TEMPORAL MONITORING OF MINE TAILINGS REVEGETATION USING HYPERSPECTRAL DATA, SUDBURY, ONTARIO*

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ABSTRACT

Hyperspectral imagery from the Compact Airborne Spectrographic Imager (*casi*) was used to monitor sulphide mine tailings revegetation progress at the Copper Cliff mine in Sudbury, Ontario. A first set of data was acquired on August 24, 1996 in 72 contiguous 9 nm wide spectral bands from 400 nm to 950 nm along with a detailed ground survey. Using the same image acquisition parameters, a second set of data was acquired on August 19, 1998 over the same area along with detailed ground reference measurements. Both sets of image data were classified using constrained linear spectral unmixing. Monitoring was achieved by comparing the 1996 and 1998 image fractions of vegetation. Results indicate that advances in reclamation of the selected sites have been made over the two-year period.

1.0 INTRODUCTION

Rehabilitation of mine tailings sites deals with a complex unnatural soil environment. Acidity is the main factor contributing to tailings infertility. At the Inco Copper Cliff Mine, tailings are the residuals of milling ore from sulphide bearing rocks (Peters, 1988). The resulting sulphide rich tailings oxidize to produce sulphuric acid when in contact with air and water (Kelley and Tuovinien, 1988). This higher acidity contributes to an increase in the availability of heavy metals and other toxic substances which can interfere with plant nutrient uptake and growth. Inco Ltd. is using the lime spreading technique to reduce acidity in the Copper Cliff tailings. Increasing pH using agricultural limestone reduce the mobility of the heavy metals and, therefore, their availability to plants.

In a previous study (Lévesque et al., 1997), the monitoring potential of high spatial and spectral resolution data was demonstrated. Three types of surfaces (vegetation, lime, and oxidized tailings) were quantified using constrained linear spectral unmixing. The resulting image fractions were validated with fractions estimated visually on the ground. This paper presents preliminary results of monitoring the Copper Cliff mine tailings revegetation using multi-temporal data acquired during the summers of 1996 and 1998.

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2.0 METHODOLOGY

2.1 STUDY SITE

The Inco Copper Cliff tailings impoundment area as outlined in Figure 1 is divided into nine main tailings storage areas (Puro et al. 1995). The tailings represent different stages of activity/reclamation ranging from active areas, where new tailings are being deposited (R1, R2, R3, R4), to inactive areas with well established 30 year old vegetation regrowth (CD). Intermediate between these are inactive areas where revegetation is under way. In Figure 1, areas labelled P and Q were chosen for this study because of their earlier stage of reclamation. Although some trees are present in these areas, they are located on rock outcrops and are not part of the tailings revegetation process. Figure 2 shows a *casi* image (band at 676 nm) containing the sample plots (sub-scenes) that were selected from each tailings area to avoid forested outcrops and to limit the study area to regions where active revegetation work is being done by Inco.

Plot P1 represents an area of older grass growth as compared to plots P2 and Q. It is also located on a hill (from higher to lower part in the image plot). Plot P2 includes an area which was actively revegetated during the last two years (mainly north of the creek) and an area where tailings are predominant (south of the creek). Area Q is dominated by tailings where revegetation work (liming, ploughing, seeding) has been done during the last two years. In all three plots some water, as part of a stream or a pond, was deliberately included to show areas where no changes in vegetation has occurred over the period August 1996 to August 1998 between image acquisitions.

2.2 IMAGE DATA

High spatial and spectral resolution *casi* radiance data were acquired on August 19, 1996 and August 24 1998 in 72 contiguous, 8.7 nm wide spectral bands covering a wavelength range from 407 nm to 944 nm. Pixel size is roughly 2.5 m in the across-track direction and 4 m in the along-track direction. Only wavelengths between 450 nm and 900 nm were used because of the drop-off of the responsivity of the silicon detector at both ends of the *casi* spectrum.

2.3 PROCESSING OF IMAGE DATA

A roll correction was applied to both datasets using the navigation data to remove the most significant aircraft motion from the imagery. Surface reflectance was retrieved using a look-up table (LUT) approach implemented in ISDAS (Staenz and Williams, 1997, Staenz et al., 1998a). After atmospheric correction, an ISDAS algorithm based on spectrally flat targets was used to remove any remaining systematic atmospheric or sensor effects in the data (Staenz et al., 1998b).

2.4 SPECTRAL UNMIXING

Constrained linear spectral unmixing was performed on both 1996 and 1998 *casi* datasets using an algorithm implemented in ISDAS (Szeredi et al., 1998; Boardman, 1989 and 1990). In linear unmixing, the spectrum from each pixel in the data cube is decomposed into a linear combination of “endmembers” spectra which represent in this case the spectra of the purest pixels in the scene.. The first step in the process involves a principal component decomposition; only the first three principal components (PC) were retained, which respectively account for 77%, 21%, and 1% of the variability in the 1996 dataset and 85%, 12% and 1% of the variability in the 1998 dataset. Figure 3 shows the scatter plots in the three PC dimensions for both 1996 and 1998 data. The endmember spectra are those corresponding to the extremities of these scatter plots; these are selected manually and their locations are indicated in Figure 3. The same endmembers were identified for both years: lime, vegetation, oxidized tailings, and two types of water. The spectra of all endmembers are displayed in Figure 4. Each data cube was unmixed in terms of the five identified endmember spectra. This resulted in a "fraction" image for each endmember. In each fraction image the pixel values correspond to the contribution of this endmember to the total reflectance of the *casi* data.

2.5 COMPARISON OF 1996 AND 1998 RESULTS

The fraction images of the endmember "vegetation" from both years were overlayed to within a RMS error of less than ±2 pixels in both spatial dimensions. This was achieved by performing an image to image registration using a third-order polynomial in combination with ground control points. A procedure which provides more accurate results as performed by Gibson (1994) was not possible because a full set of navigation data was not collected during the *casi* data acquisition. The three plots (P1, P2, Q, Figure 2) were reimaged in Figure 5 as differences (1998-1996).

3.0 RESULTS AND DISCUSSIONS

The first column in Figure 5 shows the maps of the absolute difference between vegetation image fractions derived from the 1996 and 1998 *casi* plots P1, P2, and Q, specifically the vegetation fraction of 1998 minus the vegetation fraction of 1996. The second and third columns show the scatter plots of both years for the same plots and their histograms.

On the difference maps, light tones represent positive differences between fractions of 1998 and fractions of 1996 and indicate areas where vegetation density has increased during the two-year period. Dark tones indicate a decrease in vegetation density. Middle tone (zero difference) shows vegetation areas which have not changed between the two image dates. As expected, the water, which contains no vegetation, appears grey corresponding to zero difference. The creek is hardly distinguishable in the difference map of the plot Q since there has been little change along its boundaries over this time period.

The difference map of plot P1 shows an increase of vegetation density in the lower part of the hill while the upper part shows a decrease. This could indicate a drainage effect. Plot P2 exhibits a general vegetation increase in the upper right quarter where revegetation work has been done over the last two years. The lower part, which is composed of tailings shows a medium tone indicating small changes between 1996 and 1998. Various patterns resulting from revegetation work are apparent in the difference map of plot Q; in particular, fine striations on the left side of the image are caused by ploughing performed in 1996. The brighter areas in the Q map result from more recent seeding. The dark area in the upper left corner was seeded in 1996 and ploughed over in 1998 so that the fraction difference is negative on the rows where grass was growing in 1996.

In all three scatter plots it appears that there are more points above the diagonal (equal fractions line) than below it. This indicates qualitatively an overall increase of vegetation between 1996 and 1998. A more quantitative result can be obtained from the vegetation fraction histograms. For area P1, the 1996 histogram peaks at a fraction of 0.20 and goes to zero at fraction 0.30; in contrast, the 1998 histogram peaks at fraction 0.22 and vanishes at 0.45. For area P2, both have a primary peak at approximately 0.10, the histogram for 1998 has a secondary peak at 0.20 and vanishes at about 0.31, while that for 1996 decreases gradually to zero at 0.35. Those pixels exhibiting the highest vegetation fractions in 1996 appear to have been destroyed by subsequent activities. Area Q has a significant proportion of pixels in 1998 which have fractions above the 0.30 cutoff of the 1996 data, indicating a strong improvement in revegetation.

Because of a RMS misregistration error of ±2 pixels, it was not possible to extract quantitatively accurate results on a pixel-by-pixel basis. This misregistration which represents 5 to 8 m on the ground is sufficient to cause significant errors in the comparison of the 1996 and 1998 data, especially in regions which are not homogenous. However, the analysis confirms that vegetation cover has increased from 1996 to 1998.

4.0 CONCLUSION AND RECOMMENDATIONS

This study has demonstrated the feasibility of the technique used to achieve temporal monitoring of vegetation regrowth over reclaimed mine tailings sites. The results indicate that advances in reclamation of the selected sites have been made over the period between August 1996 and August 1998. If it is desirable to have quantitative vegetation regrowth results on a pixel-to-pixel basis, then accurate aircraft track and attitude data have to be obtained to be able to overlay image data within sub-pixel accuracy.

5.0 REFERENCES

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6.0 ACKNOWLEDGEMENT

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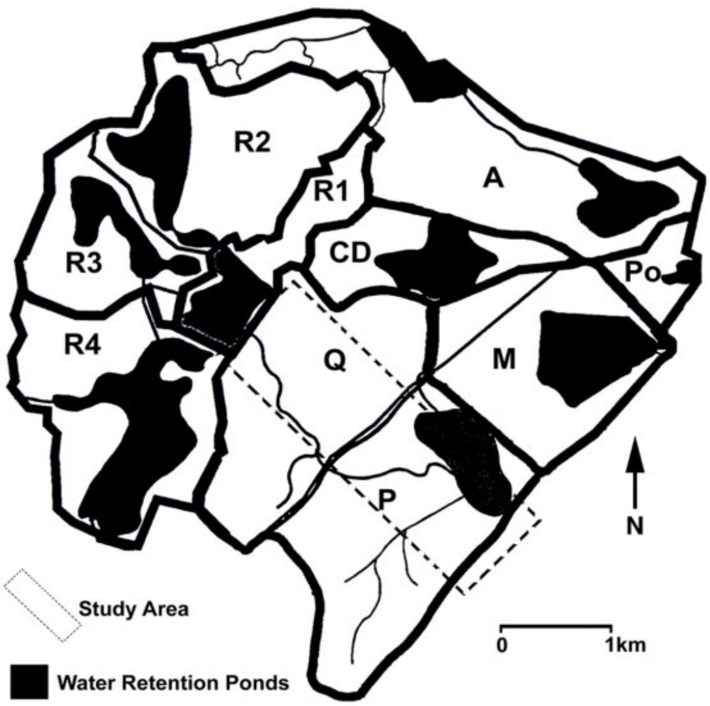

Figure1. Copper Cliff tailings Impoundment area. (Modified from Puro et al., 1995).

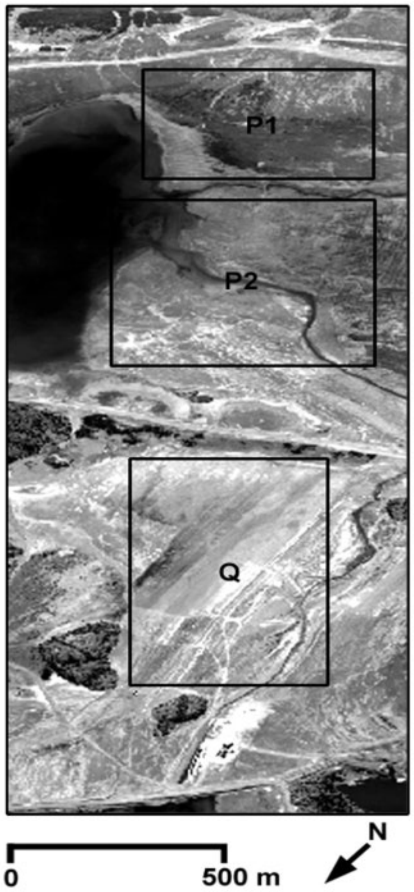

Figure 2. 1998 *casi* band ^{676} nm showing study plots extracted from P and Q areas.

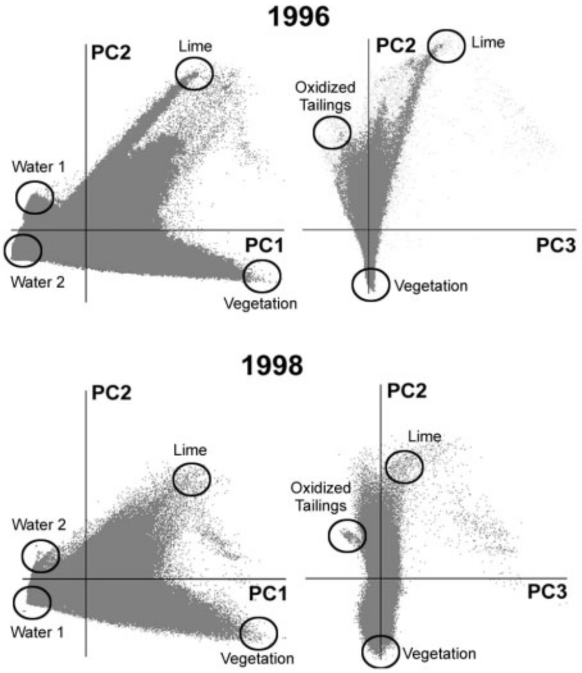

Figure 3. Scatter plots of PC1 versus PC2 and PC3 versus PC2 of 1996 and 1998 data showing the 5 endmembers

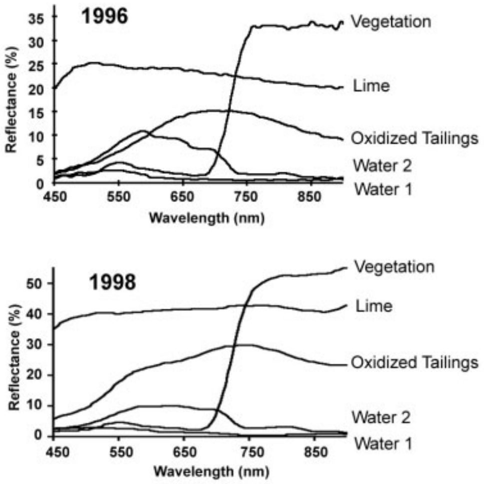

Figure 4. Endmember spectra.

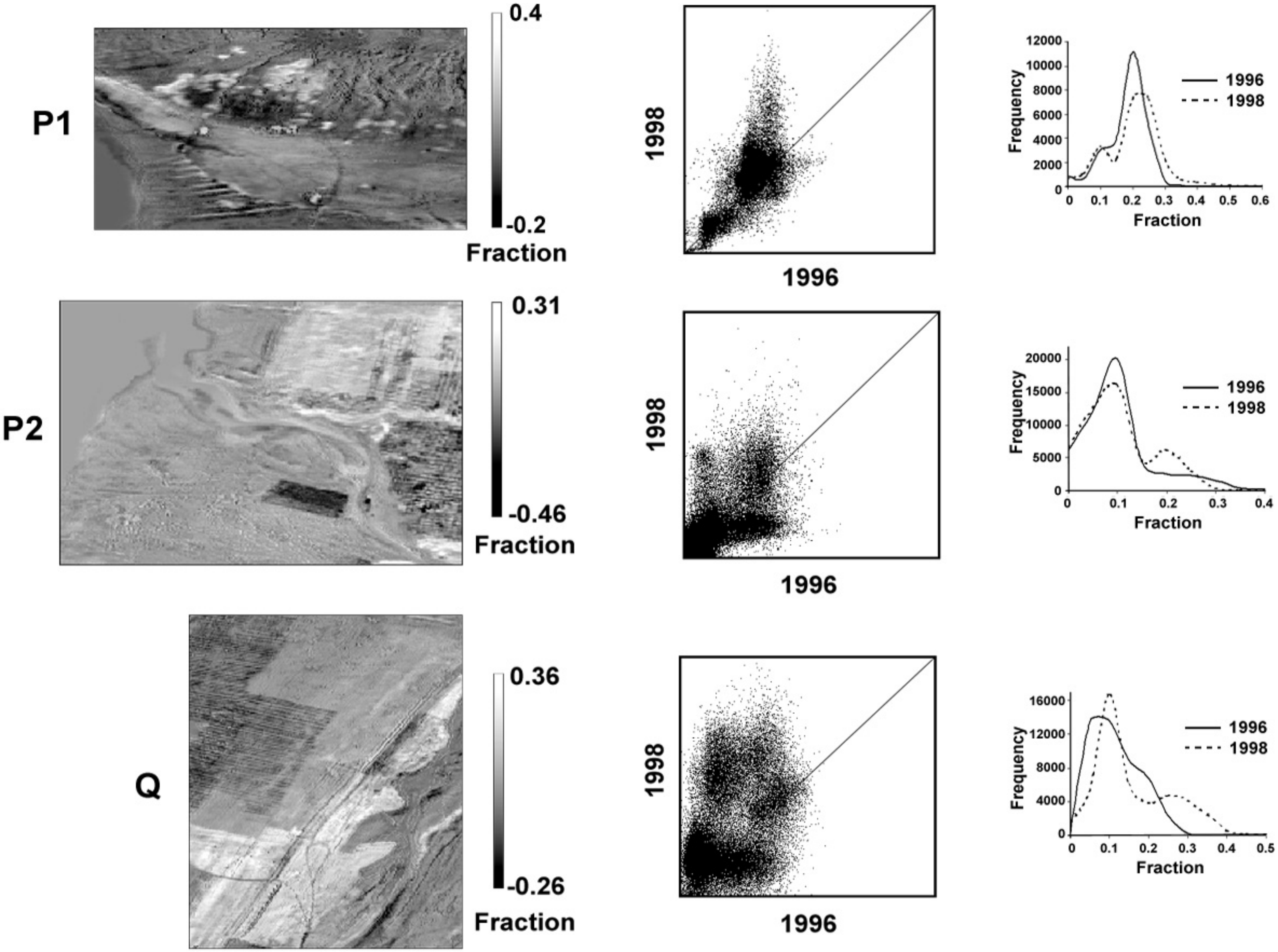

Figure 5. Maps of the absolute difference between 1998 and 1996 vegetation fractions (on the left), scatter plots of 1998 versus 1996 vegetation fractions (middle), and frequency distribution of vegetation fractions for each plot (on the right).