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Seasonal reflectance dynamics of common understory types in a northern European boreal forest

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ABSTRACT

The influence of the seasonal cycle of boreal forest understory has been noticed in global remote sensing of vegetation, especially in remote sensing of biophysical properties (e.g. leaf area index) of the tree-layer in a forest. A general problem in the validation of operationally produced global biophysical vegetation products is the lack of ground reference data on the seasonal variability of different land surface types. Currently, little is known about the spectral properties of the understory layers of boreal forests, and even less is known about the seasonal dynamics of the spectra. In this paper, we report seasonal trajectories of understory reflectance spectra measured in a European boreal forest. Four study sites representing different forest fertility site types were selected from central Finland. The understory composition was recorded and its spectra measured with an ASD FieldSpec Hand-Held UV/VNIR Spectroradiometer ten times during the growing period (from May to September) in 2010. Our results show that the spectral differences between and within understory types are the largest at the peak of the growing season in early July whereas in the beginning and end of the growing season (i.e. early May and late September, respectively) the differences between the understory types are marginal. In general, the fertile sites had the brightest NIR spectra throughout the growing season whereas infertile types appeared darker in NIR. Our results also indicated that a mismatch in the seasonal development of understory and tree layers does not occur in boreal forests: the understory and tree layer vegetation develop at a similar pace in the spring (i.e. there are no or only few spring ephemerals present), and the forests with the strongest seasonal dynamics in tree canopy structure (LAI) have also the strongest dynamics in understory spectra.

1. Introduction

The understory of a boreal forest undergoes versatile changes during its snow-free growing period. In the spring, deciduous dwarf shrubs grow leaves, grasses and pteridophytes emerge from the ground and gradually cover the mosses, lichens and litter from previous years. When senescence occurs a couple of months later, dead plant organs once again cover the forest floor. The strength of the cycle depends on site fertility—by human eye, the strongest cycles are typically observed in fertile grass-dominated sites and the smallest seasonal changes in nutrient-poor, lichen-dominated sites.

The influence of the seasonal cycle of boreal forest understory has been noticed in global remote sensing of vegetation, especially in remote sensing of biophysical properties (e.g. leaf area index (LAI)) of the tree-layer in a forest. A recent intercomparison showed that a general problem in the validation of global LAI products is the lack of ground reference data on the seasonal variability of different land surface types (Garrigues et al., 2008). Furthermore, based on an analysis of multiple year MODIS data, Ganguly et al. (2010) reported that high latitude ecosystems require further investigations in the interpretation of satellite image based phenology products, especially to determine the end of the growing season.

A reason for the uncertainties in determining seasonal metrics from satellite data is that the seasonal reflectance course of a boreal forest is a result of the temporal reflectance cycles of both the tree canopy and the understory layers (e.g. Rautiainen et al., 2009). In other words, interpreting any properties of a boreal tree canopy layer from satellite data is complicated by the presence of a varying understory layer (Chen & Cihlar, 1996; Eriksson et al., 2006; Rautiainen et al., 2007). As a solution to the problem, attempts have been made to retrieve boreal forest understory reflectance directly from remote sensing data: Canisius and Chen (2007) and Pisek et al. (2010) have developed algorithms for extracting spectral properties

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of understory from multi-angular remote sensing data. However, the lack of field measurements on understory spectra (and their seasonality) restricts the validation of the retrieved estimates.

Peltoniemi et al. (2005) initiated building a spectral library of common boreal understory species. They also documented that measuring properties of single understory species is not necessarily well justified—instead they measured naturally occurring communities consisting of both the upper understory and ground layers (i.e. dwarf shrub and moss layers). The next step in creating a boreal spectral library would be attaching the spectral data to a detailed (and preferably quantified) description of the vegetation. Several attempts have been made to couple understory or ground vegetation structural and optical properties. For example, Schaepman-Strub et al. (2009) studied species similar to the ones occurring in the boreal zone and successfully linked spectral data to fractional covers of major plant functional types. Hallik et al. (2009), on the other hand, attempted to identify other descriptors (e.g. water content, chlorophyll content, dry biomass) of boreal understory vegetation that could be used to predict its optical properties. In a more theoretical study, Kuusk et al. (2004) used a two-layer canopy reflectance model to estimate understory properties from spectral measurements, and observed that the sensitivity of simulated understory spectra to variations in leaf biochemistry parameters was rather weak in hemiboreal forests. Thus, they suggested that the association of understory reflectance properties with specific stand or site type should be further investigated.

If little is known about the spectral properties of the understory layers of boreal forests, even less is known about the seasonal dynamics of the spectra. Based on a multispectral analysis, Miller et al. (1997) reported that differences in understory reflectance between different site types in Canadian boreal forests become more pronounced as the growing season proceeds. Furthermore, they showed that including the information on understory significantly improved estimates of overstory leaf area index from multispectral satellite data. Applying data measured in northern Finland, Shibayama et al. (1999) concluded that in the detection of phenophases of subarctic plant species, vegetation indices (e.g. NDVI) should be used instead of single band reflectance factors to improve the accuracy in estimation of phenological turning point dates.

In this paper, we report the seasonal dynamics of understory reflectance spectra for North European boreal forests. We discuss the spectral differences between common understory types and their seasonal development using field data collected in central Finland in 2010.

2. Materials and methods

2.1. Study site and sampling design

Our study site, Hyytiälä, is located in central Finland (61° 50′N, 24° 17′E) and belongs to the southern boreal zone. Dominant tree species are Norway spruce (*Picea abies* (L.) Karst), Scots pine (*Pinus sylvestris* L.) and birches (*Betula pubescens* Ehrh, *Betula pendula* Roth). The growing season typically begins in early May and senescence in late August. In 2010, snow melted during the last week of April (i.e. approximately a week before our measurements commenced).

Four study sites representing different forest fertility site types were chosen from the proximity of the Hyytiälä forest field station (Table 1, Table 2, Fig. 1): 1) a xeric heath forest understory dominated by lichens and heather, 2) a sub-xeric heath forest understory dominated by mosses and dwarf shrubs, 3) a mesic heath forest understory dominated by mosses and abundant dwarf shrubs, and 4) a herb-rich heath forest understory dominated by herbaceous species and graminoids. Peatlands and their understory types are excluded from this study.

At each study site, a 28-m long permanent transect was marked with sticks. In addition, four intensive study plots (1-m × 1-m) were marked next to the transect at eight-m intervals. All transects ran either from southeast to northwest (sub-xeric site) or from southwest to northeast (herb-rich, mesic and xeric sites); the specific location of each transect was chosen so that it would minimize all topographical features and trees which could result in shadow-casting during spectral measurements, and that there would be no human or animal paths on the transect.

Our field campaign started on 4 May 2010 (day of year, DOY 124) and ended on 22 September 2010 (DOY 265). During the field campaign, the fractional cover of understory was estimated and understory spectra for each study site were estimated ten times i.e. every 2 to 3 weeks. In addition, to provide information on the tree canopy layer, the effective leaf area index (LAI) of the tree layer for the study sites was measured at approximately the same time intervals using the LAI-2000 Plant Canopy Analyzer (Li-Cor Inc.).

2.2. Estimates of fractional cover

We monitored the changes in the composition of the understory of our study sites by recording the fractional cover of each plant functional type (PFT) group throughout the growing season. The estimation of fractional cover was chosen as the most feasible method for detecting the changes because destructive sampling (e.g. biomass or leaf area index analysis) was not possible (i.e. the same plots were continuously measured and the natural phenological cycle of the community could not be disturbed). On the other hand, common indirect measurement techniques for leaf area index (e.g. LAI-2000 Plant Canopy Analyzer or hemispherical digital photography) were also not possible due to the tight structure of the understory and the presence of mosses.

The understory layer in a well-drained boreal forest in Finland is composed of two layers: the upper understory layer and the ground layer. Typically the most abundant PFT in the upper understory layer

Table 1
Species composition of the ground and upper understory layers of the study sites.

Study site	Upper understory layer			Ground layer	
	Dwarf shrubs	Pteridophytes + herbaceous	Graminoids	Mosses	Lichens
Xeric heath forest	*Vaccinium vitis-idaea, Calluna vulgaris, Empetrum nigrum*			*Pleurozium schreberi, Dicranum* spp.	*Cladina arbuscula, Cladina rangiferina*
Sub-xeric heath forest	*Vaccinium myrtillus, Vaccinium vitis-idaea*	*Luzula pilosa, Maianthenum bifolium, Oxalis acetosella, Trientalis europaea, Dryopteris carthusiana*	*Deschampsia flexuosa*	*Pleurozium schreberi, Dicranum* spp.	
Mesic heath forest	*Vaccinium myrtillus, Vaccinium vitis-idaea, Linnea borealis*	*Luzula pilosa, Maianthenum bifolium, Epilobium angustifolium, Dryopteris carthusiana*	*Deschampsia flexuosa*	*Pleurozium schreberi, Dicranum* spp. *Hylocomium splendens*	
Herb-rich heath forest	*Vaccinium myrtillus, Vaccinium vitis-idaea*	*Trientalis europaea, Maianthenum bifolium, Rubus saxatilis, Dryopteris expansa, Melampyrum sylvaticum, Oxalis acetosella*	*Deschampsia flexuosa, Calamagrostis* spp.	*Pleurozium schreberi*	