USE OF REMOTE SENSING IN RECLAMATION ASSESSMENT AT TECK COMINCO'S BULLMOOSE MINE SITE

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ABSTRACT

The Bullmoose mine site is located in northeastern British Columbia, 40 km west of the town of Tumbler Ridge. The mine was an open-pit operation that produced metallurgical coal from October 1983 until its closure in April, 2003. The mine development footprint covers 789 hectares, and includes the Engelmann Spruce – Subalpine Fir moist very cold Bullmoose variant (ESSFmv2), the subalpine ESSFmvp2 parkland, and Alpine Tundra biogeoclimatic classes (ranging in elevation from the plant site, at 1100 m a.s.l. in the Bullmoose Creek valley, to waste dumps located at 1800 m). As a component of assessing reclamation to date and to prepare for closure, Bullmoose Operating Corporation and C.E. Jones & Associates Ltd. undertook in 2002 and 2003 a site-wide assessment on the status and success of currently reclaimed areas on the mine site. To accomplish this, a reclamation assessment program was developed using supervised computer classification of satellite imagery to identify discrete vegetation units on the reclaimed mine site. Ground-truthing using established reclamation success-and-sustainability assessment methods was conducted in August 2002 to validate and refine the classification system. The remote sensing-based classification resulted in the definition of 10 vegetation classes on reclaimed coal waste on the Bullmoose mine site. The defined classes are identifiable by unique spectral signatures, and are statistically separable based on selected ground-truth vegetation productivity and sustainability parameters. This information will be used to document achievement of post-closure equivalent productivity objectives on older reclaimed sites, and to predict the success of more recent reclamation, while reducing the need for more costly and labour-intensive ground-based assessment work. This paper summarizes the methods employed and results derived from this remote sensing-based assessment program.

INTRODUCTION

The Bullmoose mine site is located in northeastern British Columbia, 40 km west of the town of Tumbler Ridge. The mine was an open-pit operation that produced metallurgical coal from October 1983 until its closure in April, 2003. The mine development footprint covers 789 hectares, and includes the Engelmann Spruce – Subalpine Fir moist very cold Bullmoose variant (ESSFmv2), the subalpine ESSFmvp2 parkland, and Alpine Tundra biogeoclimatic classes (ranging in elevation from the plant site, at 1100 m a.s.l. in the Bullmoose Creek valley, to waste dumps located at 1800 m). As a component of assessing reclamation to date and to prepare for closure, Bullmoose Operating Corporation and C.E. Jones & Associates Ltd. undertook in 2002 and 2003 a site-wide assessment on the status and success of currently reclaimed areas on the mine site. These areas, including the mine site, areas along the access road, and rail load-out facilities, totalled approximately 320 hectares at the date of project initiation. Of this, approximately 60 hectares were planted with tree and shrub seedlings, while the remainder was seeded with various agronomic grass-legume mixes. (It should be noted that the reclaimed area assessed in this paper is significantly smaller than that at the Bullmoose mine site currently. Current reported reclaimed area is 707 hectares, of a total footprint of 789 hectares [including access road and rail load-out facilities].

In order to provide a cost-effective assessment of the relatively large reclaimed area, remote-sensing (satellite) imagery was used, in combination with digital image classification (or a supervised computer-generated classification system) to stratify the mine site into different vegetation units. Digital image classification, also known as spectral pattern recognition, uses the spectral information contained in each image pixel. The resulting classified images are thematic maps containing a mosaic of pixels belonging to different classes. The objective of the classification process is to assign all pixels in the image to themes or classes that are representative of objects in the ground cover.

The vegetation units developed through computer-generated classification were ground-truthed in August 2002 using established reclamation success-and-sustainability assessment methods. The ground-truth data set was then used to validate and refine the computer-generated classification system. In this application, the advantage of using the combination of digital image classification and directed ground-truthing is that effort and resources needed for field-based assessments can be reduced through targeted selective ground-based sampling, without sacrificing the quality of vegetation assessment information that is available only through field data and observations. Once classes have been derived and correlated with unique spectral signatures, these signatures can be archived and used for classification of future images of the same area, thus enabling assessment of status of newer reclaimed areas and of change over time of existing areas to be conducted remotely, but tied to field-derived data.

METHODS

Satellite images of the Bullmoose mine site were obtained from DigitalGlobe™ using the QuickBird satellite. Images consisted of 2.44 metre (ground resolution) 4-band multispectral images and a 61-centimeter panchromatic image band. Images were obtained between July 7, 2002 and July 12, 2002. The cross-track view angle was 14.24 degrees. This indicates that the satellite was close to directly overhead when the images were obtained (a cross-track viewing angle of 0 degrees would indicate that the satellite was directly overhead).

Satellite imagery was obtained in TIFF format on CD-ROM, geo-referenced to a cartographic projection. Images were imported into PCI FOCUS software for classification purposes. The red, green, and blue spectral bands were utilized in the classification process.

Classification distinguishes between *information classes* and *spectral classes*. Information classes are ground cover categories identified from the original spectral data in the images. Existing ground plot information (from 2001 and previous assessments) was used to identify specific areas of the image that were determined to be separate *information classes*. These areas on the image are called *training areas*. Where assessment information did not exist, visually apparent differences in vegetation cover were used to define training areas. FOCUS uses the training areas to determine the *spectral classes* that they represent. In this sense, the categorization of a set of classes is *supervised*. Numerical information in all spectral bands for the pixels in a subject area is then used to train the computer to recognize spectrally similar areas for each class..

Once training areas were identified, the supervised computer-generated classification was run using the Parallelepiped classifier with the MLC (maximum likelihood) as the tie-breaker. This produces a null class of pixels that cannot be identified as belonging to any of the informational classes.

Once the classification was run, the resulting image was compared to additional ground plots to check for accuracy of the classification, with some of the resulting classes being amalgamated, as they could not be reliably distinguished from one another. Finally a sieve program was run on the resultant image to merge image value classes smaller than 15 pixels (approximately 0.1 ha) with the largest neighbouring class. This served to clean up small, misidentified classes within larger classes.

Ground-truthing was conducted through a forage assessment program that included three components: biomass (productivity) sampling, species composition (diversity) survey, and foliar nutrient (health) sampling. Field data from the forage assessment program was grouped by class, and examined to determine the efficacy of the computer-supervised pre-stratification in recognizing classes with meaningful differences in the measured parameters. Principal measures used for this determination were based on characteristics important to longer-term success of reclaimed areas and on knowledge of site-specific conditions, and included biomass, legume cover, total vegetation cover, dominance of grass mixes by creeping red fescue, and grass foliar nitrogen content (initially foliar nutrients were used as parameters for class separation, but these parameters showed few trends associated with other productivity measures, and were not statistically separable due to smaller sample sizes than the plot-based parameters.). Based on this examination, similar classes were aggregated, and dissimilar areas classified as one unit were disaggregated.

RESULTS

Final classification units are outlined in Table 1. Broad class categories are based on biogeoclimatic ecosystem classification of the mine site, with alpine areas (AT) defined as those above 1775 m in elevation, subalpine areas (ESSFmvp2) between 1575 and 1775 m, and the rest of the mine site classified as being in the ESSFmv2 subzone/variant. Grass foliar nitrogen concentrations are presented in Table 1 primarily for information purposes. Note that the classes do not collectively cover 100 percent of the total mine footprint, as only a portion of this footprint was reclaimed at the time of assessment, and due to existence of miscellaneous vegetated classes (discussed below).

Table 1
Measured Parameters by Class

Class	Number of Ground Plots	% of Total Mine Footprint	Biomass (kg/ha)	Legume Areal Cover (%)	Total Vegetation Cover (%)	Creeping Red Fescue Cover (%)	Grass Foliar Nitrogen (%)
Unproductive Reclaimed	11	<1	69	0	14	72	1.12
Subalpine Slope	25	5	240	0	22	53	0.81
ESSFmv2 Slope Limited	33	4	270	6	18	27	1.28
Subalpine Slope Higher Productivity	13	1	309	0	27	42	1.51
Subalpine Bench	88	5	369	1	33	64	1.23
Alpine Bench	29	<1	386	4	38	83	1.21
ESSFmv2 Moderate	46	4	680	6	28	31	1.19
ESSFmv2 Slope Good	33	4	995	19	54	68	1.40
ESSFmv2 High Productivity	70	8	1629	22	63	68	1.24
ESSFmv2 High Legumes	15	2	1937	44	75	69	1.27

Additional classes present on the classification map but not described in Table 1 included the non-vegetated classes (unreclaimed as of July 12, 2002), small classes based on 2001 assessment but not represented in the 2002 data set, and miscellaneous revegetated classes based on off-site features such as cleared rights-of-way or cutblocks. The first of these additional classes (non-vegetated) occasionally overlapped in the classification system onto non-productive reclaimed areas that have similar spectral characteristics as bare coal waste or coversoil stockpiles. As a result of this overlap, 11 ground-truthing plots assessed in 2002 are not represented in Table 1, as they were located in areas classed as unvegetated (at reclaimed area boundaries). These plots generally showed low productivity consistent with a non-vegetated spectral signature. At the time of the 2002 assessment, non-vegetated classes occupied approximately 380 ha of the classified image.

The small classes based on 2001 data are composed of primarily agronomic forages, and are present in the 2002 assessment classification but not represented by ground-truth assessment data from that year. These classes are based on data from the 2001 assessment and training areas derived from knowledge of these sites. Additional ground-truth information was not acquired in 2002, as these classes are isolated in area..

The miscellaneous revegetated classes based on off-site features are found predominantly on mine areas on disturbed native ground (as opposed to coal waste), primarily in the vicinity of the lower-elevation mine features such as the plant site, sedimentation ponds and mine access road, and on remaining undisturbed areas within the mine footprint. Visual assessment of these areas indicates successful regeneration on these disturbed sites. Total area within these classes is approximately 150 ha. These classes are also represented as small, isolated components of reclaimed sites on coal waste, which represent a minor misclassification due to specific difficulties in distinguishing spectral signatures.

It should be noted that apparent misclassification is partially an artifact of the size of the "sieve" run in the computer program to clean up the image. Requiring larger minimum unit sizes would have eliminated much of the above reported misclassification. However, this would have sacrificed resolution in terms of the smallest area that was capable of being distinguished as a separate class. For the purpose of this assessment, one-tenth of a hectare was used as the minimum unit size, because it was determined to be a reasonable compromise between high desired spatial resolution and apparent misclassification.

All parameters included in Table 1 were compared by analysis of variance and Bonferroni's pair-wise comparison testing to determine statistical difference (α=0.05). While this procedure was not used as the sole determinant of class separation, it was used to guide decisions on class similarity and appropriate merging or retention of original classes as well as to confirm that final classes are meaningful (e.g. are distinguishable from other classes). The power of the statistical testing is a combination of differences in mean parameter values, in spread of observations around this mean, and in number of observations. As a result some of the less-represented classes are difficult to distinguish from similar classes due to smaller sample sizes, while other classes (*e.g.* Alpine Bench and Subalpine Bench) are difficult to distinguish due to smaller differences between classes and relatively high variability within classes.

Despite these limitations to statistical testing, results of this testing show that all classes are statistically distinguishable from their immediate neighbours as arranged in Table 1 (by biomass) by *at least* one of the tested parameters, with the exception of the Subalpine/Alpine benches discussed above. This conclusion provides a check on the validity of the classification process and results, and demonstrates that the remote sensing-based assessment is a reliable method of providing high-resolution data on reclamation success.

DISCUSSION/CONCLUSION

The remote sensing-based classification of the Bullmoose mine site reclamation assessment resulted in definition of 10 vegetation classes on reclaimed coal waste, and additional miscellaneous revegetated classes and unvegetated classes. Despite sometimes low sample numbers, all classes were well defined, with each class except the Subalpine-Alpine Bench units statistically separable from its immediate productivity neighbour by at least one classification parameter. Classification results demonstrate that 108 ha, or over 50 percent of lower-elevation sites reclaimed in 2002 (14 percent of total footprint) are successfully reclaimed, supporting forage stands with mean biomass levels at or above 1000 kg/ha. Building on previous assessment data compiled during the 2001 reclamation assessment, these sites are either declared to be successfully and sustainably reclaimed, requiring no further assessment, or are recommended for a limited final assessment prior to application for reclamation release. An additional 150 ha were classified as miscellaneous revegetated, the majority of these being regenerating native ground requiring only visual assessment to document long-term reclamation or regeneration success. An additional 33 hectares of lower-elevation sites, or 16 percent of lower-elevation area reclaimed in 2002, are within an intermediate success category, likely requiring further assessment to document long-term stability and sustainability. Sixty-one hectares of lower-elevation sites, or approximately 30 percent of total reclaimed area in 2002 (8 percent of total footprint) were classified as having limited productivity. In response to recognized limitations to reclamation success on these sites, Bullmoose Operating Corporation invested significant effort and resources in 2002 and 2003 in resloping both accessible, reclaimed-but-limited areas and areas being prepared for new reclamation.

In the upper-elevation (alpine and subalpine areas), approximately 55 hectares (or 72 percent of this upper elevation area reclaimed in 2002) were classified as having moderate to good reclamation success, with mean biomass levels over 300 kg/ha. Although this productivity is relatively limited compared to that achieved at lower elevations, it appears to represent the higher end of site carrying capacity at upper elevations due to harsher climatic conditions and shorter growing seasons. This carrying capacity and species represented will be shifted as invasion of native species from adjacent seed sources progresses. An additional 21 ha, or 28 percent of upper-elevation area reclaimed in 2002, is classified in a more limited category, with mean biomass levels below 250 kg/ha. As noted in the above discussion on lower-elevation areas, recognition of reclamation limitations has resulted in improvement in material preparation prior to more recent reclamation, as well as significant resources and effort spent in remediating unsuccessful older reclamation, where accessible.

The remote sensing-based reclamation assessment conducted on the Bullmoose mine site represents a combination of newly available and affordable technology (high-resolution, acquired-to-order satellite imagery) with established, ground-based vegetation sampling programs. This combination resulted in an assessment program that used spectral information to define similar vegetation types within the project area, and to thus to objectively direct ground-based data collection. The integration of remote and on-site assessment methods allows program delivery at a substantial reduction in time and effort in comparison to a strictly ground-based program, but that retains the high data quality and reliability associated with data sets derived through on-site sampling. The resulting classification system defined by vegetation parameters and spectral classes can be applied to future assessments, thus enabling efficient assessment of newer reclaimed areas, and of sustainability (change over time) of existing areas.

Positive results from the application of a hybrid remote sensing/ground-based assessment program at the Bullmoose mine site demonstrate the potential for successful use in reclamation assessment and in associated documentation of fulfillment of regulatory obligations. Due to the spatial nature of information generated by this type of assessment, there is also the potential to integrate it with related reclamation and closure tasks such as end land use prediction and planning and materials handling.