Detection of sugar maple condition using ground-based indicators and hyperspectral remote sensing

Thomas L. Noland[1], Pablo J. Zarco-Tejada[2], John R. Miller[2], Gina H. Mohammed[1], and Paul H. Sampson[1]

[1]Ontario Forest Research Institute, 1235 Queen St. E., Sault Ste. Marie, Ontario, P6A 2E5 Canada
[2]Centre for Research in Earth and Space Science (CRESS), York University, 4700 Keele Street, Toronto, M3J 1P3 Canada
[3]Centre for Research in Earth and Space Technology (CRESTech), York University, 4850 Keele Street, Toronto, M3J 1P3 Canada

Abstract

A major objective of the bioindicators of forest sustainability project is to develop optical indices from hyperspectral remote sensing data that are linked with ground-based physiological bioindicators of forest condition. In June and July of 1998, twelve sugar maple (Acer saccharum) sites located in the Algoma region of Ontario were assessed by collecting leaves for physiological analysis and using a compact airborne spectrographic imager (CASI) to acquire hyperspectral data. Reflectance, transmittance, chlorophyll fluorescence, chlorophyll a and b, total carotenoids, total anthocyanins, and nutrient levels were measured in the laboratory for individual leaves from five trees per site. Crown cover and leaf area index measurements were measured for all plots. Thirty-two optical indices from the following four categories were tested: i) Visible ratios; ii) Visible/NIR ratios; iii) Red edge reflectance-ratio indices; and iv) Spectral and derivative red edge indices. Single leaf reflectance data, infinite reflectance data (calculated from optically-thick leaf simulation formulae), and canopy reflectance (CR) models were the three scales used to calculate the optical indices which are expected to progressively more closely represent the observed above-canopy reflectance spectra of the sites. Leaf level analysis indicated that various red edge and visible ratios had the best correlation with chlorophyll, total carotenoids, and chlorophyll fluorescence. Leaf nutrients Ca, Mg, Mn, and P were correlated with chlorophyll and total carotenoid levels at the leaf level. Canopy level analysis using CASI derived indices calculated from leaf-level relationships scaled up through CR models showed that red edge reflectance-ratio indices and spectral and derivative red edge indices were best correlated with chlorophyll, total carotenoids, and chlorophyll fluorescence.

Introduction

The need for objective measures of forest ecosystem condition (health) as articulated by the Canadian Council of Forest Ministers was a primary reason for initiating the Bioindicators of Forest Sustainability Project in 1996. A major objective of the bioindicators of forest sustainability project is to develop optical indices from hyperspectral remote sensing data that are linked with ground-based physiological bioindicators of forest condition. This poster reports on progress towards identifying hyperspectral indices that are correlated with the physiological condition of an array of forest stands.

After identification of useful hyperspectral indices, another major objective of this project is to use these optical indices to develop a Forest Condition Rating (FCR) system that could be used to assess forest condition. The FCR would classify the forest on a scale of healthy to stressed, relative to known benchmark for a healthy forest. The FCR could then be used by the Ontario Ministry of Natural Resources and forest industry as one measure of whether Ontario is managing its forest sustainably.

Materials and Methods

In 1997, 12 maple plots of known condition located in the Algoma region of Ontario were chosen to represent a broad range in physiological condition from the maple decline and growth and yield plot networks. These 12 stands were chosen from existing plot networks to represent an array physiological condition in sugar maple.

In 1998 two field campaigns were conducted in late June and late July. Ground-based measurements of reflectance, transmittance, chlorophyll fluorescence, chlorophyll a and b, total carotenoids, total anthocyanins, and nutrient levels were measured in the laboratory for individual leaves from five trees per site. A Li-Cor 1800 sphere apparatus measured reflectance and transmittance with 0.5 nm spacing and 7.5 nm spectral resolution for the 400-900 nm range. The ratio of variable to maximum chlorophyll fluorescence (Fv/Fm) was measured by a PAM 2000 fluorometer. Leaf nutrients were determined by ICP analysis. Chlorophyll, total carotenoids, and anthocyanins were extracted from individual leaves and measured by a Cary 1 UV-Visible spectrophotometer. Crown cover and LAI measurements were acquired for all plots using hemispherical photography, a PCA LiCor 2000, and a spherical densitometer. Coefficients of determination calculated using Pearson Product Moment correlation test.

The CASI data acquisition was divided into three missions:

1) Mapping mission, with 0.5 m spatial resolution and 5 spectral bands.

2) Hyperspectral mission, with 2.0 m spatial resolution, 72 channels and 7.5 nm spectral resolution.

3) Full-spectral hyperspectral mission, with 288 channels and 2.5 nm spectral resolution.

For calculation of indices the brightest 25% pixels in the NIR of the hyperspectral mission in a 20 m X 20 m plot area were selected to target crowns and minimize understory reflectance.

The optical indices were calculated at 3 scales:

i) from single leaf reflectance data;
ii) from infinite reflectance (R_∞) data, calculated by using single leaf reflectance and transmittance data in optically-thick leaf simulation formulae; and
iii) from canopy reflectance models using single leaf reflectance and transmittance data and nominal canopy architecture data.

Optical Indices Used:

(a) Visible Ratios: SRPI (R_{430}/R_{680}); NPQI $(R_{415}-R_{435})/(R_{415}+R_{435})$; PRI calculated as $(R_{531}-R_{570})/(R_{531}+R_{570})$, $(R_{550}-R_{531})/(R_{550}+R_{531})$ and $(R_{570}-R_{539})/(R_{570}+R_{539})$; NPCI $(R_{680}-R_{430})/(R_{680}+R_{430})$; Carter (R_{695}/R_{420}), G (R_{554}/R_{677}) and Lichtenthaler (R_{440}/R_{690}).

(b) Visible/NIR Ratios: NDVI $(R_{774}-R_{677})/(R_{774}+R_{677})$; SR (R_{774}/R_{677}); Lichtenthaler $(R_{800}-R_{680})/(R_{800}+R_{680})$, (R_{440}/R_{740}); Gitelson & Merzylak (R_{750}/R_{550}) and SIPI $(R_{800}-R_{450})/(R_{800}+R_{650})$.

(c) Red Edge Reflectance-Ratio Indices: Vogelmann (R_{740}/R_{720}), $(R_{734}-R_{747})/(R_{715}+R_{726})$, $(R_{734}-R_{747})/(R_{715}+R_{720})$; Gitelson & Merzylak (R_{750}/R_{700}); and Carter (R_{695}/R_{760}).

(d) Spectral and Derivative Red Edge Indices: λp, λo, Ro, Rs and σ from red edge *inverted-gaussian* curve fitting, as well as spectral indices calculated from derivative analysis: (D_{715}/D_{705}); DPR1 $(D_{\lambda o}/D_{\lambda o+12})$, DPR2 $(D_{\lambda o}/D_{\lambda o+22})$, DP21 $(D_{\lambda o}/D_{703})$ and DP22 $(D_{\lambda o}/D_{720})$.

Results

Table 1. Determination coefficients (r>0.6) obtained in the statistical analysis between chlorophyll-*a*, chlorophyll a&*b*, total carotenoids and Fv/Fm, and optical indices obtained from *Acer saccharum* M. leaf level reflectance and transmittance measurements.

Optical Index	chl-*a*/cm^2	*a&b*/cm^2	carot/cm^2	Chl Fluor Fv/Fm
Vogelmann (R_{740}/R_{720})	0.82	0.80	0.80	0.69
PRI $(R_{531}-R_{570})/(R_{531}+R_{570})$	-	-	-	0.72
PRI $(R_{550}-R_{531})/(R_{550}+R_{531})$	-0.61	-0.63	-	-0.68
PRI $(R_{570}-R_{539})/(R_{570}+R_{539})$	-	-	-	-0.68
Carter (R_{695}/R_{760})	-0.77	-0.75	-0.74	-0.64
Gitelson & Merzylak (R_{750}/R_{700})	0.82	0.80	0.80	0.66
Vogelmann $(R_{734}-R_{747})/(R_{715}+R_{726})$	-0.82	-0.81	-0.81	-0.66
Vogelmann $(R_{734}-R_{747})/(R_{715}+R_{720})$	-0.83	-0.81	-0.81	-0.66
Lichtenthaler (R_{440}/R_{690})	0.74	0.73	0.74	0.61
λp	0.81	0.79	0.79	0.69
DP22 $(D_{\lambda o}/D_{720})$	-0.73	-0.72	-0.68	-0.71
Vogelmann (D_{715}/D_{705})	0.82	0.79	0.79	0.69
DP21 $(D_{\lambda o}/D_{703})$	0.82	0.79	0.79	0.65
Gitelson & Merzylak (R_{750}/R_{550})	0.81	0.79	0.76	--
G (R_{554}/R_{677})	-0.74	-0.72	-0.71	-

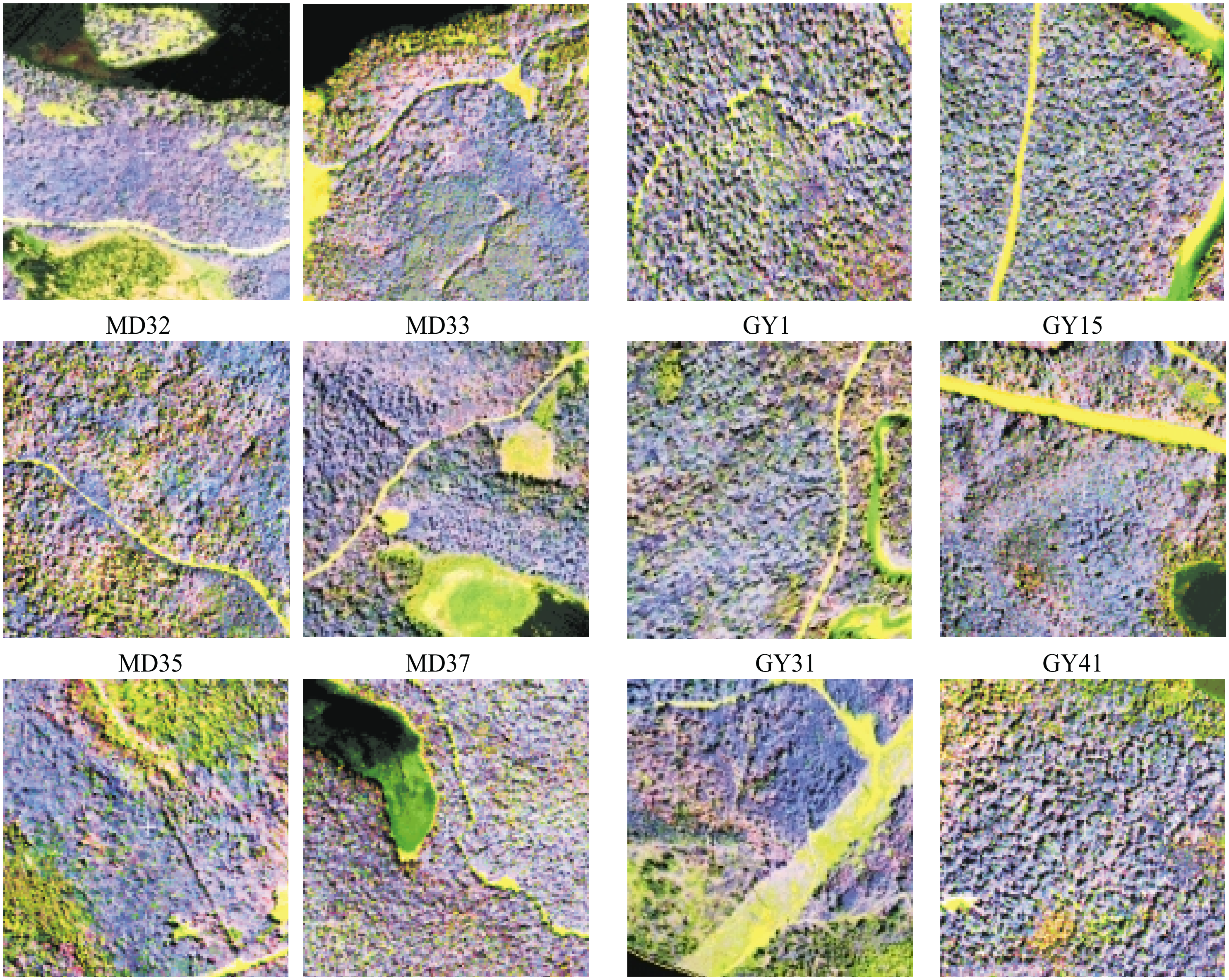
Table 2. Determination coefficients (r>0.4) obtained in the statistical analysis between chlorophyll-*a*, chlorophyll-*b*, chlorophyll a&*b*, total carotenoids and Fv/Fm, and July nutrient levels of Ca, Mg, Mn, and P levels obtained from *Acer saccharum* M. leaf analysis by ICP.

Nutrient	chl-*a*/gDW	chl-*b*/gDW	*a*&b/gDW	carot/gDW	Chl Fluor Fv/Fm
Calcium	0.62	0.61	0.63	0.62	-
Magnesium	0.51	0.51	0.52	0.47	-
Manganese	0.43	0.45	0.44	0.53	-
Phosphorous	-	-	-	-	0.45

Table 3. Canopy level determination coefficients (r>0.4) obtained in chlorophyll-*a*, chlorophyll a&*b*, carotenoids and Fv/Fm estimations applying relationships from optically-thick leaf simulation models and CR models to *CASI* data collected over *Acer saccharum* study sites.

Optical Index	chl-*a*cm^2	*a*&*b*/cm^2	carot/cm^2	Chl Fluor Fv/Fm
DP21 ($D_{\lambda o}/D_{703}$)	0.64	0.63	0.42	0.91
Vogelmann (R_{740}/R_{720})	0.60	0.60	-	0.90
Vogelmann ($(R_{734}-R_{747})/(R_{715}+R_{726})$)	0.61	0.60	-	0.87
Vogelmann ($(R_{734}-R_{747})/(R_{715}+R_{720})$)	0.61	0.61	-	0.87
Gitelson & Merzylak (R_{750}/R_{700})	0.45	0.44	-	0.84
Carter (R_{695}/R_{760})	-	-	-	0.83
λp	0.56	0.56	-	0.82
Vogelmann (D_{715}/D_{705})	0.46	0.45	0.42	0.79
DPR2 ($D_{\lambda o}/D_{\lambda o+22}$)	-	-	-	-0.68
Gitelson & Merzylak (R_{750}/R_{700})	0.45	0.44	-	0.67
Dp22 ($D_{\lambda o}/D_{720}$)	-0.55	-0.54	-	-0.63
PRI ($(R_{570}-R_{539})/(R_{570}+R_{539})$)	-	-	-	0.63
DPRI ($D_{\lambda o}/D_{\lambda o+12}$)	-	-	-	-0.60
PRI ($(R_{531}-R_{570})/(R_{531}+R_{570})$)	-	-	-	0.59
PRI ($(R_{550}-R_{531})/(R_{550}+R_{531})$)	0.59	0.58	-	-
Lichtenthaler (R_{440}/R_{690})	0.46	0.46	-	-
Carter (R_{695}/R_{420})	0.46	0.47	-	-
G (R_{554}/R_{677})	0.46	0.44	-	-

Figure 1. Sites where hyperspectral data were collected during mapping missions. (MD =maple decline plot; GY= growth and yield plot)



MD32 MD33 GY1 GY15

MD35 MD37 GY31 GY41

MD38 MD39 GY42 GY45

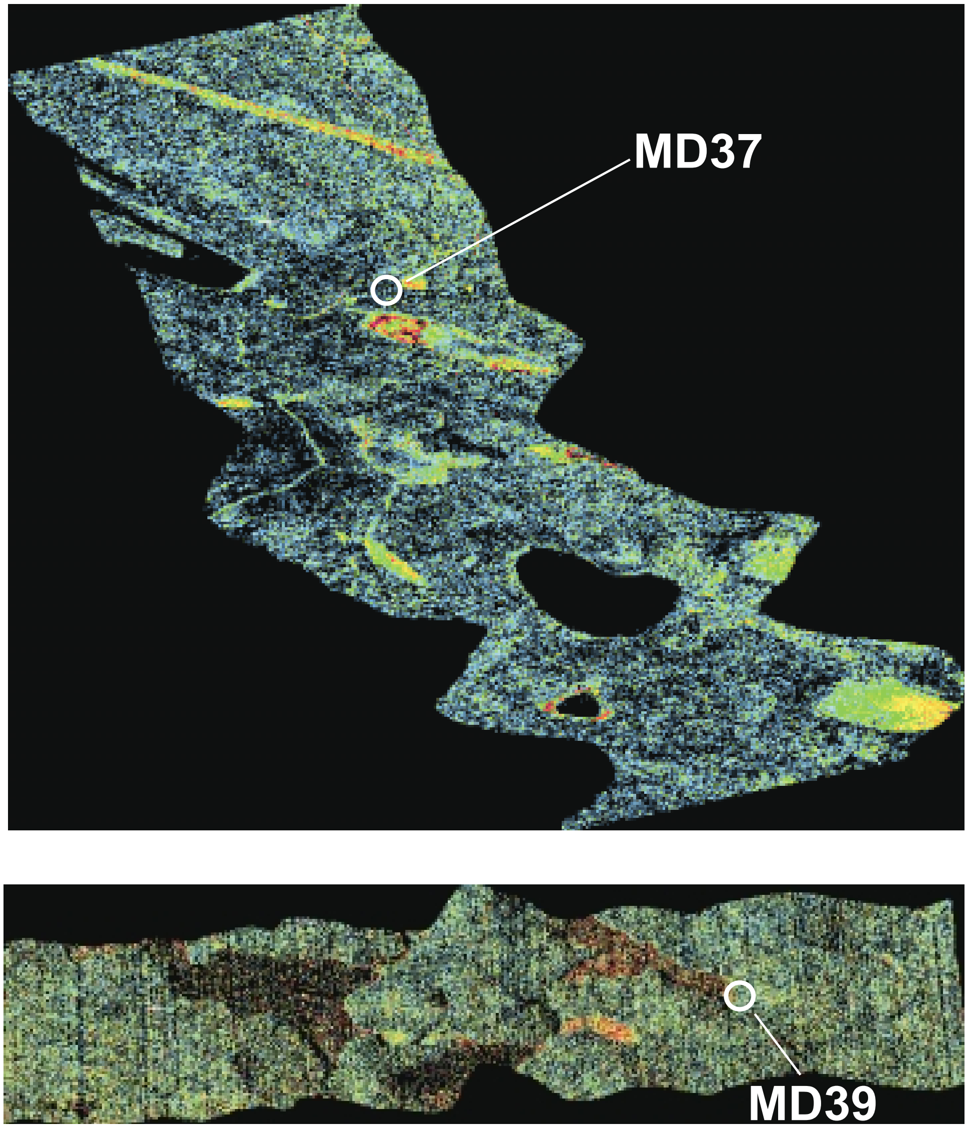


Figure 2.
PRI (R531-R570)/(R531+R570) index CASI images of Maple decline plots 37 and 39 in 1997.

Conclusions

Physiological bioindicators of forest condition in sugar maple sites have linked with optical indices from hyperspectral remote sensing in this study. We also demonstrates the value of using leaf-level measurements of pigments, chlorophyll fluorescence, reflectance, and transmittance to produce algorithms to estimate these variables from above canopy spectral reflectance. As the data is processed through the three scales (simple reflectance, optically thick leaf simulation formulae, and CR models) it progressively more closely represents the observed above canopy reflectance data from the sites as evidenced by the improvements in the estimation of leaf-based physiological indicators such as chlorophyll a, chlorophyll a&b, and Fv/Fm chlorophyll fluorescence. Finally, red-edge and derivative red-edge indices derived from high spatial hyperspectral remote sensing data seem to be the most suitable for bioindicator prediction and mapping.