# ENVIRONMENTAL CONTROLS ON FOREST CHEMISTRY: EVALUATING AND REFINING FOLIAR CHEMISTRY FROM IMAGE SPECTROSCOPY

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## ABSTRACT

The potential for forest species and health inventory has been demonstrated through advanced image spectroscopy [1, 2]. Variation in foliar chemistry provides the means through which vegetation health classification is possible[3]. We have developed and implemented a method for retrieving high resolution forest chemistry maps [4]. Through the spatial analysis of these forest chemistry products we evaluated topographic effects on forest health. Topography significantly effects forest chemistry through slope and aspect. Elevation effects on chemistry were not significant at our Greater Victoria Watershed District (GVWD) study site, likely a reflection of the relatively low relief of the area (~160m). This paper reports on the topographic control of foliar chemistry and a validation protocol based.

The Greater Victoria Watershed District has been a long standing research forest for the University of Victoria and the Pacific Forestry Centre. The GVWD is a protected uninhabited watershed. The 350 $km^2$ watershed is covered predominantly by Douglas-fir (*Pseudotsuga menziesii*). Other species found include: Western Red Cedar (*Thuja plicata*), Western Hemlock (*Tsuga heterophylla*), Lodgepole Pine (*Pinus contorta*), Red Alder (*Alus rubra)* and to a lesser extent Grand Fir (*Abies grandis*), Western White Pine (*Pinus monticola*) and occasionally some spruce (*Picea*) species. Where canopy closure is sufficiently low to permit its growth, the understory species is either Salal (*Gaultheria shallon*) or Western Swordfern (*Polystichum munitum*). The area experiences the typical weather associated with temperate rainforests, high precipitation and moderate temperatures during winter months and warm dry summers. The GVWD provides for excellent growing conditions. Due to a 100-year logging history and consequent reforestation, the forest contains various age classes. Another confounding attribute is the population of forest pathogens that thrive within the GVWD. Various insects (spruce budworm, bark beetles) and fungi (needle blight and root diseases) are capable of inducing stress and potentially mortality.

The research site was expected to provide a range of forest health conditions and likely a diverse chemistry dataset.

During the summer of 2006, the University of Victoria's AISA hyperspectral sensor was flown and data were acquired over the (GVWD) test site. The 492 bands of the AISA sensor sampled the spectral range of 395-2503nm every 2.37nm (VNIR) and 6.30nm (SWIR). The hyperspectral sensor was integrated with a discrete return lidar system flown on a Navajo aircraft platform. The resulting posting density of the lidar data was ~1.2/$m^2$. In preprocessing, the AISA data were geometrically corrected to 2m pixels with the aid of airborne navigation files and a digital surface model (DSM) derived from LIDAR data. An extensive field campaign was conducted prior to the airborne acquisition that sampled the upper portions of mature Douglas-fir canopies. At each of 54 forest plots ten trees were sampled from a helicopter platform, while recording the position of each canopy with dGPS [5]. The samples were processed in a laboratory for chemical constituents, which were ultimately used as representative chemistry measurements for plot areas of 30m x 30m.

Plot chemistry values and transformed plot reflectance spectra were applied in partial least squares regression analysis (PLS) to generate three optimized latent variables and an associated PLS coefficient vector [6]. The dot product of the coefficient vector and the hyperspectral data produced forest chemistry maps for chlorophyll-a, chlorophyll-b and nitrogen. The model was generated using two thirds of the data set and validated using the remaining, this procedure was iterated 10,000 times and the final coefficients were generated as an average coefficient vector. The accuracies of the models were determined through the regression of the predicted and the observed plot chemistry values. AISA hyperspectral data accurately estimated chemistry with coefficients of determination of 0.91, 0.87 and 0.80 for nitrogen, chlorophyll-a and chlorophyll-b respectively. We determined that foliar age significantly effects chemical concentrations, particularly in nitrogen and chlorophyll-a. Pigment concentrations respond to the growing light environment, where pigment pools are increased under low light conditions [7]. The interaction between slope and aspect can moderate the amount of solar radiation that is incident on the Earth's surface. Therefore, we expected to find chemistry differences that could be attributed to aspect. The analysis of aspect and chemistry suggested that that there were significant differences for virtually all aspects and chemical components with minimum chlorophyll-a occurring at southerly aspects (figure 1). Ground reference chemistry was analyzed for correspondence with canopy level results. The pressure gradient through altitude causes temperature changes with elevation. Vegetation is known to respond to the lapse rate, at sufficient altitudes the lower temperature limit of growth is exceeded [8]. The effect of elevation on foliar chemistry was investigated. However, a significant relationship with elevation was not found. We expect that the variation in

temperature attributed to elevation change is roughly 2°C which may not be sufficient to induce health changes expressed in foliar chemistry at this site.

A spectral validation protocol was implemented that assessed the hyperspectral chemistry products for correspondence with widely accepted principals of foliar pigmentation and electromagnetic energy interaction. The procedure was performed through generating extreme classes from the estimated chemistry and conducting spectral analysis on these data. The results of the spectral validation suggested that the PLS method for estimating chemistry concentrations was very sensitive to reflectance magnitude. The influence of shadow on estimated chemistry was also investigated. The results of these investigations will be presented at the conference. The ultimate goal is to be able to detect healthy and stressed forested areas for future forest management decisions.

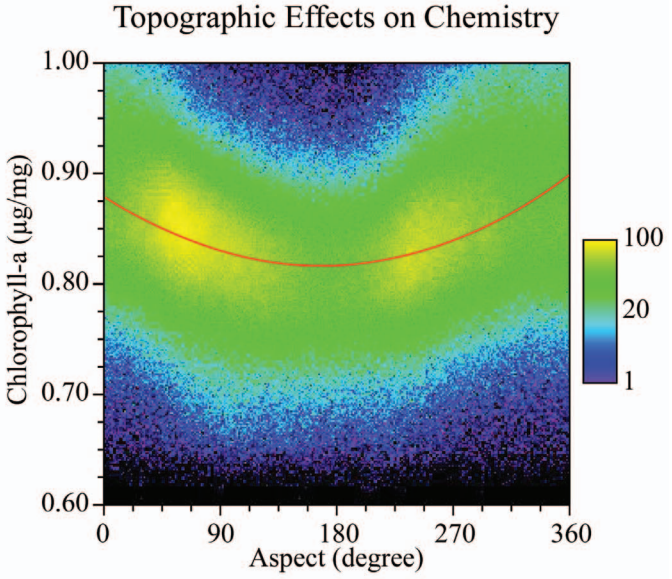


**Figure 1.** Point density cloud illustrates trend to higher chlorophyll-a on north aspects (0 and 360°). The pseudo-color scale refers to the number of pixels. The relationship between chlorophyll-a and aspect is modeled by a quadratic function.

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