USING MULTISPECTRAL REMOTE SENSING TO MONITOR AQUATIC VEGETATION IN PONDS AT A RECLAIMED MINE SITE

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ABSTRACT

Multispectral remote sensing is being investigated to monitor mine-site reclamation at Highland Valley Copper, a large copper-molybdenum mine in southern British Columbia. Two examples of the application of aerial mapping to the aquatic portions of the mine are presented here: Trojan Pond, a deep tailings pond that supports a small fishery, and Highmont Tailings Pond, a shallow tailings pond and wetland.

Trojan Pond has a narrow band (1 to 3 m), of benthic aquatic vegetation around its shore, because it has a rapidly shoaling littoral zone, with very little shallow area – quite typical for a shallow, small lake in this region. By contrast, Highmont Pond is shallow and supports extensive benthic vegetation that was impossible to properly sample from the ground because a very soft bottom limits access. This vegetation was well mapped by the multispectral imagery in 2001 and 2002, and was only sampled from the ground after the pond was drained in 2003 – at which time the abundant vegetation in the centre of the pond came as a surprise to ground biologists.

INTRODUCTION

Highland Valley Copper is a large open pit copper mining complex, situated between 1200 and 1600 m above sea level on the Thompson Plateau, near the town of Logan Lake British Columbia (BC), 220 Km northeast of Vancouver and 55 Km southwest of Kamloops (Figure 1). Since the beginning of 2004, the mine is almost entirely owned by Teck Cominco.

Highland Valley Copper consists of four mining operations: Lornex, Valley, Bethlehem and Highmont. Operations at the latter two were discontinued in the mid-1980s and decommissioning begun. Production is currently planned to cease in early-2009 but may be extended to 2013 pending approval of a new plan. The total area disturbed is currently 6200 ha.

Reclamation is an integral part of production and decommissioning. Reclamation monitoring programs are conducted annually to assess the progress toward achieving the end land use objectives, and to determine when individual sites achieve a self-sustaining state. Beginning in 2001, remote sensing has been evaluated as a way of improving the efficiency and effectiveness of the monitoring program (Richards et al., 2003; Richards et al, 2004).

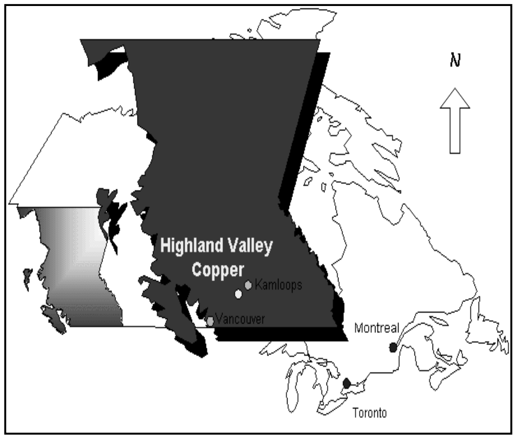

Figure 1: Location Map of Highland Valley Copper

We present here examples of the use of airborne remote sensing data to help describe two different types of water bodies at Highland Valley Copper. Trojan Pond is a deep tailings pond that supports a small fishery, while Highmont Tailings Pond is a very shallow tailings pond that has been recently stabilized (2003) with a spillway and is surrounded by wetland. Construction of the spillway has created a stable high-water line which is conducive to wetland development.

Trojan Pond

With a maximum depth of 7 to 8m, Trojan Tailings Pond is the deepest of the Highland Valley decommissioned tailings ponds. This pond intermittently stratifies in the summer, with a thermocline at 4m, and supports an average fish population for a lake of this size. Water levels fluctuate from year to year, limiting the establishment of an abundant littoral benthic plant community.

The final management plan for Trojan pond is a self-sustained fishery. The pond has an average surface area of 15.6 ha and an average depth of 3 m and a soft bottom of fine tailings. Aquatic macrophytes produce more organic carbon for bacterial growth than any other pond flora, provide habitat for microflora, reduce sediment movement and bioaccumulate metals. The dominant species change with time but are currently *Potamogeton (pectinatus and Richardsonii*), *Chara vulgaris* – a macro algae, native milfoil (*myriophyllum*) and *Ranunculus aquatilus*. Plant production covers 10% of the pond at a median production of 150 g dry wt/m^2. Trojan's dramatically fluctuating water levels make it difficult for emergent vegetation to establish. Trials of willow (*Salix spp.*) and cottonwood (*populus balsaifera*) were successfully established in 2004, indicating that riparian shrubs could be introduced on a larger scale.

Highmont Tailings Pond

The final management objective for the Highmont tailings pond is a wetland and wildlife habitat. It has a surface area of about 24 ha, an average depth of 1.5m and a very soft bottom of fine tailings. It has been planted with several species of aquatic macrophytes and emergent vegetation (buttercup, sedge, cattail, cottonwood and willow) as part of the management strategy. The submerged aquatic macrophytes present in this pond include; *Potamogeton (pusillis* and *pectinatus), Ruppia maritima, Myriophyllum exalbescens, Vallisneria Americana, Zannichellia palustris* and the stonewort algae, *Chara vulgaris.* Several of these species are only found in the narrow pond to the side of the main tailings pond where turbidity is low. *Ruppia* and *Myriophyllum* grew vigorously in the deepest water with the lowest light penetration. Several emergent species *Equisetum spp* (horsetail) and *Carex spp* (sedge), have volunteered around the edges of the pond.

MULTISPECTRAL CLASSIFICATION METHODS

Using the same airborne multispectral imagery as used for the land vegetation, the aquatic vegetation in two ponds at Highland Valley was classified using a combination of standard image processing techniques. For Highmont Pond, airborne imagery for 2001 and 2002 was first classified with 'unsupervised[1]' multispectral classification techniques (without ground truth calibration points), and then interpreted based on our (Heather Larratt's) general knowledge of the pond. Later in 2003 when it became possible to more adequately sample the area, the image maps were used to direct ground sampling specifically to interpret the multispectral classes. For Trojan Pond, the results were evaluated by comparing the class distributions with *in situ* observations made July 10-24, 2003, 3 to 17 days prior to CASI image acquisition, using supervised techniques. Ground truth data consisted of position, species and depth observations at 37 stations around the Trojan Pond and 22 stations at Highmont Pond. Unfortunately, only qualitative species observations could be made at the time. No density estimates were available.

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[1] Supervised multispectral classification requires the analyst to 'train' the Image Processing software. Thematic classes are defined by the spectral characteristics of the pixels in the image that correspond to training areas in the field chosen to represent known features (e.g. habitats). Each pixel within the image is then assigned to a thematic class using one of several decision rules.

Unsupervised techniques make class separations purely on the basis of their spectral signatures with no analyst input. The clusters may then be assigned labels (e.g. habitat names) using the operator's field knowledge.

Imagery over Trojan and Highmont Ponds was isolated from the rest of the image data and classified using a combination of the unsupervised ISODATA and the supervised Spectral Angle Mapper (SAM) image analysis techniques, as well as an aquatic vegetation index we refer to as Shifted Red Peak Height (SRPH). SRPH measures the height of the large increase in brightness near 700nm that occurs in Reflectance spectra of all chlorophyll containing living plants. In aquatic environments, where longer wavelengths are strongly attenuated by water, this "Red Edge" becomes a red peak when vegetation is covered by water (Figure 2) providing an unambiguous indication of aquatic vegetation. The techniques used for aquatic classification therefore differ somewhat from terrestrial application because of this modulating effect of water on the vegetation signal.

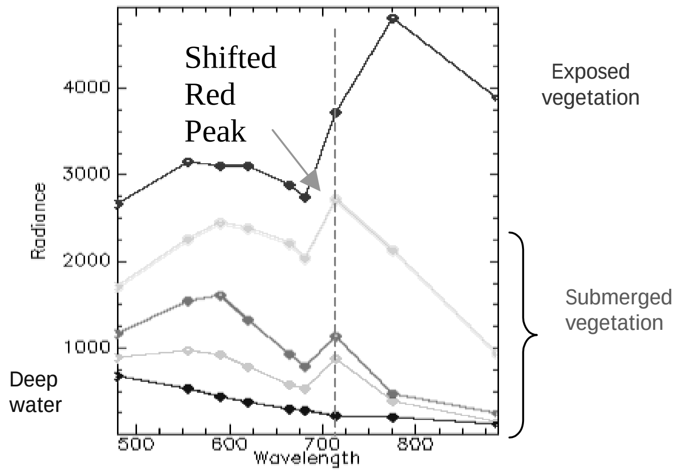


Figure 2. Effect of water submersion on vegetation spectra. The SRPH index measures the height of the peak at 714nm.

RESULTS

<u>Trojan Pond</u>

Figure 3 shows the distribution of aquatic vegetation (as SRPH) in Trojan. Since the height of the red peak measured by SRPH is proportional to vegetation density and inversely proportional to water depth, high SRPH values (reddish to yellowish in the images) indicate dense, shallow vegetation, while low values (blue) represent sparsely vegetated and/or deep areas. The vegetation appears to be restricted to the shorelines and shallower parts of the ponds, but it is possible that vegetation also exists in deeper areas, beyond the limit of visibility into the water.

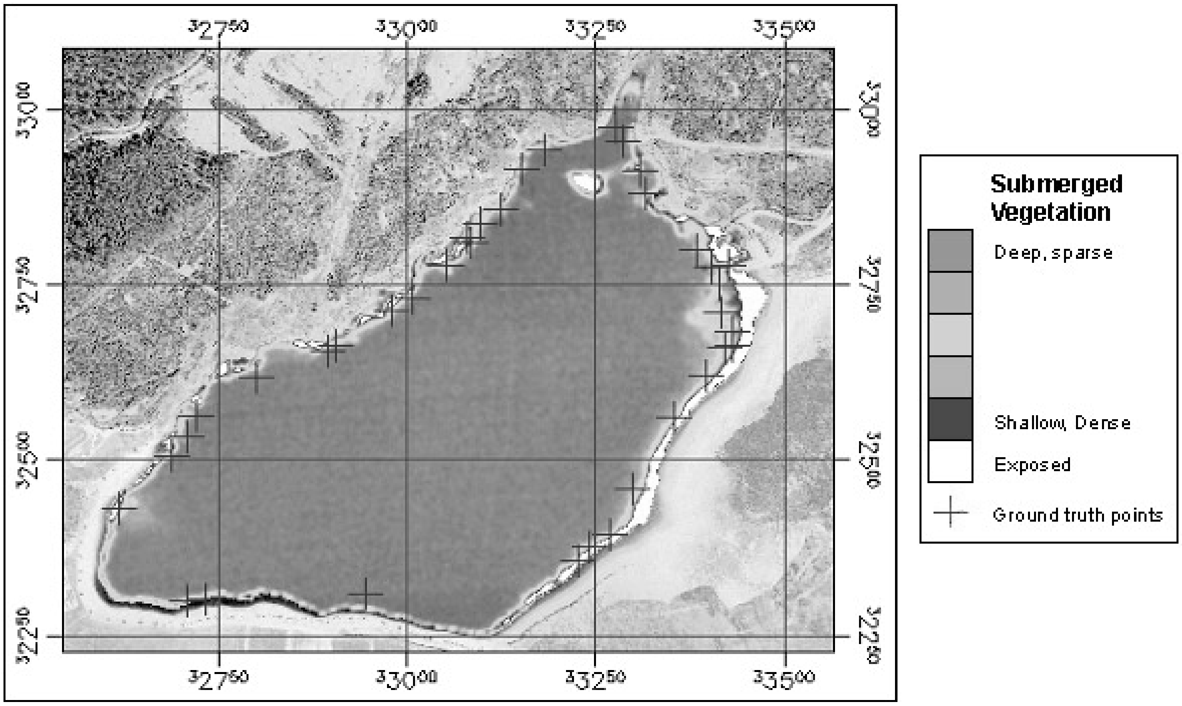


Figure 3. A quantitative map of aquatic vegetation in Trojan Pond, as indicated by the height of the shifted red peak (SPRH).

Figure 4 shows the interpreted multispectral classification of Trojan Pond. There were not enough ground truth stations to undertake a rigorous accuracy assessment, but comparison with ground truth shows that all of the areas mapped as *P. pusillis* were correct . On the other hand, *P. richardsii* and *Chara* were overestimated. At many of the stations identified as dominated by these two species, in fact *P. pusillis* was dominant. At 7 ground truth stations, a dominant species was reported, but the vegetation was not dense enough to be optically characterized to species. In these cases the spectra were dominated by substrate.

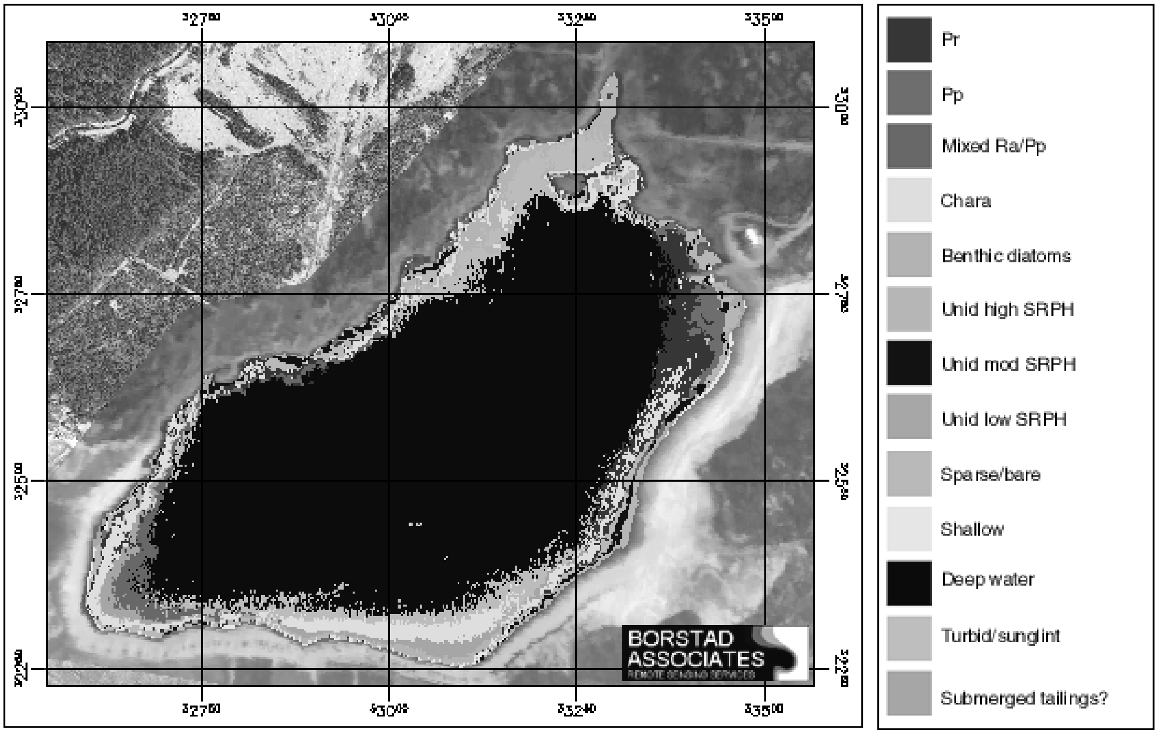


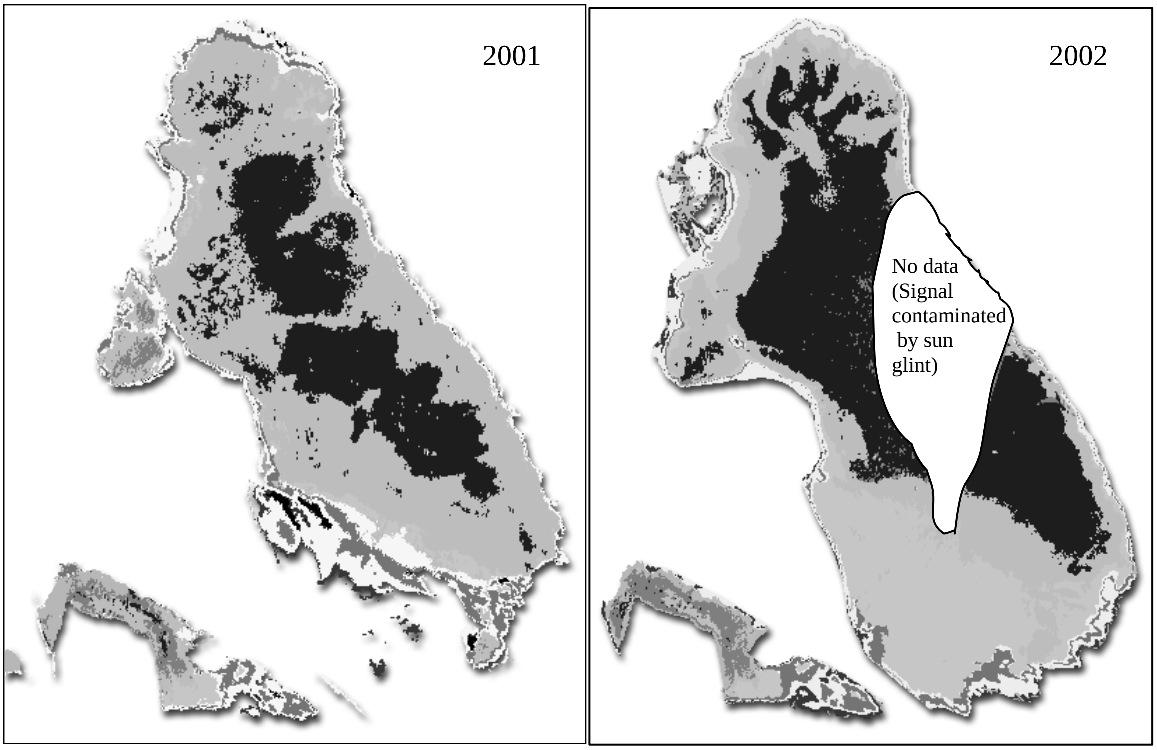
Figure 4. Classification map for Trojan Pond. Background imagery is CASI false colour and greyscale digital orthophoto. Pr = *Potamogeton richardsii*, Pp = *P. pusillis*, Ra = *Ranunculus aquatilis.*

Highmont Pond

The water-covered tailings in Highmont Pond are very fine. The bottom is very soft (0% sand, 68% silt, 32% clay) and treacherous to traverse for people or animals. This has severely limited ground-based sampling to around the periphery of the pond, and prevented any understanding of what was happening in deeper water in the centre of the pond. The soft bottom and shallow water around the edges has also prevented use of small boats. For such water bodies, remote sensing provides an alternative means of detecting and monitoring submerged vegetation (figure 5). Until the pond was partially drained in June 2003, the abundant growth of *Ruppia maritime* in the centre of the lake was unsuspected, although a large area of unidentified sub-surface vegetation was seen in the remote sensing imagery in 2001 and 2002 (Figure 6).

DISCUSSION

The remote sensing imagery has allowed us to produce estimates of vegetative cover, and to monitor changes over time in response to the management regime. An aquatic vegetation index (SRPH) was introduced as a rapid semi-quantitative index of aquatic vegetation that increases with increasing vegetation density and decreases with depth.



	Ruppia maritime + SRB /high Density
	Pondweed > Milfoil > *Chara*
	Chara
	Low Density *Ranunculus* > Milfoil> Slender Pondweed
	Low Density *Ranunculus* >Slender Pondweed >Milfoil
	Equisetum, Carex
	Emergent
	Bare tailings

Figure 5. Aquatic plant distribution in Highmont Tailings Pond in 2001 and 2002

Figure 6. Stranded aquatic macrophytes at Highmont, after the water levels were drawn down.

The airborne multispectral imaging acquisition took place in July to maximize the quality of the imagery over the land parts of the mine site, with no consideration for the aquatic environments. We do not have a large number of ground samples, and many classes are represented by only one plot or are in very heterogeneous areas. *Potamogeton pusillis, mixed Potomogeton* and benthic diatoms were well mapped in both ponds, although *P. pusmillus* was confused with other species and other species tended to be overestimated (*P. richardsii, Chara* spp.). A number of plots with very low-density vegetation were classified as sparse or bare.

If the flight timing were determined solely on the basis of the aquatic monitoring, it should be later in the late summer or early fall when the vegetation is maximally developed and when water levels are low, and possibly flying at a lower altitude to increase the spatial resolution of the imagery. A potential disadvantage to this latter strategy would be a loss of spectral information, since the number of spectral bands acquired is inversely related to the spatial resolution. The implication of losing spectral information is a possible reduction in the ability to make species level identifications, although experiments could be conducted (by decimating the current data) to determine this.

The thematic maps have proved to be quite useful, allowing us to produce areal estimates for the first time, visualize changes between years and to map areas that were impossible to sample from the ground. The maps show for example, that in the seven years since planting, the aquatic plants have expanded to cover 13 hectares in low-density weed-beds with occasional high-density milfoil patches. While the increase in algae production was modest after fertilization, the rooted aquatic macrophyte growth soared between 2001 and 2003, including several species important to waterfowl.

REFERENCES

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