MULTISPECTRAL MAPPING OF VEGETATION CHANGES IN RECLAIMED AREAS AT HIGHLAND VALLEY BETWEEN 2001 AND 2011

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ABSTRACT

Airborne remote sensing has been used at Highland Valley Copper since 2001 as part of the reclamation program to provide annual high spatial resolution maps of vegetation cover and complement the vegetative assessments. In 2011, the multi-temporal analysis was applied to all sites undergoing reclamation, with the exception of Valley and Lornex, where mining operations have been extended to 2025. As in previous years, Remote Sensing biomass was calculated based on the Normalized Difference Vegetation Index (NDVI) and then appended to the existing NDVI time series. This unique and growing dataset allows us to examine vegetation changes over time with spatial resolution of 2.5m.

We can now classify the entire mine site according to its vegetation history and whether or not it has reached and maintained biomass above 1500 kg/ha, which is one of the permit thresholds for self-sustaining status. The resulting 'reclamation status maps' provide a detailed synopsis of the vegetation trends between 2001 and 2011. These maps are designed to be helpful tools to reclamation managers, as they provide a means to focus further remediation efforts on specific locations most needing it, rather than having to make costly wholesale changes to entire sites.

Keywords: Highland Valley Copper, reclamation, remote sensing, vegetation, change detection.

INTRODUCTION

Highland Valley Copper (HVC) mine is situated between 1200 and 1600 m above sea level on the Thompson Plateau, near Logan Lake in British Columbia, 75 km southwest of Kamloops. HVC one of the larger copper mining operations in the world, originated from the merging of four mining operations: Lornex, Valley, Bethlehem and Highmont. Decommission begun at the latter two in the mid-1980s. Current Mine Plan has been extended into 2026 with expansion of Lornex, Valley and Highmont pits. It is estimated that more than 7,000 ha will have been disturbed by the end of the mine’s life, of which 1,800 ha have already been reclaimed.

Reclamation is an integral part of operation and decommissioning at HVC, and both conventional and remote sensing monitoring programs are being conducted annually to assess the progress toward achieving the end land use objectives, and to determine when individual sites reach a self-sustaining state.

The remote sensing program provides continuous maps of the vegetative changes over time for the entire mine site, supplementing the more detailed but less synoptic ground biological surveys, and providing a means to focus further remediation efforts on specific locations most needing it, rather than having to make wholesale changes to entire sites.

METHODS

Remote sensing data

Aerial multispectral surveys over revegetated areas have been acquired every year between 2001 and 2011, except for 2004. As in past years, multispectral airborne image data were acquired in early July using a Compact Airborne Spectrographic Imager (CASI) configured to acquire imagery in 9 spectral bands at 2.5 m spatial resolution (Richards et al., 2003, 2004; Borstad et al., 2005, 2009; Martínez et al., 2011). The aerial imagery is acquired along parallel transects with 50% overlap to obtain complete coverage of the revegetated areas, then radiometrically calibrated, and geometrically corrected and geographically mapped consistent with the mine Geographic Information System (Mine Units). The mapped at-sensor radiance imagery was then calibrated to apparent surface reflectance. Reflectance is a unitless ratio of the light reflected from the ground to the light illuminating the area, and is measured on a scale from 0 to 1 (or 0-100%) and permits direct comparison of the mapped imagery.

In 2011, we also acquired a 2 m resolution multispectral image for the same day from the World View 2 satellite (WV2) - which turned out to be on the same day as the airborne acquisition. This allowed us to cross-calibrate the two datasets and use the satellite data in place of the airborne data this year. Both datasets were similarly mapped and converted to surface reflectance. A comparison of the two datasets showed that they could be used interchangeably and therefore, the satellite data were used this year in preference to the more labour intensive airborne imagery.

Vegetation Indices

Two vegetation indices were computed for both airborne and satellite imagery. The Normalized Difference Vegetation Index (NDVI) as shown in Table 1 is commonly used in remote sensing as a proxy for green plant biomass, % c (Tucker, 1979: Tucker et al., 1991; Jackson et al., 1983; Peñuelas and Filella, 1998). It is calculated as a normalized difference between reflectance in the near infrared and red portions of the electromagnetic spectrum. The underlying principle is that red reflectance (near 660 nm) from healthy green vegetation is low because of light absorption by photosynthetic pigments, mainly chlorophylls, whereas a plant's spongy mesophyll leaf structure creates considerable reflectance in the near infrared region of the spectrum.

NDVI is not a perfect measure of *in situ* biomass. Effects such as self-shading and consequent saturation of the index at very high *in situ* biomass, variability of the NDVI/biomass relationship between grasses and broad leaved plants, disease, flowering, water availability and other successional effects can interfere (Yin and Williams, 1997; Carter and Knapp, 2001; Wang et al., 2001). We try to reduce this variability by conducting the survey at the same time every year. We know that NDVI is for any particular class of vegetation is strongly controlled by precipitation and slope (Borstad Associates, 2009). At Highland Valley, grasses are more susceptible to desiccation, and we can use the precipitation response and interannual variability of NDVI to help us identify areas with poor moisture retention.

The Normalized Green Index (NGI) was therefore developed in 2006 to assist with the interpretation of the NDVI maps by differentiating low NDVI values caused by chlorophyll degradation from those caused by moderate or sparsely vegetated green areas (Borstad Associates, 2006). NGI compares spectral bands in the green and the red wavelengths, having positive values for dense green vegetation, and negative values for yellowish vegetation.

As the CASI and WV2 multispectral bandsets were different, the vegetation indices were calculated using slightly different wavelengths (Table 1).

Table 1. Calculation of vegetation Indices for CASI and World View 2. R_λ = reflectance at wavelength λ (in nanometres).

Index	**CASI**	**WV2**
NDVI	$(R_{776} - R_{665}) / (R_{776} + R_{665})$	$(R_{832} - R_{660}) / (R_{832} + R_{660})$
NGI	$(R_{555} – R_{665}) / (R_{555} + R_{665})$	$(R_{545} – R_{660}) / (R_{545} + R_{660})$

Remote Sensing Biomass (RSB)

For application to Highland Valley, we calibrated NDVI to ‘remote sensing biomass’ (RSB) based on a comparison of CASI and *in situ* biomass measurements for a wide range of conditions from 2001 to 2005 (Borstad Associates, 2006):

$$RSB = b*(NDVI-c)/(a-NDVI+c)$$

where a=1.355, b=6959.7, c=0.129

Temporal classification

In order to assess vegetation changes over time, the 2011 calibrated WV2 NDVI was appended to the existing 2001-2010 CASI NDVI dataset to produce an 11-year time series (excluding 2004, as there was no flight that year). The annual NDVI images were classified using an unsupervised algorithm (ISODATA in ENVI 4.2™) that created 100 classes with similar NDVI histories, which were then grouped manually according to the observed trends in RS Biomass, and whether or not they had reached and maintained biomass above 1500 kg/ha, the accepted reclamation threshold for sustainability (Jones & Associates, 2005, Borstad Associates, 2006; Borstad et al., 2009; Martinez et al., 2011). The algorithm was applied to reclaimed areas on a local basis due to the complexity of each area, but the criteria for the final grouping were the same for all areas. The NGI data were used to assist in the interpretation of low NDVI values. Photographs and visual observations made during a field visit on 24th August 2011 were used to assist the interpretations.

RESULTS

Temporal Classes

Table 2 illustrates the eleven groupings derived from the 11-year NDVI classification. Areas with RSB > 1500 kg/ha are considered “good” or successfully reclaimed, while those with RSB in the range 750 – 1500 kg/ha are termed “marginal” and could require further remediation to achieve reclamation status, especially if showing a rapid decline. Areas that remained consistently below 750 kg/ha are considered “limited” and indicate that vegetation is not establishing and intervention is required. Areas disturbed *before* 2007 were described in terms of their NDVI trend since then. Only areas disturbed *after* 2006 were grouped into classes 10 (recovered) and 11 (not recovered).

Table 2. Descriptions of temporal change classes derived from the unsupervised classification of the 2001(02)-2011 NDVI time series. RSB =Remote Sensing Biomass. Note that although class 5 is included in the table, it did not appear in the 2011 reclamation maps.

2001/2002 - 2011 Trend	**2011 RS biomass** (kg/ha) and **Class**			**Interpretation** (based on ground truth and photographs)
	>1500	750 -1500	<750	
Stable or weakly varying	1	5	9	(1) good areas: dense green vegetation (5) marginal areas: green /dry/ sparse vegetation (9) limited areas: poorly vegetated areas that are not establishing
Rapid growth since 2001 or 2002, or since disturbance *before 2006*	2	6		(2) previously new / limited /marginal areas that have become established by 2011. (6) not yet established by 2011
Rapid decrease	3	7		(3) areas experiencing a rapid loss of RSB, but still >1500kg/ha in 2011 (7) loss leading to RSB <1500 kg/ha in 2011
Very variable, strongly affected by desiccation	4	8		(4) dense grass areas (8) marginal grass areas
Disturbed *after 2006*, and recovered by 2011	10			good / marginal areas that were disturbed *after* 2006 and had RSB >1500kg/ha by 2011
Disturbed *after 2006*, and **not** recovered by 2011		11		good / marginal areas that were disturbed *after* 2006 and had RSB <1500kg/ha by 2011 includes areas that suffered vegetation loss not caused by mine activities

<u>Reclamation Status</u>

Figure 1 illustrates the 2011 reclamation status for two of the three major reclamation areas at Highland Valley. The 11 classes listed in Table 2 were merged into 3 categories that summarize the RS biomass status in 2011, whether successfully reclaimed (>1500 kg/ha, classes 1-4, 10), not yet established (750-1500 hg/ka, classes 6, 7, 8), or limited or disturbed and not recovered (<750 kg/ha, classes 9, 11).

The results show that in 2011 the reclaimed areas had been successfully reclaimed for the most part (70-78%). The ‘limited/loss’ areas (black in Figure 2) tended to be found mostly along Bethlehem Main Dam, south Heustis, southeast Bethlehem Plant site, and some areas recently disturbed in Bethlehem Tailings and Bethlehem South that remained limited in 2011. Pond margins were included in this class, although they represent areas of submerged and emergent macrophytes. In 2011 high water levels caused flooding in east Trojan and Bethlehem Main I pond (white arrows in Figure 2). The presence of water reduces NDVI values in wet areas even if vegetation growth is dense. The flooding is believed to have been caused by the combination of a very wet spring and the impact of intense beetle-salvage logging in the watershed north of Trojan.

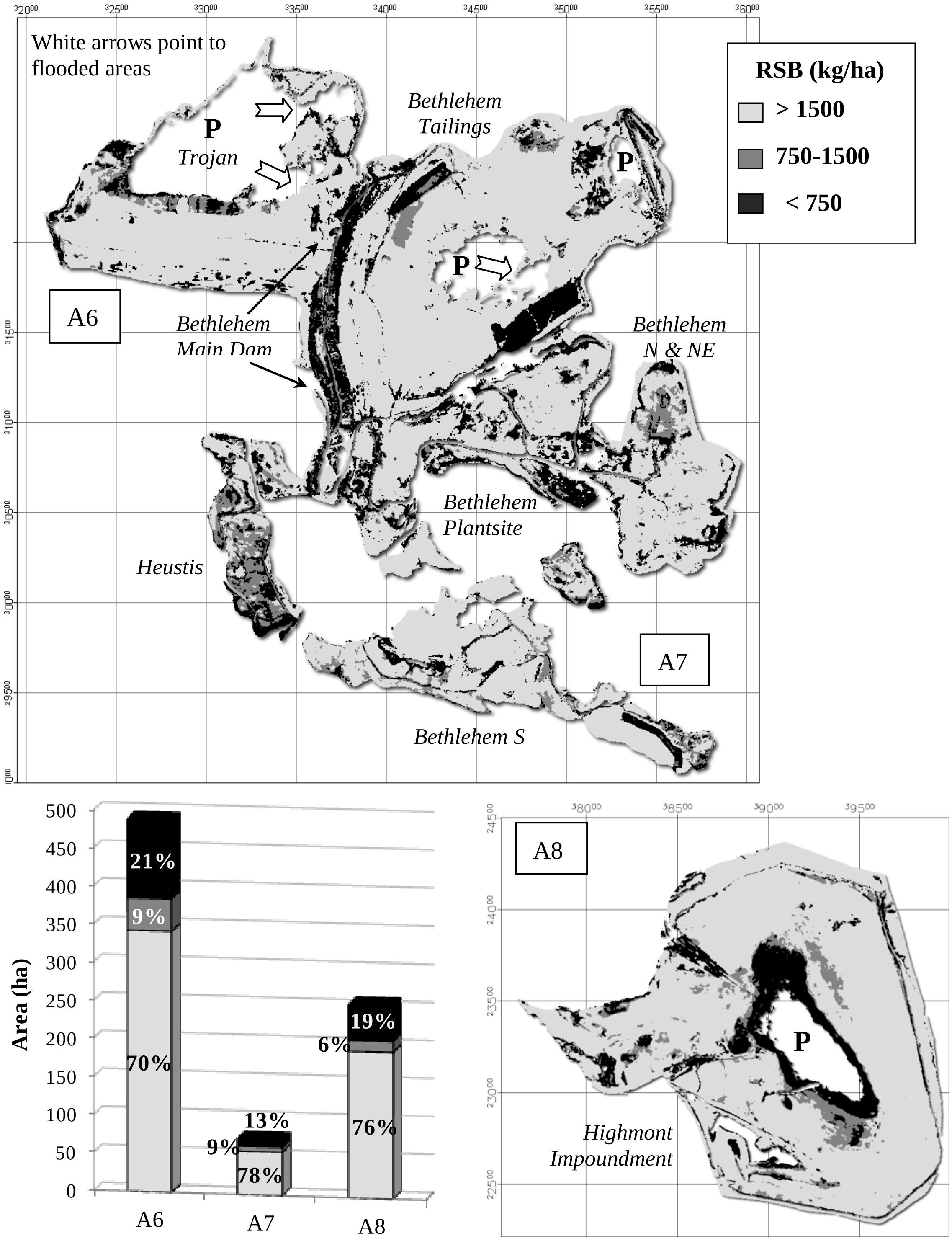

Figure 1. Reclamation status maps for the 3 study areas at Highland Valley Copper, showing remote sensing biomass estimates for 2011. **P**: location of ponds.

Table 3 gives the full classification breakdown, showing not only the current reclamation status but also the 11-year trends at each study area. A large fraction of the areas rated ‘successfully reclaimed’ were subject to desiccation (class ‘AD’), especially at area A6 (37%). Our interpretation of this class is that although the biomass is generally good, there is a strong year-to-year variability in vegetation greenness, as shown by the NDVI trends. This variability is strongest in areas of grass and helps the analyst interpret vegetation type. Observation of these areas in August 2011 confirmed a dominance of grasses, which bleach under drought conditions.

A more detailed analysis of the 750-1500 kg/ha ‘not yet established’ classes (marginal) shows that some of these areas are on track to reclamation success if the current growth trend continues (‘rapid growth’ class 6), while others will likely require intervention (‘rapid decrease’ class 7).

Table 3. Summary of 2001-2011 temporal classifications at the 3 study areas.

RSB: remotely sensed biomass (kg/ha), WV: weakly varying, RG: rapid growth, RD: rapid decrease, AD: affected by desiccation, DR: disturbed & recovered, DNR: disturbed & not recovered

2011 RSB	**>1500 kg/ha** (successfully reclaimed)						**750-1500 kg/ha** (not yet established)				**<750 kg/ha** (limited/loss)		
Class	*1*	*2*	*3*	*4*	*10*		*6*	*7*	*8*		*9*	*11*	
	WV	RG	RD	AD	DR	**Total**	RG	RD	AD	**Total**	WV	DNR	**Total**
Trojan, Heustis, Bethlehem Tailings, N, NE, Plantsite (area A6)													
Ha	37.7	68.9	16.0	179.1	41.5	**343.2**			42.4	**42.4**	76.1	27.2	**103.3**
% Area	*7.7*	*14.1*	*3.3*	*36.6*	*8.5*	***70.2***			*8.7*	***8.7***	*15.6*	*5.6*	***21.1***
Avg RSB						**4042.7**				**1101.2**			**563.3**
Bethlehem S (area A7)													
Ha		32.8		15.6	9.0	**57.4**			6.3	**6.3**	8.0	1.9	**9.9**
% Area		*44.6*		*21.2*	*12.2*	***78.0***			*8.5*	***8.5***	*10.9*	*2.5*	***13.4***
Avg RSB						**3816.1**				**1042.9**			**156.4**
Highmont Impoundment (area A8)													
Ha	16.9	59.0	31.4	39.5	45.9	**192.7**	9.9	8.9	4.4	**23.21**	38.2		**38.2**
% Area	*6.7*	*23.2*	*12.4*	*15.6*	*18.1*	***75.8***	*3.9*	*3.5*	*1.7*	***9.1***	*15.0*		***15.0***
Avg RSB						**3788.4**				**1114.9**			**385.8**
All areas													
Ha	54.7	160.7	47.4	234.2	96.3	**593.3**	9.9	8.9	53.0	**71.8**	122.3	29.1	**151.4**
% Area	*6.7*	*19.7*	*5.8*	*28.7*	*11.8*	***72.7***	*1.2*	*1.1*	*6.5*	***8.8***	*15.0*	*3.6*	***18.5***

CONCLUSIONS

The 11-year remote sensing program at Highland Valley Copper has been very successful, and has produced a history of reclamation that is perhaps unique in the world. One of the values of the program is that it provides continuous maps of the vegetation changes over time for the entire mine site, thus extending the more detailed but sparsely distributed *in situ* sampling.

Using NDVI as an indicator of vegetation greenness as well as biomass, the temporal classification of the 11-year time series has enabled us to directly measure revegetation success or failure at 2.5m spatial detail.

It is well known that vegetation (especially grass) yellows if water is limited, and conversely responds quickly to rain or watering. NDVI varies with precipitation during the preceding weeks and depending on slope and substrate (Wang et al., 2001; Martínez et al, 2011), so analysis of NDVI for only one year would be different in wet and dry years. In our analysis of the time series, we ignore variation at this time scale and look for longer term changes. On the other hand, the year-to-year NDVI variability allows separation of areas generally dominated by grasses, where greenness varies widely with variations in precipitation, from areas undergoing steady increases or decreases, and those that remain poorly vegetated. Measuring and mapping the *vegetation trends* in specific sites has provided a cost-effective means to focus remediation effort at Highland Valley Copper.

The strength of remote sensing is the consistent, synoptic view it is able to provide of a mine reclamation program and its progress over time. The high spatial resolution and flexibility of spectral configuration and acquisition timing characteristic of airborne systems make them ideal for this application, but satellites have seen recent improvements in spatial resolution in particular that make them a less expensive alternative. However, the reduction in cost comes at significantly increased risk, since satellite surveys are more affected by cloud than those from aircraft that can be more readily tasked to avoid cloud.

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