The Bioindicators of Forest Condition Project: A physiological, remote sensing approach

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Objective measures of forest ecosystem condition are needed to gauge the effects of management activities and natural phenomena on sustainability. The Bioindicators of Forest Condition Project seeks to develop a Forest Condition Rating (FCR) system using a physiological, remote sensing approach. In particular, the goal of the project is to test whether hyperspectral remote sensing may be used to infer stand-level information about pigment concentration, chlorophyll fluorescence, and other physiological features of condition. The project spans a four-year period of intensive sampling in tolerant hardwood forests in Ontario using the Compact Airborne Spectrographic Imager (CASI). For each airborne campaign, concurrent ground-based sampling for leaf physiological features was performed. Controlled laboratory and greenhouse studies were also conducted to derive relationships between leaf-based spectral measurements and physiology in the presence of environmental stresses. The project has identified several promising bioindicators of strain that are discernible from hyperspectral images and related to ground-based physiology. The most promising remote indicator for semi-operational testing is estimation of chlorophyll content, which can be used to classify maple stands on a five-stage scale of health. Chlorophyll fluorescence has also been discerned from spectral signatures, but our studies indicate it may be confounded by chlorophyll content. The intent here is to update the forestry community on progress made, insights gained, and the practical implications of the research.

Keywords: chlorophyll fluorescence, hyperspectral, indices, pigments, reflectance, tolerant hardwoods

Les mesures objectives de l'état de l'écosystème forestier sont nécessaires pour évaluer les impacts des activités d'aménagement et des phénomènes naturels sur la durabilité. Le Projet des bio-indicateurs de l'état des forêts cherche à élaborer un système de classement de la condition des forêts (FCR) au moyen d'une approche de télédétection physiologique. Plus précisément, le 'objectif du projet est de voir si la télédétection hyperspectrale peut être utilisée pour obtenir de l'information au-delà du niveau du peuplement sur la concentration des pigments, la fluorescence de la chlorophylle et d'autres éléments physiologiques de l'état du peuplement. Le projet couvre une période de quatre ans d'intense échantillonnage dans les forêts de feuillus tolérants de l'Ontario, et utilise le Compact Airborne Spectrographic Imager (CASI). Pour chacune des campagnes aéroportées, un échantillonnage parallèle au sol a été effectué sur les éléments physiologiques des feuilles. Des études contrôlées en laboratoire et sous serre ont été entreprises pour établir les relations entre les mesures spectrales des feuilles et leur physiologie en présence de stress environnementaux. Le projet a identifié quelques bio-indicateurs prometteurs de contraintes qui sont perceptibles à partir d'images hyperspectrales et reliées à un état physiologique au sol. L'indicateur le plus prometteur pour des essais partiellement opérationnels se trouve à être l'estimation du contenu en chlorophylle, qui peut être utilisé pour classifier les peuplements d'érable selon cinq classes de santé. La fluorescènce de la chlorophylle a été également discernée parmi les signatures spectrales, mais nos études indiquent qu'elle peut être confondue avec le contenu en chlorophylle. Cet article vise à informer la communauté forestière sur les progrès réalisé, les connaissances acquises et les implications pratiques de cette recherche.

Mots-clés : fluorescence de la chlorophylle, hypersprectrale, indices, pigments, réflexibilité, feuillus tolérants

Introduction

The Bioindicators of Forest Condition Project was initiated in 1996 by the Ontario Forest Research Institute (OFRI) to identify and develop physiological indicators of forest condition (Mohammed *et al.* 1997). The project focus is to develop objective measures of condition at the stand level. The stimulus for initiating the project came from two sources: (1) international and national commitments by policy-makers to develop a standard set of criteria and indicators of forest sustainability (Canadian Council of Forest Ministers 1995); and (2) an ongoing need for operational tools to assess the effects of forest management practices on forest health.

Most current assessments of forest condition are limited to ground-based visual evaluation (e.g., Canadian Forest Service 1999). While the benefits of these conventional field assessments are recognized, they do not reveal changes in physiology that characterize early stress responses. For it has been shown that physiological responses can indicate productivity and adaptability to environmental stress (Chapin 1991, Colombo and Parker 1999). Assessment of forest physiological condition may provide an early indication of decline in stand vigour and productive capacity. Early detection could help to identify stands requiring remedial or salvage action prior to the development of visible damage and, potentially, unrecoverable losses in biomass.

The Bioindicators Project does not intend to diagnose causal agent(s). For the present, we seek to develop a Forest Condition Rating (FCR) System to classify condition on a quantitative scale from healthy to stressed, relative to an acceptable range of values. This is consistent with the accepted definition of forest health where desirable ecosystem functions and process are sustained within a natural range of variability (Canadian For-

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