REMOTE-SENSING-BASED ASSESSMENT OF RECLAMATION AT TECK COAL'S ELK VALLEY OPERATIONS

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ABSTRACT

Teck Coal operates five metallurgical coal mines in the Elk Valley of southeast B.C.: Fording River, Greenhills, Line Creek, Elkview, and Coal Mountain Operations. Along with their sister mine in Alberta, Cardinal River, these mines make Teck the second-largest exporter of coking coal in the world. Reclamation and reclamation research has been conducted on some of these sites since the beginning of mine development in the late 1960s. Together, these mines have reclaimed over 2700 hectares of land. In 2008, site-wide assessments of reclamation success were conducted on all five Elk Valley mines. The desire to provide reclamation information on all reclaimed areas at the Elk Valley mines, and the overall aggregate size of these areas, required the development of innovative assessment methods. Projects that assess reclamation success tend to use ground-based monitoring methods that involve frequent site visits and assess on a site-by-site basis. As the number of reclaimed sites increase, the area that needs to be monitored continues to grow, along with corresponding costs. By using a combination of computer-aided (supervised) classification of remote-sensing satellite imagery supported by a reduced (targeted) ground-based sampling program, reclamation assessment information can be provided on a site-wide basis at reduced cost. These methods are particularly effective for assessment of large sites and/or sites with long operating horizons, due to large current or future areas requiring assessment (and to continuing improvement of remote-sensing technology).

Following this model, the reclamation monitoring program conducted in 2008 for Teck's Elk Valley operations employed high-resolution multi-spectral imagery from the Quickbird satellite platform to produce a spectra-based classification of reclaimed areas, ground-truthed through a field sampling campaign. This paper will present methods and results of this assessment, and discuss planned future use of these reclamation assessment tools at Teck's Elk Valley operations.

Key Words: forage, productivity, satellite, coal, biomass, classification

INTRODUCTION

Teck Coal operates five metallurgical coal mines in the Elk Valley of southeast B.C.: Fording River, Elkview, Greenhills, Line Creek and Coal Mountain Operations. Mining at the Elkview and Coal Mountain sites started as early as the turn of the last century, with modern large-scale operations generally commencing in the late 1960s to early 1980s, and an outlook for continued mining well into the future. Teck Coal is one of the largest landholders in British Columbia, with almost 40,000 hectares of privately held land, and crown licences on approximately 67,000 hectares. Together, these mining operations are the largest-scale, open-pit metallurgical coal mines in the northern hemisphere, and are the second-largest supplier in the world, delivering products to customers in 28 countries on five continents, and employing almost 3000 people.

The Elk Valley coal mines were some of the first coal mines to be permitted under the *Mines Act* when it was first enacted in 1969, with Elkview and Fording River Operations holding permits C-2 and C-3, respectively. Reclamation research began at Fording River Operations in 1969, prior to the commencement of mining operations in 1972. Many reclamation programs at Elkview Operations began in the early 1970s, and included reclaiming historic mining disturbance in Michel Creek dating back to the beginning of coal mining operations on the site in 1898. All five Teck Coal Elk Valley operations currently conduct active reclamation programs on their sites, with the goal of returning these sites to productive end land uses following mine closure.

The majority of the Teck Coal Elk Valley operations have employed some form of ground-based assessment of reclamation success. These assessments typically include collection of information on forage biomass productivity, species composition, and foliar nutrient and metals concentrations. However, as the area to be assessed on these sites increases, the cost of conducting this monitoring without modification becomes progressively more onerous. Adaptation of remote-sensing technology for reclamation assessment in a hybrid program (in that it incorporates both remote and ground-based sampling data) allows retention of the same vegetation and reclamation parameters currently utilized, but reduces ground-sampling effort through extrapolation of similar spectral signatures to non-sampled areas. Such an assessment was completed on four of the five Teck Coal Elk Valley operations in 2008-2009 to provide site-wide information on reclamation success.

METHODS

Images of Fording River, Greenhills, Line Creek and Coal Mountain Operations were captured in September 2008 (the cloud-free period) from the Quickbird platform. A cloud-free satellite image of Elkview Operations was not successfully obtained in 2008, but will be re-tasked in 2009. PCI Geomatica software (*Focus*, version 10.1) was used to perform image processing and classification. The Quickbird images were clipped to the reclaimed polygons and subsets of the images were used in subsequent analyses.

Classified images are thematic maps containing a mosaic of pixels belonging to different classes. Digital image classification, also known as spectral pattern recognition, transforms the spectral information

contained in each pixel of the original satellite imagery. The objective of the classification process is to assign all pixels in the original satellite image to themes or classes that represent objects in the ground cover.

Classification used spectral data to distinguish ground-cover "information classes" (e.g., areas with very high, high, moderate, low and very low biomass cover). The information classes are created based on ground plot information such as biomass production and total vegetation cover. Spectral data include the signatures associated with the various types and densities of vegetation and associated ground surface. In order to associate the spectral data with the information classes, GPS coordinates for ground plots were overlaid on top of the satellite imagery.

Areas with ground information (plot data) that are used in the classification process are called training areas. PCI Geomatica software was used to determine the range of spectral signatures represented by training areas. It is this directed delineation of training areas for identification of spectral signatures that constitutes the supervision component of the classification. Numeric information in all spectral bands for the pixels in a subject area is used to train the computer to recognize spectrally similar areas for each class. The creation of training sites is a critical step, as the data collected at the training sites are used to define the statistical limits of classes. These statistics are used to assign unknown pixels to appropriate classes. Therefore, training sites must represent the range of data in the image.

The following biomass/productivity classes (based on Demarchi and Harcombe, 1982) were used in the training sites:

Very High Productivity	>1000 kg/ha
High Productivity	500-1000 kg/ha
Moderate Productivity	225-500 kg/ha
Low Productivity	110-225 kg/ha
Very Low Productivity	<110 kg/ha

Once training areas were identified and the classes defined, the supervised classification was run to generate a map image. The classification was then exported to ArcGIS v9.2 for thematic map production.

Field sampling in support of the assessment program was completed between August 12 and 26, 2008. The field program was designed to provide information on productivity, species composition and foliar quality to assist with the classification of the satellite image. Field assessment of areas reclaimed with forage mixes consisted of productivity (biomass) sampling, a quadrat-based species survey and foliar nutrient sampling. A total of 48 sites were established across the five operations.

RESULTS

The final forage assessment classes, and associated mean values for selected ground-sampling parameters at the 48 ground sampling sites established in 2008, are presented in Table 1. Thirty-five of the 48 sample sites were located within the classified images; the remaining 13 sites were located on Elkview operations. Class categories are based on biomass productivity, but also reflect secondary characteristics

such as total cover and legume cover. Foliar nutrient concentrations are also provided but were not used to define the classes.

Table 1: Summary of Measured Parameters by Forage Assessment Class

Class		Measured Parameter Values by Class					
Name	Forage Productivity[1] (kg/ha)	No. Sampled Sites	Mean Biomass (kg/ha)	Mean Vegetation Cover (%)	Mean Vegetation Cover + Crypto (%)	Mean Legume Cover (%)	Foliar Nitrogen (%)
Very High Productivity	> 1000	21	1655	68	73	39	1.46
High Productivity	500 – 1000	14	736	45	48	18	1.44
Moderate Productivity	225 – 500	10	333	30	33	8	1.43
Low Productivity	110 – 225	2	202	23	23	14	1.07
Very Low Productivity	< 110	1[2]	99	16	23	0	1.07

[1] Forage Productivity class names and ranges are from Forage Capability Classification for British Columbia: A Biophysical Approach (Demarchi and Harcombe 1982).
[2] Additional low productivity areas were identified and used for training but were not sampled for biomass or other parameters.

Additional classes present on the classification map but not described in Table 1 include Treed and Shadow classes.
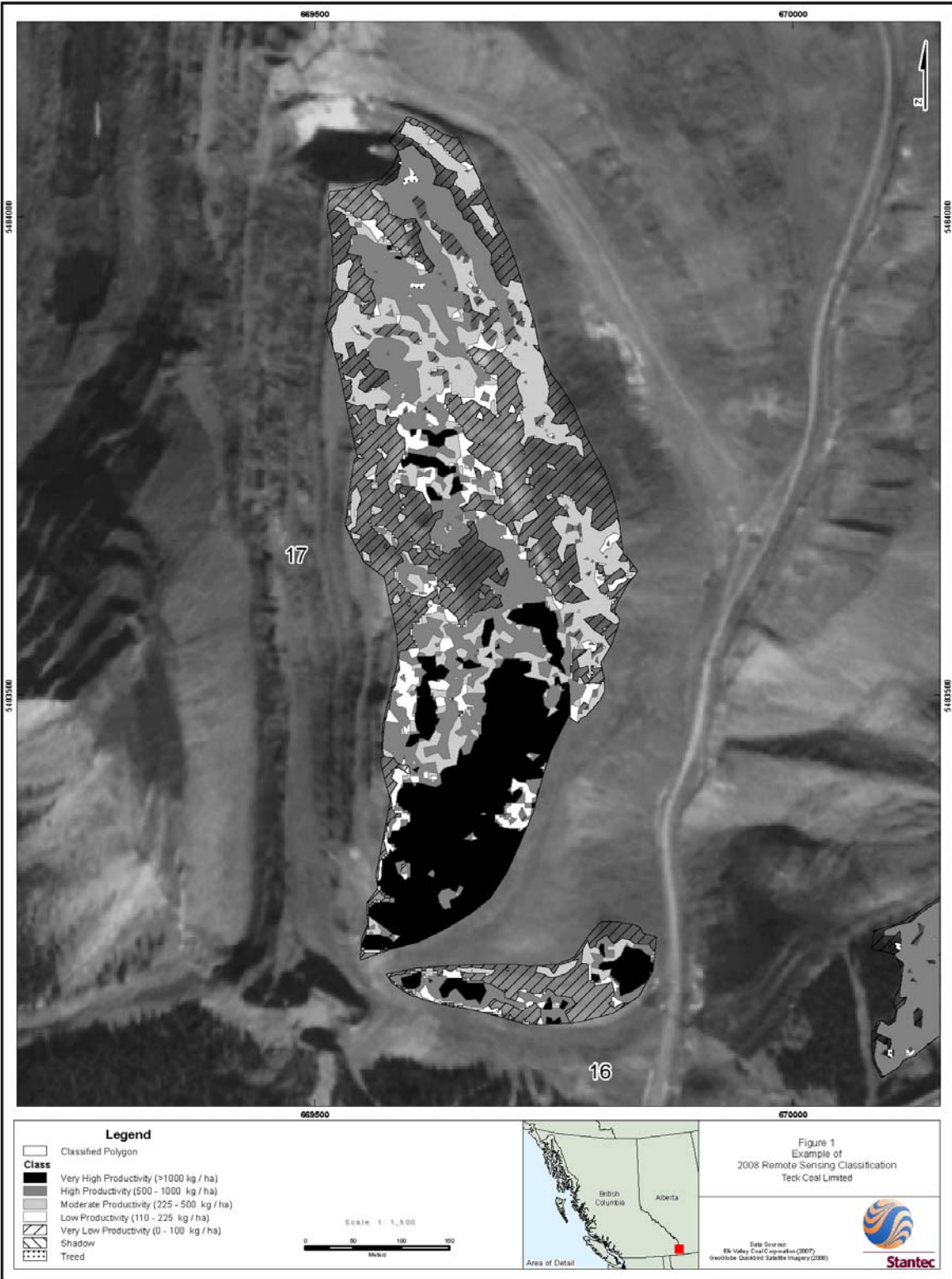
A total of 270 biomass samples, each $1m^2$, were collected at the 35 sample sites (average 7.7 per site) established across the four operations. The data from the field sample sites were used to create training sites for the supervised classification. A summary of the data by productivity class is provided in Table 2.

Table 2: Summary of Biomass Samples by Productivity Class

Class			
Name	Forage Productivity[1] (kg/ha)	No. Biomass Samples	% of Biomass Samples
Very High Productivity	> 1000	101	37
High Productivity	500 – 1000	67	25
Moderate Productivity	225 – 500	62	23
Low Productivity	110 – 225	25	9
Very Low Productivity	< 110	15	6

An example of a portion of a classified image is presented in Figure 1.

Figure 1. Example of 2008 Remote Sensing Classification

Legend

Classified Polygon

Class
- Very High Productivity (>1000 kg / ha)
- High Productivity (500 - 1000 kg / ha)
- Moderate Productivity (225 - 500 kg / ha)
- Low Productivity (110 - 225 kg / ha)
- Very Low Productivity (0 - 100 kg / ha)
- Shadow
- Treed

Scale 1 : 1,500

Figure 1
Example of
2008 Remote Sensing Classification
Teck Coal Limited

Data Sources:
Elk Valley Coal Corporation (2007)
GeoGlobe Quickbird Satellite Imagery (2008)

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A total of 1118.8 hectares were classified at the four mine sites in 2008. Results of this classification are summarized in Table 3.

Table 3: Total Area in Each Class by Mine Operation

Productivity Class	Coal Mountain (ha)	Fording River (ha)	Greenhills (ha)	Line Creek (ha)	Totals (ha)
Very High	28.4	40.5	245.1	74.3	388.4
High	34.9	12.0	54.4	67.4	168.7
Moderate	15.9	47.5	50.2	28.9	142.4
Low	7.5	29.2	46.8	16.4	99.9
Very Low	17.7	71.3	132.5	97.8	319.3

Figure 2. Percent of Assessed Area in each Productivity Class
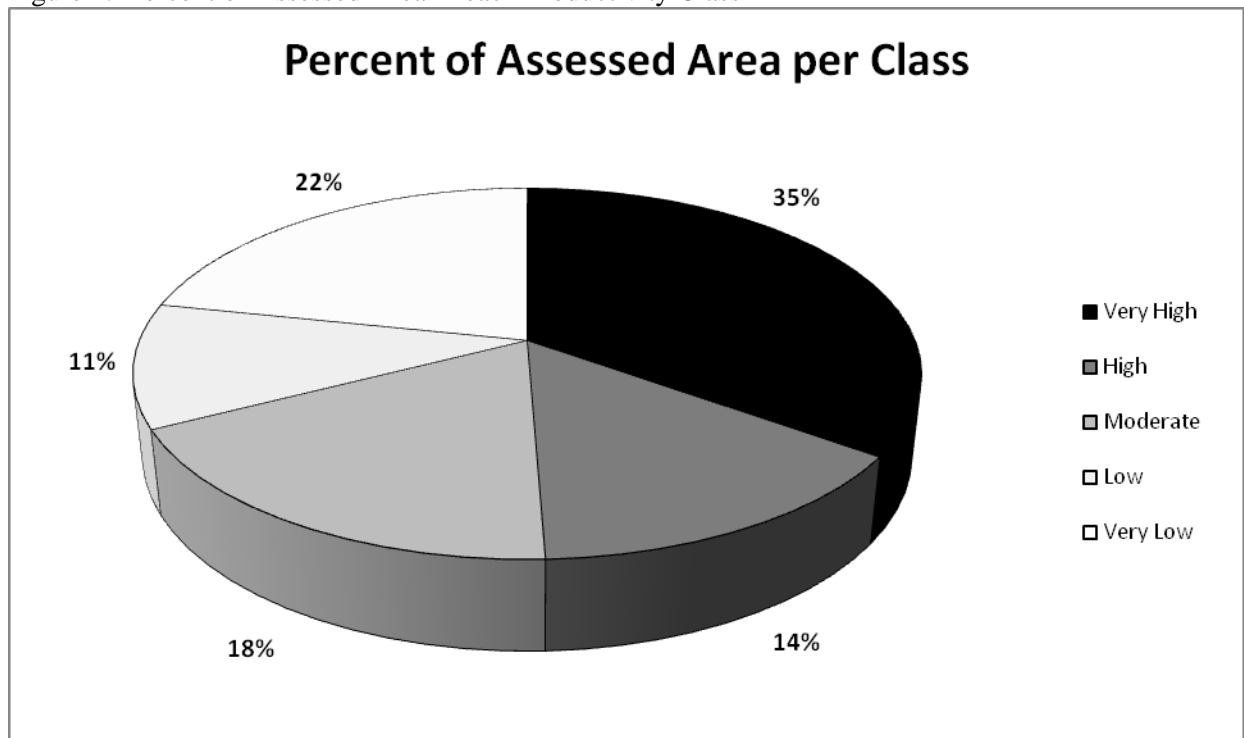
Very High Productivity Class

The Very High Productivity class includes areas that are dominated by legumes or mixtures of legumes and grasses. It has the highest total vegetation cover (68%) and legume content (39%) of any of the classes (Table 1). This class has well developed litter and organic-matter layers which when combined with the vegetative cover result in the lowest mean bare ground cover of all the classes. Coarse fragment content at ground surface is lowest for this class. Foliar nitrogen content, while not a significant contributor to classification, is highest in this class.

High Productivity Class

The High Productivity class has a significantly lower mean biomass (approximately half) and total vegetation cover than the Very High Productivity class, but biomass production is substantially greater than in the Moderate and Low classes. Grasses and grass-legume mixes dominate the sites. Mean legume cover is about 18%. Coarse fragment content is similar to the Very High class.

Moderate Productivity

The Moderate productivity class is defined by lower total vegetation cover (30%) as compared to the High and Very High classes and a lower legume cover (8%). These sites are generally characterized by a plant layer that is dominated by creeping red fescue.

Low Productivity

Vegetation cover is a relatively even grass-legume mix. Mean legume cover is 14% for this class. Sites in this class also have high coarse fragment content visible at the ground surface.

<u>Very Low Productivity</u>

One sample site demonstrates Very Low productivity. No legumes are present. This class has the highest proportion of cryptogams of all the classes and has the highest amount of bare ground. This site is also noted as having high coarse fragment content visible at the surface.

DISCUSSION

The site-wide reclamation assessment program conducted on the Teck Coal Elk Valley operations in 2008 classified reclaimed areas into five productivity units, using a defined forage-productivity classification system developed for British Columbia. Results of this assessment program indicate that, on average, approximately 65% of the assessed reclaimed sites are in the Moderate to Very High productivity classes. Proportion of these classes on the individual operations ranged from 45% (Fording River) to 75% (Coal Mountain). The remainder of the assessed area falls in lower productivity or other assessed classes.

The hybrid remote-ground reclamation assessment program implemented in 2008 will, if completed at regular intervals (e.g., every five years), provide a long-term system for documenting reclamation trends and results on the individual operations. Changes in productivity can be measured by comparing spectral signatures from the 2008 satellite image (and their corresponding vegetation characteristics) to those of subsequent classified images. Definition of trends indicative of real changes in site productivity/capability versus those simply due to inter-annual climatic variation will be determined through research conducted at a limited number of repeat sites measured on an annual basis. It is the intent that this program, along with other reclamation assessment efforts at the Teck Coal operations, will ultimately provide the information to document successful achievement of reclamation objectives, and be used to support application for release from reclamation obligations, where applicable.

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