REMOTE SENSING IN VEGETATION MONITORING:
MORE THAN JUST A PRETTY PICTURE

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ABSTRACT

Monitoring of reclaimed sites is a complex, interdisciplinary undertaking, especially in large, disturbed areas with difficult access. In that context, remote sensing is a unique and valuable tool that provides a synoptic view of an entire reclamation program and its progress over time, extending the more detailed but sparsely distributed *in situ* monitoring. Using remote sensing data, we are creating reclamation maps that provide easily understood information about a site's vegetation history, and whether or not it has reached and maintained biomass above the permit threshold for self-sustaining status. These maps are produced at various scales, are Geographic Information Systems (GIS) compatible, and often provide data for remote, inaccessible locations or for locations where historical data are missing. Reclamation maps are designed to help decision-makers focus remediation efforts on specific locations most needing it, rather than making unnecessary and potentially costly wholesale changes to entire sites. The maps are useful, not only in reclamation and multidisciplinary studies, but also in public demonstration of industry's successful reclamation practices. As climate in the north continues to change, and resource exploration and extraction activities increase, mapping the changing landscape becomes key for the conservation and sustainable management of resources. In this paper, we present two examples of long-term remote sensing monitoring at reclaimed mine sites in British Columbia and one of long-term vegetation changes in the Northwest Territories. Other applications of remote sensing are also discussed, such as the generation of habitat maps for wetland monitoring at reclaimed tailings ponds in support of wildlife habitat or biodiversity studies. Examples of field applications of remote sensing will be presented in a companion poster entitled "Practical field uses of remote sensing."

Keywords: Mine reclamation, NDVI, change detection, vegetation trends, habitat mapping.

1 INTRODUCTION

Reclamation is a central part of the decommissioning of mining operations, and requires monitoring of re-vegetated areas to assess the progress toward the end land use objectives, as well as to determine whether individual sites have achieved a self-sustaining state. Traditional *in situ* monitoring programs provide very detailed information on selected sampling sites, but ground-based surveying of entire reclaimed areas and hard-to-reach sites can prove to be a difficult, many times impossible, task.

Remote sensing, whether from aircraft or satellites, is a practical tool that provides continuous maps of vegetation changes over time for entire mine sites, supplementing the more detailed but less synoptic ground biological surveys. It provides a means to focus remediation efforts on specific locations that need it most, instead of making wholesale changes to entire sites (Borstad *et al*., 2005; Martínez *et al*., 2012;

Richards *et al.*, 2003), and is also a valuable tool for monitoring and quantifying a wide array of biophysical changes attributed to climate change in northern ecoregions (Borstad *et al.*, 2008; Laidler *et al.*, 2008).

2 METHODS

2.1 Remote sensing data

The high spatial resolution, together with the flexibility of spectral configuration and acquisition timing characteristic of airborne systems, make them ideal for reclamation monitoring (Borstad *et al.*, 2005). Recently satellites have seen improvements in spatial resolution in particular that make them a less expensive alternative; however this reduction in cost comes at a significantly increased risk, since satellite surveys are more affected by cloud than those from aircraft that can be more readily adapted to avoid or operate under cloud (Borstad *et al.*, 2005).

In this paper we present examples of data obtained with the Compact Airborne Spectrographic Imager (CASI) configured to acquire imagery in 9 spectral bands at 2.5 m spatial resolution (Richards *et al.*, 2003; Borstad *et al.*, 2005; Brown *et al.*, 2006; Martínez *et al.*, 2011), as well as from satellites such as Landsat, and QuickBird2 (QB2) and WorldView-2 (WV2) (Digital Globe, 2012). The free data from the Landsat series, launched in 1972 and extended with the successful launch of Landsat 8 in 2013, provides consistent global coverage (GLOVIS, 2013). WV2 and QB2, launched in 2009 and 2011 respectively, provide higher spatial and spectral resolution than the Landsat series; however they are not free, and must be specifically tasked to acquire imagery over any particular target. Their short historical catalogue makes them less useful for long-term analyses, but their higher spatial resolution makes them better suited to study smaller areas in more detail.

2.2 Land Vegetation Indices

For land vegetation studies we use two vegetation indices derived from reflectance data for both airborne and satellite imagery. The Normalized Difference Vegetation Index (NDVI) is commonly used in remote sensing as an index that provides a measure of green vegetative cover or biomass (Rouse *et al.*, 1974; Tucker, 1979; Peñuelas and Filella, 1998). Our 'Normalized Yellow Index' (NYI) provides an index of desiccation and/or senescence (Borstad Associates, 2007).

Table 1. Calculation of vegetation indices and interpretation.

Index	**Formula**	**Interpretation**
NDVI	(Infrared – Red)/(Infrared + Red)	< 0 unvegetated, > 0 vegetated (1 maximum)
NYI	(Green – Red) / (Green + Red)	< 0 dry or senescent, > 0 green sparse to dense (1 maximum)

NDVI is a measure of plant chlorophyll. 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 can be calibrated to apparent biomass, as shown in Figure 1, but NDVI plateaus at high biomass values (Figure 1), and it can also be affected by disease, flowering, and water availability (Yin and Williams, 1997; Carter and Knapp, 2001; Wang *et al.*, 2001). We developed the Normalized Yellow

Index (NYI) to assist differentiating the low NDVI values caused by chlorophyll degradation from those caused by moderate or sparsely vegetated green areas (Borstad Associates, 2006). As plants lose chlorophyll, red reflectance (near 660 nm) values increase, thus NYI compares spectral bands in the green (560nm) and the red wavelengths, having positive values for dense green vegetation, and negative values for yellowish vegetation.

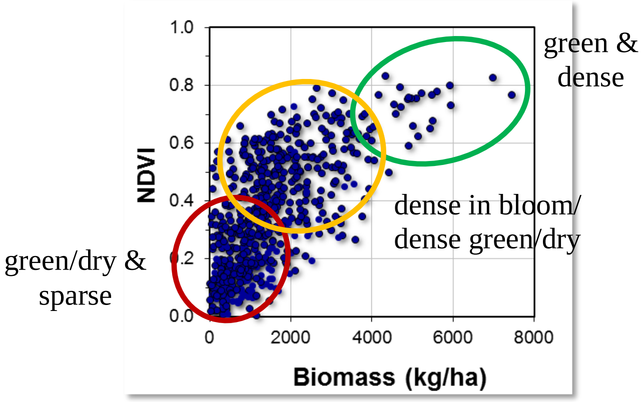

Figure 1. NDVI calibration to apparent biomass.

2.3 Multi-temporal Analysis

In order to assess vegetation changes over time, we build time series datasets using the annual NDVI images, and classify them using an unsupervised algorithm (ISODATA), which groups similar NDVI histories into up to 255 statistical classes. Pixels with similar trends are then grouped manually (Borstad *et al.*, 2009; Martinez *et al.*, 2012) to create maps of reclamation status (see Figure 2). As described above, NYI data are used to assist to interpret low NDVI values, as are photographs and visual observations when available.

Another way that we use NDVI time series is to assess long-term trends in vegetation, such as those associated with climate change. Changes of this nature are evaluated using regressions of NDVI versus year (see Figure 3). The images of r^2 and slope allow us to map the rate and direction of change and its level of statistical significance. Maps of regression slope clearly delimit regions of positive and negative change as well as their magnitude, facilitating interpretation of the underlying factors, as well as permitting the calculation of such statistics as area of habitat loss. It is important in any vegetation monitoring program to understand the long-term context within which reclamation efforts are conducted.

2.4 Mapping Aquatic Habitat

Different habitat types can be characterized from remote sensing imagery based on the optical properties of the vegetation types present (communities or species), as well as the non-biological components. These optical properties need to be considered when selecting the remote sensing data type, processes and techniques. Aquatic habitat mapping presents a special case, as the vegetation has unique spectral properties due to the modulating effect of water. For this reason airborne sensors, with their flexible spectral configurations, are often used for aquatic applications. Specific bandsets can be used to extract information for aquatic vegetation and water quality parameters such as turbidity, and phytoplankton blooms.

The techniques used for aquatic mapping differ somewhat from terrestrial applications because of the unique spectral properties of the vegetation. For example, instead of NDVI used for terrestrial vegetation, for aquatic vegetation we use an index referred to as Shifted Red Peak Height (SRPH). Like NDVI, this index measures the height of the near infrared reflectance near 700 nm that occurs in spectra of all multicellular plants. In aquatic environments, where longer wavelengths are strongly attenuated by water, this near infrared "plateau" becomes a "red peak" when vegetation is covered by water, thus providing an unambiguous indication of aquatic vegetation (see Figure 4A2).

3 EXAMPLES

3.1 Long-term changes at reclaimed mine sites

We have been monitoring reclaimed areas at a large copper mine using aerial remote sensing since 2001. The time series has permitted a variety of analyses that are being used in the management of the reclamation program. The trends in annual NDVI (Figure 2)) and apparent biomass demonstrate the history of the reclamation at each site, and more importantly, clearly delimit the extents of areas that have reached a biomass above 1500 kg/ha ('Rapid growth'; green in the reclamation map), the accepted reclamation threshold in this case. The analyses also show which areas considered successfully reclaimed are subject to desiccation (shown in yellow) and those requiring additional intervention ('Limited cover' shown in red).

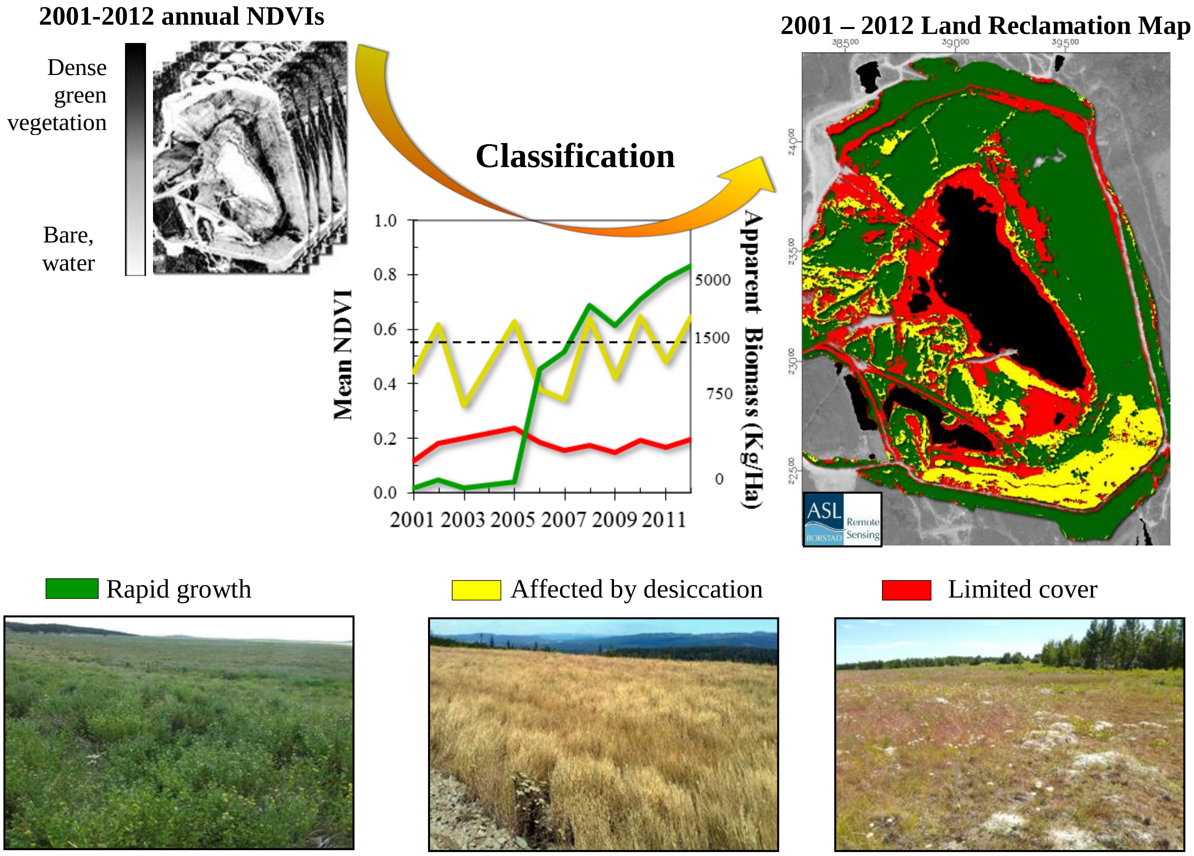

Figure 2. Reclamation map and 2001-2012 vegetation trends at a reclaimed mine site.

3.2 Vegetation trends at Anderson River Delta, NWT

The primary objectives of this study (Figure 3A) were to quantify reports of habitat loss in the Anderson River Delta and identify areas that had been impacted. Analysis of four large regions of interest (ROIs) showed that the largest reductions in vegetation cover occurred in the Outer Islands between 1972 and 2003 (Figure 3B), with an NDVI decline of 38% during the study period, corresponding primarily to areas most heavily used by nesting Lesser Snow Geese and Black Brant (Armstrong 1995, Kerbes *et al*. 1999).

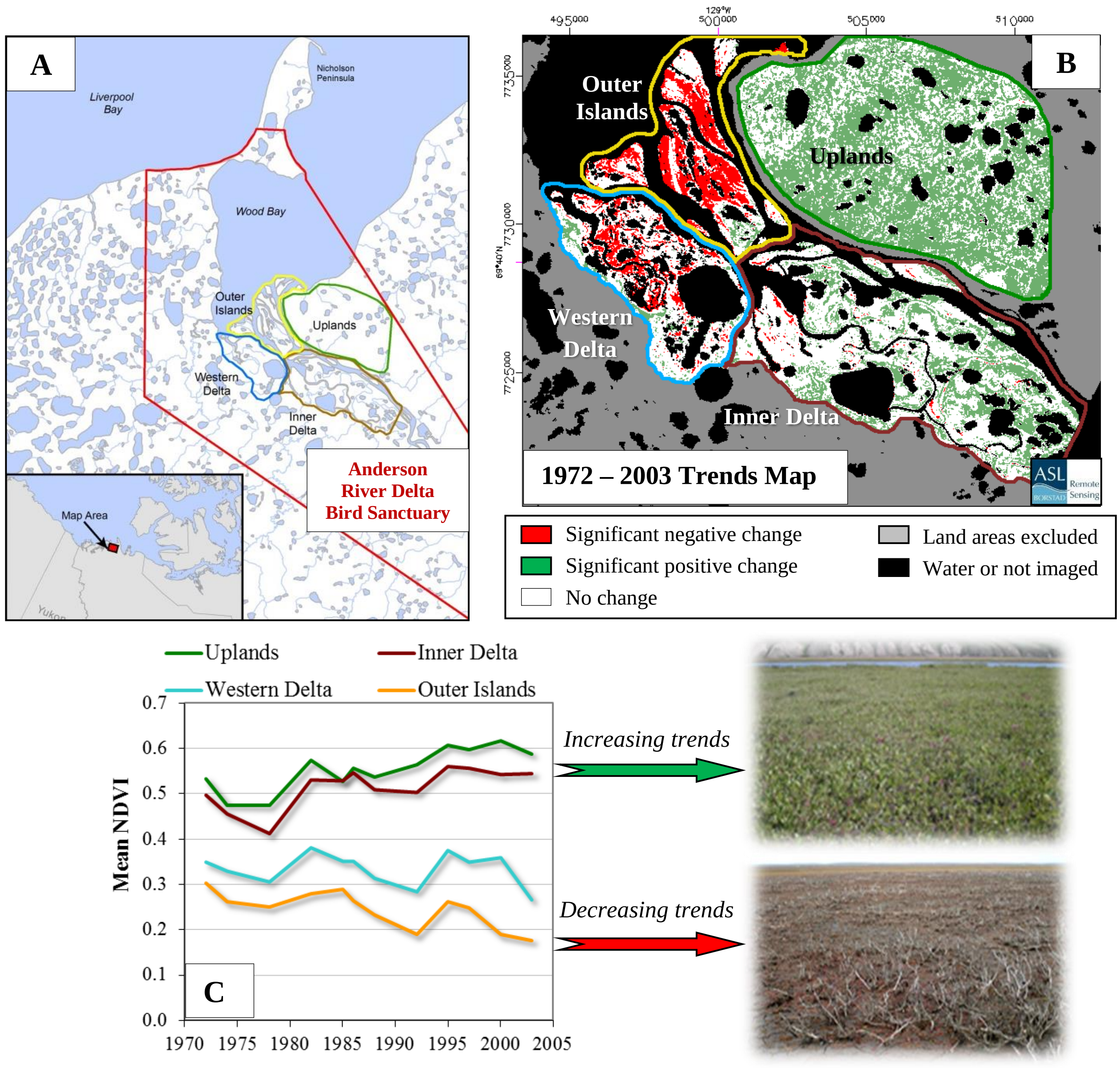

Figure 3. Vegetation changes over 31 years in four regions of interest (ROIs) in the Anderson River Delta.

The Western Delta ROI showed a 12% decline in vegetation over the study period, while further inland, the Inner Delta showed little vegetation loss. The Uplands had a statistically significant increase in NDVI over time, which agreed well with results from other studies in North America and Eurasia for the same time period (Jia *et al.* 2003, Jiang *et al*., 2011; Verbyla, 2008; Walker *et al*, 2012). The changes seen in the satellite time series were confirmed by qualitative reports (Barry, 1967; Armstrong, 1995).

3.3 Mapping wetland habitat

Tailings ponds can be converted to functional wetlands once water levels are stabilized, but they are often treacherous to traverse. This severely limits ground-based sampling, and presents a hurdle to clear understanding of the ecology and evolution of the reclamation. For such water bodies, remote sensing provides an alternative means of detecting and monitoring submerged vegetation. The pond shown in Figure 4A has very soft tailings, and had developed channels where streams of bubbles created holes 4-10 m in diameter and several meters deep (photo shown in Figure4 A1, taken on the northwest shore), preventing access even from small boats. The airborne imagery (Figure 4A) revealed large amounts of submerged aquatic vegetation in the center of the pond. The discovery of *Ruppia maritima*, was a complete surprise to the limnologists (Borstad *et al*., 2005). As well as detecting *Ruppia*, the maps of aquatic plant distribution helped to quantify the success of the aquatic reclamation program. Twelve milfoil and aquatic buttercup plant sandwiches had been installed 1996, and in seven years the plants had expanded to cover 13 hectares in low density weed beds, with occasional high density milfoil patches (Larrat Aquatic, 2003).

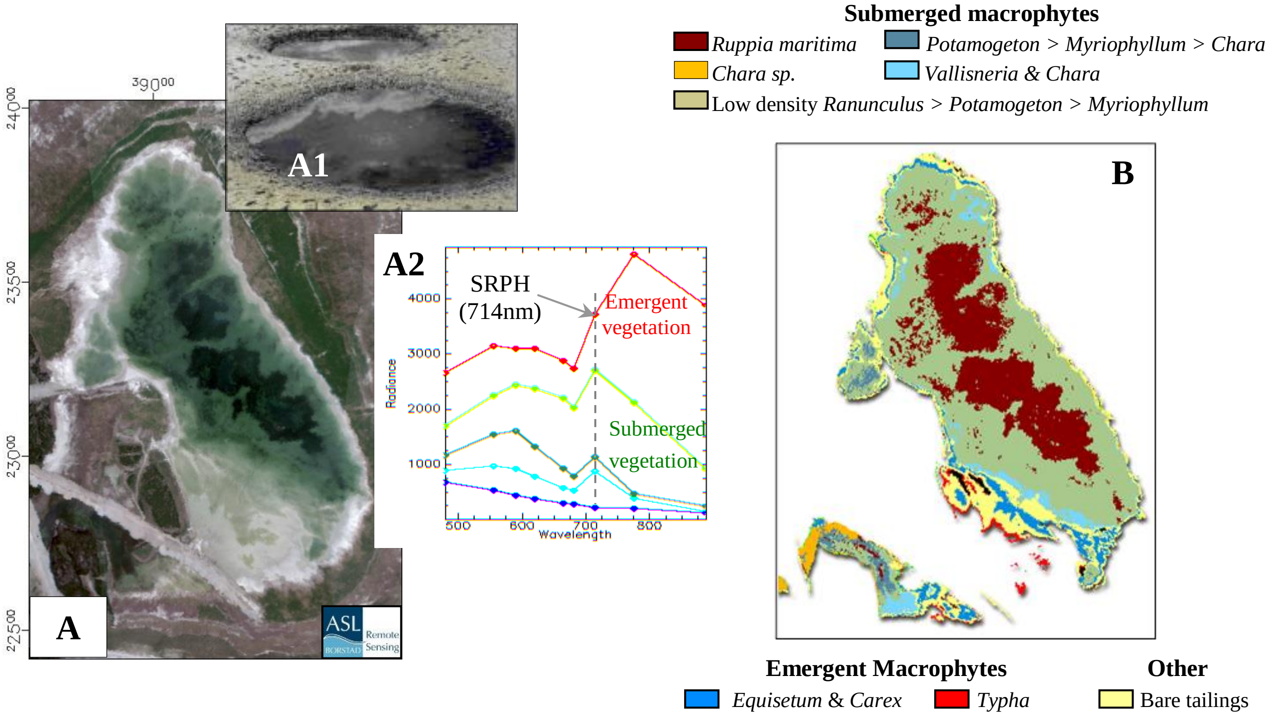

Figure 4. Aquatic plant distribution in a reclaimed tailings pond derived from multispectral CASI imagery

4 CONCLUSIONS

Remote sensing maps are more than just pretty pictures; they are valuable tools for monitoring and quantifying biophysical changes (Borstad *et al.*, 2008; Landtuit and Polland, 2008; Verbyla, 2008; Walker, 2005). Aerial remote sensing surveys can be optimized using specific spectral bands to acquire information for vegetation changes in a variety of habitats. Long-term series imagery from aerial or satellite sensors support many kinds of land and water quality monitoring studies, and help to understand where and what changes are taken place, and to quantify the rate of change. Recent cost reductions of remote sensing data have also made this tool more accessible to non-profit groups and other small, independent interests.

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