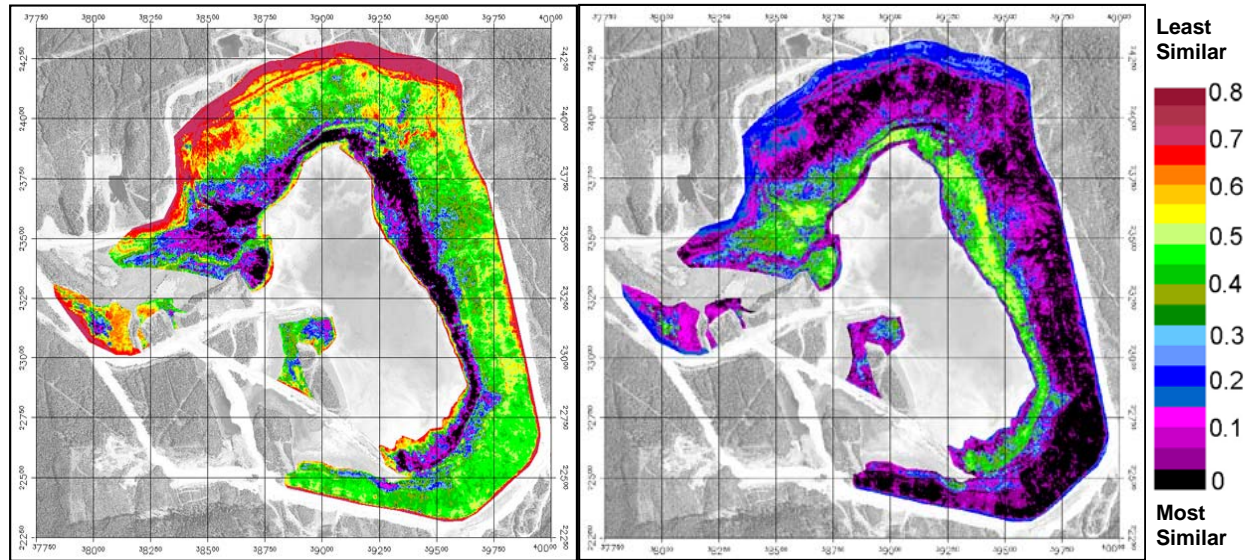


Figure 3. SAM Rule images for Dense Legume (left) and Dense Grass (right) at Highmont Tailings

Thematic maps: two classifications were created using the directed ground truth plots (DGTPs) as end-members. The first SAM classification used the 37 Highmont Tailings DGTPs to produce an equal number of SAM classes, which were then grouped according to the names assigned in the ground survey. While this method was fast and 100% accurate at the location of the ground truth plots, it was not accurate everywhere - reflecting the heterogeneity and inconsistencies seen in the ground classes.

The second SAM classification used only 10 selected spectra as end-members from the Highmont DGTPs best representing the desired classes, while the remaining 27 plots were used to test the classification. This method produced classes that matched the classes established by the ground survey, and seemed to have fewer obvious errors.

Field photographs helped to explain misclassifications, such as ‘Dense Legumes/Grasses’ plots with bare white substrate showing, which were classified as ‘Dense Grasses’. Simple linear modelling showed how spectral mixtures of white rock and green legumes can produce spectra very much like that of dense grass, when the overall brightness is ignored (which is what SAM does). It should be possible to resolve this confusion by testing for the brightness at wavelengths around 600 nm.

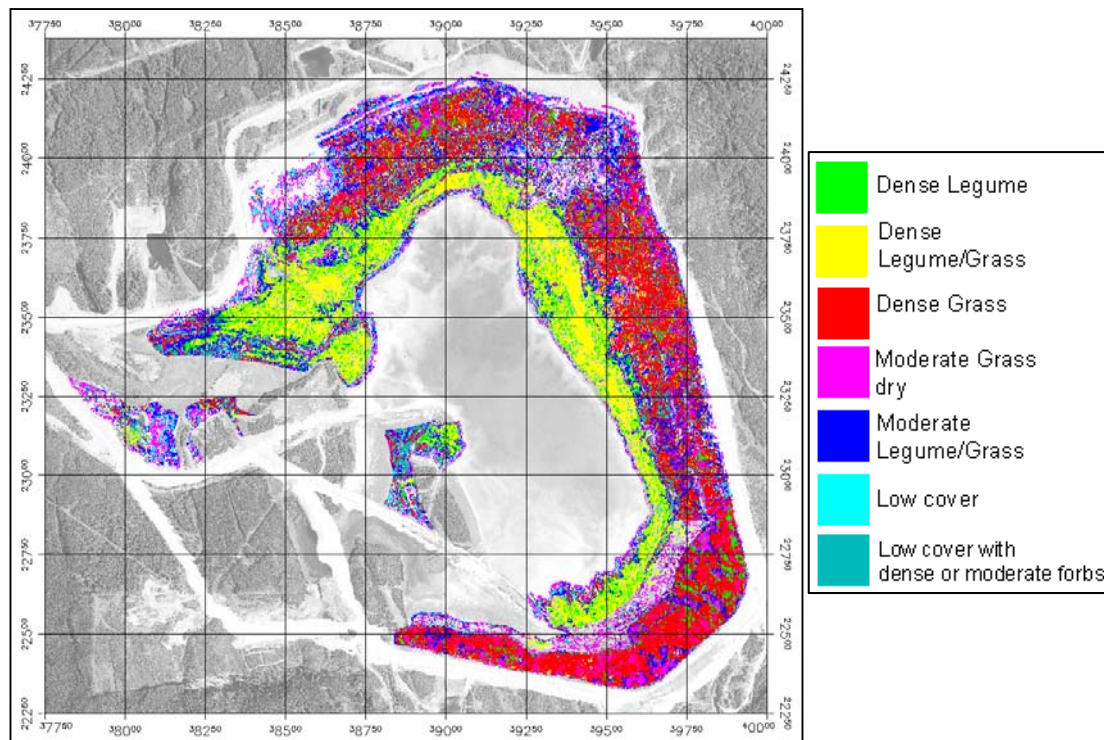


Figure 4. Supervised 'Full Training' SAM Classification of Highmont Tailings

Green-Dry Vegetation Index (GDI): both previous methods of classification are valid, but require several time-consuming steps to clean-up the resulting classes and produce one final satisfactory vegetation map. A potentially simpler method is to use the “Green-Dry Index” (GDI), as a basis for Vegetation Maps. The GDI was formulated to measure the green colour and the depth of chlorophyll absorption at red wavelengths. At the time of the flight in late July 2003, most grasses were dry and brown, whereas the legumes were still mostly green. GDI was formulated to separate the vegetation into broad classes representing 7 different community assemblages based on colour. Classes developed on the basis of GDI and ground observations at Highmont Tailings were tested and confirmed using observations at Bethlehem, achieving 100% accuracy for both target areas with n=37 and 38.

The GDI map for Highmont Tailings (Figure 5) shows similar, but not exactly the same zonation seen in the previous class map (Figure 4).

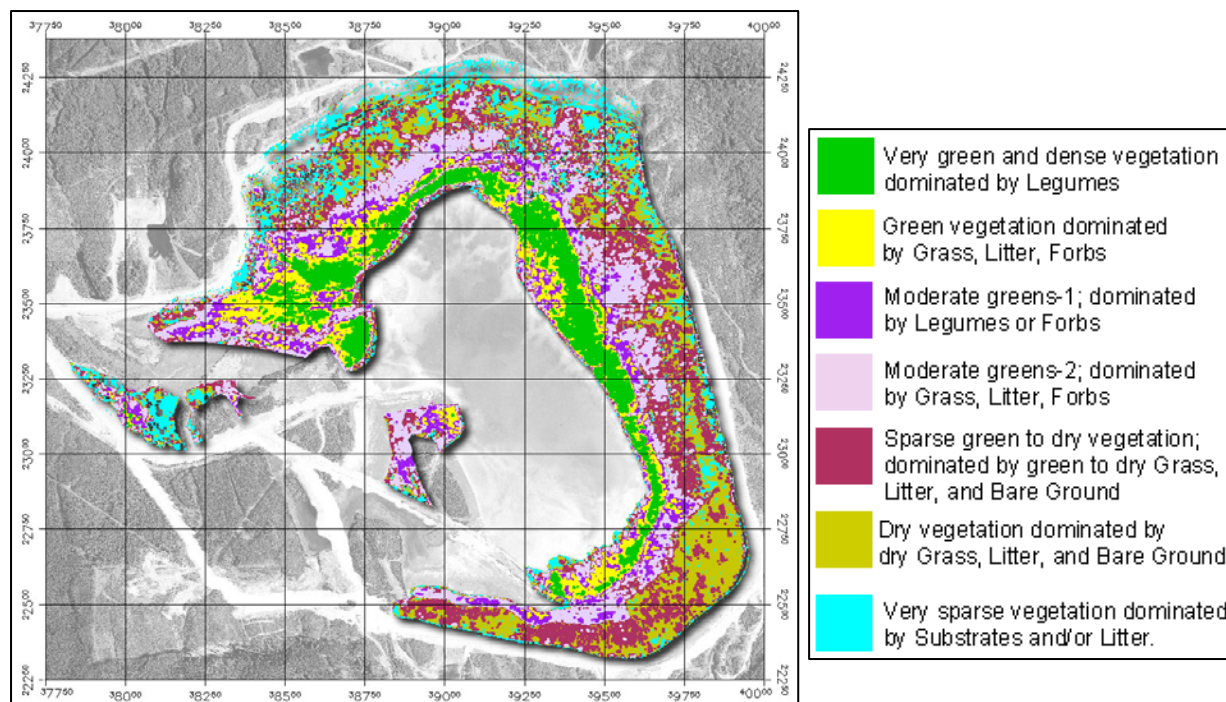


Figure 5. GDI Classification of Highmont Tailings

CONCLUSIONS

After three years of aerial surveys, it is now possible to look at year-to-year changes. The 2003 analysis has begun to do this qualitatively with NDVI maps, but the generation of quantitative biomass maps is still at an early stage. It has become clear that the ability to separate vegetation types on the basis of their colour is greatly affected by the different susceptibility of the shallow rooted grasses and more deeply rooted legumes to desiccation. Even so, the maps dramatically illustrate important changes in some areas where the vegetation is known to have ‘crashed’. More work is required to produce biomass maps with error limits.

The results from the different classification methods show that all have advantages and disadvantages. While good progress has been made thus far, a classification protocol that mixes the different methods using the most powerful aspects of each has not yet been achieved. Results to date show that the best class separations are likely to be between *dry* grasses and *green* legumes. If it is determined that this is the most important objective of the monitoring program, then surveys should be made later in the season (late July - early August) than was done in the first two years. An added advantage of flying later in the season would be the ability to better classify aquatic vegetation.

With experience, the sources of the errors in classification are being determined and eliminated. In the first year, it was attempted to use data collected as part of the conventional biological program as ground truth. However, the extreme local variability and slight inaccuracies in positioning significantly affected our accuracies. In the following years, the use of ground truth surveys directed to homogenous areas has reduced the disagreement due to local variability within and between plots. It was also recognised that an important source of 'error' is associated with the broad nature of some of the class descriptions. The class labels assigned to the ground observations in 2003 were much better than in other years in that they better reflected the linear measure of grasses, legumes and other vegetation on the transects. This resulted in fewer incongruities than in previous years. In 2002, the use of photographs of the test plots was introduced, and in 2003 was extended to all sample points, thus enabling the analysts to better see what was actually in each plot, and to understand apparently anomalous plots. For example, several plots classified as 'Low Cover' were labelled 'Moderate' by the ground survey. The photos showed that they had large amounts of bright substrate showing. The solution is probably a modification of that class to better reflect what the aerial sensor is seeing.

An important observation is that all map labels are by their very nature an attempt at simplification, and an admittedly poor reflection of the almost infinite possible combination of abundance and species composition on the ground. It should be possible to further improve them by re-examining the ground data and photos for the spectrally anomalous plots.

FUTURE DIRECTION

It is intended to extend the procedures to derive an iterative multi-stage classification using several different methods as well as spectral modelling. Class nomenclature will be further modified to include non-agronomic species, and to better reflect the amount of bare substrate. It is also intended to convert the NDVI maps to biomass units, with known error limits, so that quantitative year-to-year comparisons of biomass can be made.

While not discussed here, preliminary mapping of aquatic vegetation has also been encouraging. Further work to produce maps of all of the water bodies on the site is warranted.

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