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Using excess greenness and green chromatic coordinate colour indices from aerial images to assess lodgepole pine vigour, mortality and disease occurrence

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ABSTRACT

Here, we test the feasibility of using two colour indices to assess differences in stand-health metrics in 54 plots of lodgepole pine in British Columbia, Canada. Colour indices of excess greenness (EG) and green chromatic coordinate (GCC) were calculated over two spatial scales from colour images captured from a Cessna T210 flying at 600 m above ground level. EG and GCC were then compared to five ground-based metrics of stand health: vigour, mortality, foliar disease occurrence, western gall rust occurrence, and root disease symptoms. Colour indices, calculated at both tree and plot scales, significantly related to the ground-based metrics of stand health, except western gall rust occurrence. These relationships were influenced by canopy closure, but were unaffected by foliar nitrogen concentration. Using linear regression models, ground-based stand-health metrics accounted for 36.5–60.9% of the variability in colour indices. Within research projects, EG and GCC values could be used to set thresholds below which ground-checks of stand health would be warranted.

1. Introduction

The amount of insect and disease damage to forests is predicted to increase by 2% per year in North America (Mickler, 1996). In mid-rotation stands in British Columbia (BC), Woods and Coates (2013) found much greater mortality than predicted by growth-and-yield models mainly caused by insects and disease. As this has implications for merchantable volumes at harvest, they recommended more intensive monitoring of forest health. Ground assessments of forest health over large areas, such as BC, are time consuming and expensive. Small planes are used in BC to survey visible outbreaks of forest pests over the entire province: the Aerial Overview Survey (Westfall and Ebata, 2015). This sketch-mapping technique occurs every year and captures what trained observers can see from the plane window and record on a paper map (McConnell et al., 2000; BC Ministry of Forests, 2000). Consistency in identifying pest occurrence and severity levels among observers is critical, but difficult (Harris and Dawson, 1979; Leckie et al., 2005; Wulder et al., 2005, 2006). Analysis of forest health from images captured from planes or satellites can provide a more standardized and objective method for detecting changes to forest health (Wulder et al., 2005; Coops et al., 2006a) and could possibly be used to prioritize areas for more detailed ground-based surveys of forest health issues.

From either satellite or aerial images, the proportions of reflected wavelengths are used to calculate vegetation indices, which provide an indication of plant condition based on the unique spectral reflectance patterns of photosynthesizing vegetation (Myneni et al., 1995). The most common vegetation index is the normalized difference vegetation index (NDVI; Tucker, 1979; Soudani et al., 2012). NDVI uses the longer red- and near-infrared wavelengths, which have less atmospheric scattering, and therefore are preferable when using satellite images. However, vegetation indices that use the visible light spectrum (green, red and blue) outperformed NDVI when assessing vegetation cover and condition using images collected at close range (Nijland et al., 2014).

Excess Greenness (EG) and Green Chromatic Coordinate (GCC) are two such colour indices that were found to outperform NDVI when using near-sensing images (Nijland et al., 2014). Differences in scene illumination are standardized by EG and GCC because they measure green light relative to red and blue light. Limitations of this approach are that vegetation greenness depends on plant species, canopy structure, and foliar nitrogen (Dillen et al., 2012). Comparisons within plant species, and simultaneous measurements of

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canopy structure and foliar nitrogen can overcome these limitations. Of these two measures, GCC is better at suppressing variability caused by differences in scene illumination among images (Nijland et al., 2014). While, EG is superior at distinguishing plant material from background soil compared to other colour indices (Woebbecke et al., 1995).

EG and GCC have been used to assess gross primary productivity of forests (Saitoh et al., 2012) and to monitor forest phenology (Richardson et al., 2007; Sonnentag et al., 2012; Petach et al., 2014; Keenan et al., 2014; Yang et al., 2014). Using EG and GCC to indicate plant health assumes that healthy vegetation will reflect a higher proportion of green light than will unhealthy vegetation. EG and GCC have successfully indicated plant condition in agricultural and laboratory settings focusing on individual plants and surfaces (e.g. Bacci et al., 1998; de Jong et al., 2012). For tree species, GCC has been used to identify damage classes in branches of declining Norway spruce trees in a laboratory setting (Ruth et al., 1991). The utility of these indices for monitoring forest health at larger spatial scales still needs to be assessed.

Forest management primarily occurs on a 'stand' scale of around 2–20 ha. The use of colour indices, based on imagery to monitor vegetation condition, can occur on individual needles (Ruth et al., 1991) to entire landscapes (Brown et al., 2016). When measuring phonological changes with fixed cameras, it is possible to integrate multiple spatial scales by selecting ROI on individual trees or entire canopies (Vartanian et al., 2014), and then combining this data at multiple sites across the landscape (Richardson et al., 2007; Yang et al., 2014; Petach et al., 2014; Brown et al., 2016). This model of combined spatial scales could be useful when monitoring forest health because pests attack individual trees but it is the cumulative damage over the landscape that is relevant to forest management. Another important aspect related to spatial scale of analysis is the amount of shading and non-target area within the ROI. For example, analysis of entire forest stands would include some understory vegetation and forest floor depending on how closed the canopies were, as well as shaded parts of the canopy (Coops et al., 2006b). Analysis of individual tree crowns would remove the effect of shading and non-target area, but may not capture stand health effects concentrated in the tree perimeter or acting on overall tree size.

In this paper, we assess the utility of aerial imagery for monitoring forest health by comparing EG and GCC values with ground-based metrics of stand health collected on six coniferous forest stands in interior British Columbia, Canada. Specifically, this paper asks:

1. Are EG or GCC related to ground-based metrics of stand health (vigour, mortality and disease occurrence)?
2. How does canopy closure and foliar nitrogen concentrations influence the relationships between colour indices and stand-health metrics?
3. How much of the variability in EG and GCC values can be attributed stand-health metrics?
4. Is the application of colour indices for stand-health measurement more useful at the spatial scale of individual trees, or on larger plots?
5. Can colour indices be used to prioritize areas to conduct ground-based forest-health surveys, within a research project?

2. Materials and methods

2.1. Study sites and species

This study was conducted on six Long-Term Soil Productivity (LTSP) sites in the interior of British Columbia (Table 1). Three sites were in the Interior Douglas Fir (IDF) ecosystem zone (Black Pines, Dairy Creek and O'Connor Lake) and three in the Sub-Boreal Spruce (SBS) ecosystem zone (Log Lake, Skulow Lake and Topley). Each site was divided into nine 40 m by 70 m (0.28 ha) plots (Berch et al., 2010). Plots were divided in half and planted with two tree species, one species in each half. Here we only consider the plots planted with lodgepole pine (*Pinus contorta* Dougl. ex Loud.) because this species occurs at all six sites. Lodgepole pine at these sites ranged in age from 15 to 20 years old (Table 1). Canopy closure at these sites ranged from 50% to 78%. Skulow Lake and O'Connor Lake had the lowest canopy-closure values (50% and 51%). Black Pines and Dairy Creek had intermediate canopy closures (63% and 69%). Log Lake and Topley had the highest canopy closures (78% and 74%).

2.2. Colour indices

Images were captured by Terrasaurus (Delta, BC Canada) from a Cessna T210 Centurion II Survey Aircraft between July and November 2013, except at Topley, which was photographed in August 2014. The growing season in our study area is approximately late May to mid-September. Images were captured from a flying height of approximately 600 m above ground level with an Alpa aerial metric 60-megapixel camera. Images had a 5 by 5 cm ground sampling resolution and were aerially triangulated, georeferenced, and mosaicked by Terrasaurus (Delta, BC Canada) before delivery. Plot 9 at Dairy Creek was not photographed and therefore not included in this analysis.

Mosaicked red-green-blue images were loaded into the software program ENvironment for Visualizing Images (ENVI) 4.8 for analysis (Exelis Visual Information Solutions) in TIFF file format. Using the 'band math' tool excess greenness (EG) and green chromatic coordinate (GCC) indices were calculated by the equations,

$$\mathrm{EG} = 2\mathrm{G} - (\mathrm{R} + \mathrm{B}),\ \text{and}$$

$$\mathrm{GCC} = \mathrm{G}/(\mathrm{R} + \mathrm{G} + \mathrm{B})$$

respectively, where G is green light, R is red light and B is blue light (Nijland et al., 2014). Larger EG and GCC values indicated that a higher proportion of green light is being reflected, suggesting healthier trees (lighter hues in Fig. 1).

EG and GCC values were calculated over two regions of interest (ROIs) covering different spatial scales. First, ROIs were created over ten individual tree crowns near the center of each treatment plot: hereafter $\mathrm{EG_{tree}}$ or $\mathrm{GCC_{tree}}$ (Fig. 2). Analysis of individual tree crowns minimizes background noise from the non-tree vegetation and ground cover. Crown delineation was done conservatively, only selecting the sunlit portion of the tree. Polygons were created by hand with the most appropriate shape to capture the majority of the tree crown. Second, ROIs were created over the entire treatment plot to capture differences in overall stand condition: hereafter $\mathrm{EG_{plot}}$ or $\mathrm{GCC_{plot}}$ (Fig. 2). These ROIs included the 100-core-research trees that were included in the visual forest-health survey with the two buffer rows of trees being excluded. Plot ROIs could be expected to have higher variability but could be more useful for forest management in assessing overall stand condition.

2.3. Visual forest-health survey

To determine how EG and GCC values relate to forest health and to determine how much variability in EG and GCC values is accounted for by forest health, ground-based visual forest-health surveys were conducted in the summer of 2013 (Reid et al., 2015). Each of the 5400 trees were located and inspected for damage to leaders, foliage, stem, branches and root collar (Reid et al., 2015). Each tree was given a vigour classification rating from 1 to 5 based on Newsome and Perry (2002). Western gall rust