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A multi-resolution satellite imagery approach for large area mapping of ericaceous shrubs in Northern Quebec, Canada

Olivier R. van Lier [a], Richard A. Fournier [a,*], Robert L. Bradley [b], Nelson Thiffault [b,c]

[a] Centre d'Applications et de Recherche en Télédétection, Département de géomatique appliquée, Université de Sherbrooke, Sherbrooke, QC, Canada J1K 2R1
[b] Centre d'Étude de la Forêt, Département de biologie, Université de Sherbrooke, Sherbrooke, QC, Canada J1K 2R1
[c] Direction de la recherche forestière, Ministère des Ressources Naturelles et de la Faune du Québec, Québec, QC, Canada G1P 3W8

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ABSTRACT

Invasive ericaceous shrubs (e.g. *Kalmia angustifolia*, *Rhododendron groenlandicum*, *Vaccinium* spp.) may reduce the regeneration and early growth of black spruce (*Picea mariana*) seedlings, the most economically important boreal tree species in Quebec. Our study focused, therefore, on developing a method for mapping ericaceous shrubs from satellite images. The method integrates very high resolution satellite imagery (IKONOS) to guide classifiers applied to medium resolution satellite imagery (Landsat-TM). An object-oriented image classification approach was applied using Definiens eCognition software. An independent ground survey revealed 80% accuracy at the very high spatial resolution. We found that the partial use (70%) of classified polygons derived from the IKONOS images were an effective way to guide classification algorithms applied to the Landsat-TM imagery. The results of this latter classification (78.4% overall accuracy) were assessed by the remaining portion (30%) of unused very high resolution classified polygons. We further validated our method (65.5% overall accuracy) by assessing the correspondence of an ericaceous cover classification scheme done with a Landsat-TM image and results of our ground survey using an independent set of 275 sample plots. Discrimination of ericaceous shrub cover from other land cover types was achieved with precision at both spatial resolutions with producer accuracies of 87.7% and 79.4% from IKONOS and Landsat, respectively. The method is weaker for areas with sparse cover of ericaceous shrubs or dense tree cover. Our method is adapted, therefore, for mapping the spatial distribution of ericaceous shrubs and is compatible with existing forest stand maps.
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1. Introduction

Forests cover nearly half the total geographic area of Canada (402.1 m ha) and play a vital role in its socio-economic development. Forest management is predicated, therefore, on the sustainability of this resource for future generations. In north-eastern Canada, foresters are increasingly preoccupied by the growth check of black spruce (*Picea mariana* (Mill.) BSP) seedlings induced by ericaceous shrubs such as *Kalmia angustifolia* L., *Rhododendron groenlandicum* (Oeder) Kron & Judd, and *Vaccinium* spp. that can quickly invade sites following harvesting or wildfires. These shrubs interfere with black spruce growth through direct competition for resources (e.g. Thiffault et al., 2004) and by modifying soil properties such as pH, litter decomposition and nutrient mineralization rates (e.g. Joanisse et al., 2007). The transformation of productive forest stands into heaths poses a threat to the sustainability of Canada's forest sector; adequate monitoring tools must be developed to assess the magnitude of the problem. It is thus essential that we develop a method to map ericaceous swards, as this would give us an indication of conditions favoring their encroachment on disturbed forest sites.

Remote sensing technologies offer various options which are compatible to detection, mapping, and monitoring of invasive species (Wang, 1994; Joshi et al., 2004). Mapping the presence of ericaceous shrubs on regenerating forest sites has already been achieved with 96% overall accuracy through the interpretation of high resolution Compact Airborne Spectrographic Imager (CASI, 2.5 m spatial resolution) images (Franklin et al., 1994a). Likewise, Franklin et al. (1997) were able to distinguish three different classes of ericaceous shrub cover (low, moderate, and heavy) on disturbed sites with high accuracies (87–99%) using high spatial resolution imagery (CASI). The use of very high spatial resolution imagery is, however, costly and time-consuming for large-scale detection purposes. *K. angustifolia* can be detected with lower resolution images (i.e. Landsat-TM), but with a concomitant lower overall accuracy of 82% (Franklin et al., 1994b). The studies from Franklin et al. were limited to the detection of these shrubs at a local scale mapped on one image and confined to disturbed sites.

* Corresponding author. Tel.: +1 819 821 8000x63209; fax: +1 819 821 7944.
E-mail address: Richard.Fournier@USherbrooke.ca (R.A. Fournier).

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There is, therefore, a need to develop a method to detect the abundance of ericaceous shrubs for more diverse forest conditions and to expand the application to mapping ericaceous shrubs on a regional scale consistent with forest management planning.

We now face the interesting situation of selecting images from many alternative technologies varying in all spatial and spectral resolutions. Very high resolution aerial photographs continue to be the most used remotely sensed data in forestry, specially in evaluating natural resources for inventory and monitoring purposes (Howard, 1992). Sometimes, aerial photographs have been used to define *a posteriori* sample sites derived from an unsupervised classification's spectral clusters (Kindscher et al., 1998). Research has also shown the application of high resolution IKONOS satellite imageries in relevance to the extraction of forest stand information and mapping (Kayitakire et al., 2002). Katoh (2004) concluded that information on individual trees can be acquired by combining aerial photographs with IKONOS images. This same principle was applied to define the data used to train classifiers for the thematic classification of the IKONOS mosaic.

Object-oriented based image classification has sometimes been found to be superior in accuracy to traditional pixel-based classification approaches (Rego and Koch, 2003; Oruc et al., 2004), specifically for high resolution image analysis (Xiaoxia et al., 2004). If surface textures are complex, polygon-based multi-resolution segmentation can be beneficial for an initial delineation of different land cover types (e.g. Hess et al., 2003). The segmentation process is a bottom-up region-merging procedure which begins with single-pixel segments (Definiens, 2006). The multi-resolution segmentation allows for object creation at different scales, thus facilitating the thematic classification of larger objects (i.e. forested areas, disturbances, waterbodies, etc.…) to finer objects (i.e. ericaceous shrub dominated sites). The need for an ericaceous shrub mapping method which takes advantage of very high spatial resolution information applied at a super-regional level on high spatial resolution information is essential to further understand the spatial distribution of these species. The complexity of the species' distribution forces, however, the use of a classification method beyond the traditional classification techniques (i.e. pixel-based supervised maximum likelihood).

The aim of this study was to provide a method for mapping land cover with respect to ericaceous shrub densities at a regional scale which could be applied to larger eastern boreal regions of Canada. We integrated multi-resolution data for mapping large areas, which has proven to be beneficial. The mapping method was designed for two spatial resolutions: (1) very high spatial resolution (with pixel of ~3 m) for detailed maps at the local scale, and (2) medium spatial resolution (with pixel of ~30 m) for regional maps. In so doing, we developed a new procedure to use very high spatial resolution images to guide the thematic classification of a medium spatial resolution image. The method is compatible with procedures and datasets used in the existing forest inventory.

2. Materials and methods

2.1. Study area

The study area (19,178 km^2) is located on the North shore of the St. Lawrence River, 350 km northeast of Quebec City and 105 km north of the Town of Baie-Comeau, Quebec, Canada (Fig. 1). It is situated in the boreal shield ecozone (Lowe et al., 1994) comprising many lakes, rivers, peatlands and bogs in a rolling topography of pre-Cambrian Canadian Shield. Rock outbreaks occupy approximately 40% of the land area, especially present on vast tabular peaks, along major waterbodies and on steep slopes. A thin layer of glacial till material often covers moderate slopes and certain low rising hills, while thick till can be found in thalwegs and along easy sloped interfluves (Robitaille and Saucier, 1998). Fluvioglacial deposits occupy the larger valleys of the area (Robitaille and Saucier, 1998). The climate is classified as Subpolar Subhumid Continental (Robitaille and Saucier, 1998) and species diversity is much lower than in any temperate deciduous forests further south. The growing season is but 140 days and annual average temperatures range between −2.5 and 0.0 °C. Precipitation is abundant with an annual average of 1300 mm, of which 35–40% fall as snow. The major tree species are black spruce and balsam fir (*Abies balsamea* (L.) Mill.), with occasional white spruce (*Picea glauca* (Moench.) Voss), white birch (*Betula papyrifera* Marsh.), aspen (*Populus tremuloides* Michx.) and jack pine (*Pinus banksiana* Lamb.). The study area has been logged for a century and is subject to a natural fire disturbance cycle of 270 years (Bouchard et al., 2008). Ericaceous shrubs dominate many disturbed sites within the study area.

2.2. Image datasets

The multi-resolution image dataset for this project is composed of 152 aerial photographs, seven adjacent IKONOS images and one

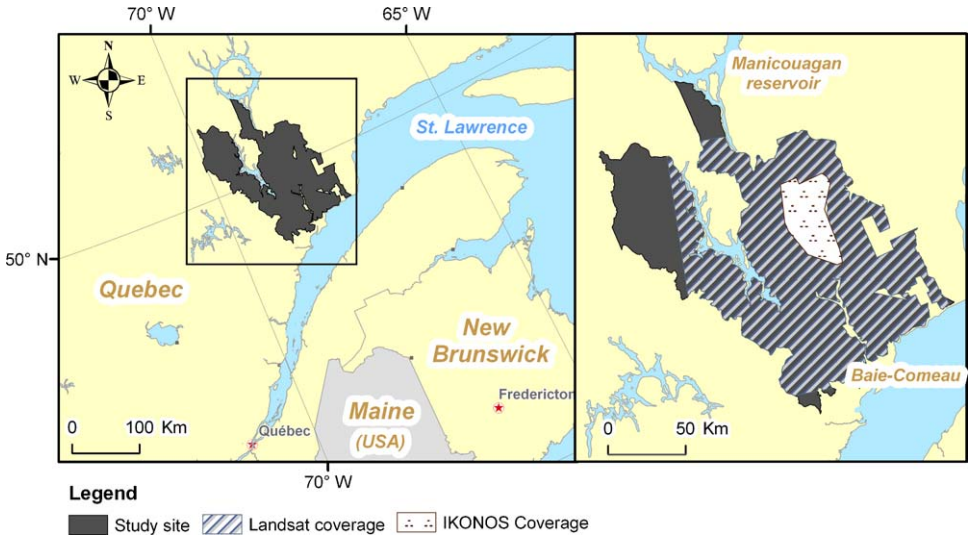

Fig. 1. Study site and spatial coverage of data.

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