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Spectral reflectance patterns and seasonal dynamics of common understory types in three mature hemi-boreal forests

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ABSTRACT

Due to the growing demand on more accurate prediction of biophysical properties (e.g., leaf area index) or carbon balance models based on remotely sensed data, the understory effect needs to be separated from the overstory. Reflectance models can provide possibility to model and retrieve understory reflectance over large scales, but ground truth data is needed to validate such models and algorithms. In this study, we documented the seasonal variation (April–September) and spectral changes occurring in understory layers of a typical European hemi-boreal forest. The understory composition was recorded and its spectra measured with an ASD FieldSpec Hand-Held UV/VNIR Spectroradiometer eight times at four site types during the growing period (from May to September) in 2013. The collected dataset presented within this study would be of much use to improve and validate algorithms or models for extracting spectral properties of understory from remote sensing data. It can be also further used as a valuable input in radiative transfer simulations that are used to quantify the roles of forest tree layer and understory components in forming a seasonal reflectance course of a hemi-boreal forest, and the upcoming phases of the RAdiation Model Intercomparison (RAMI) experiment.

Introduction

The understory is like a miniature forest. Similarly to forest tree layer or canopy, the understory (also called forest floor or background) goes through versatile changes during the vegetation period (Rautiainen et al., 2011). When compared to tree layer it is more compact, but structurally more complex due to large species variation (Peltoniemi et al., 2005). Similarly to forest tree layer, the scattering properties of understory are determined by leaves, their orientation, and spatial distribution. The underlying soil, litter layer, and topography also affect the scattering properties of understory (Kuusk, 2001). Due to vast variety of species the reflectance factor is formed by each individual component within a certain understory community (Nilson et al., 2012).

The properties of understory vegetation are also determined by the properties of a tree layer. For example, the solar radiation transmitted to the forest floor is one of the factors which determine the understory vegetation (Nilson and Peterson, 1994). That means changes in canopy closure or tree layer leaf area index (LAI) will lead to a change in the species composition, green LAI, roughness characteristics of ground vegetation, and consequently the reflectance (e.g., Waring et al., 1998; Rautiainen and Heiskanen, 2013). Understory vegetation is thus not entirely independent from the tree canopy (Hallik et al., 2009).

The tree layer influences the understory, but the forest floor contributes to the total stand reflectance considerably as well (Eriksson et al., 2006; Rautiainen and Stenberg, 2005). Modelling studies have shown that background optical properties become essential in predicting total stand reflectance especially at low values of upper canopy cover (Nilson and Peterson, 1994; Hanan, 2001; Rautiainen, 2005). It has been also previously highlighted that the understory effect has to be removed from the forest reflectance for more reliable estimation of biophysical properties of the tree layer (e.g., Eriksson et al., 2006; Garrigues et al., 2008; Rautiainen and Heiskanen, 2013).

Due to the fact that ground measurements are time-consuming, there have been recent attempts to retrieve boreal forest understory reflectance directly from remote sensing data (e.g., Pisek et al., 2010, 2012). However, the understory reflectance retrieval algorithms still need to be further validated with in situ measurements. Only relatively few efforts had been previously undertaken to collect various understory components and/or creating limited spectral databases (e.g., Goward et al., 1994; Miller et al., 1997; Lang et al., 2002; Rees et al., 2004; Peltoniemi et al., 2005; Rautiainen

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et al., 2007; Hallik et al., 2009). The most recent study was conducted by Rautiainen et al. (2011) who tracked a wide range of seasonal dynamics and temporal patterns of different understory types in a southern boreal forest. Their results confirmed that indeed the understory signal cannot be ignored due to its spatial and temporal variation.

The main objective of this paper was to track out temporal reflectance courses of common hemi-boreal understory types in three forest stands with different overstory species in Järvselja, Estonia, in 2013. Importantly, we highlight how similar or different might be the seasonal dynamics in understory composition and reflectance spectra for stands with similar overstory in the neighboring hemi-boreal and boreal zones.

Materials and methods

Study site

The study site is located in South-East Estonia (58.3°N, 27.3°E) at the Järvselja Training and Experimental Forestry District. Järvselja forests are typical for the hemi-boreal zone. Dominant tree species are Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) Karst), and birches (*Betula pendula* Roth, *Betula pubescens*) (Kuusk et al., 2009a,b). Three sites representing different forest fertility types were selected (Table 1). In this study, to maintain the comparability with Rautiainen et al. (2011), we use the Cajander (1930) forest site type classification. The RAMI (Radiation Model Intercomparison; Widlowski et al., 2007) birch stand can be described as an herb-rich forest, dominated by the herbaceous species and graminoids; moss layer is sparse or missing. The RAMI pine stand grows on a transitional bog. The understory vegetation is composed of sparse labrador tea (*Ledum palustre*), cotton grass (*Eriophorum vaginatum*), and a continuous Sphagnum ssp. moss layer. The sampling area in the additional spruce stand consists of two parts with different conditions for understory growth: a sub-xeric section where the understory vegetation is virtually missing, and a mesic part dominated by mosses and dwarf shrubs. More details about the stand parameters for the tree-layer vegetation can be found in Kuusk et al. (2010).

A 100 m long permanent transect was set up at each test site. All transects ran across the stands from northwest to southeast. In addition, four intensive study plots (1 m × 1 m) were marked next to the transects at 20 m intervals. The field campaign started on 9 May (day of year, DOY 128) and ended on 29 September 2013 (DOY 272). The fractional cover of understory and understory spectra were estimated every 2–3 weeks.

Estimates of fractional cover

Digital camera (Pentax K100D) was used to photograph the four 1 m × 1 m intensive study plots at each site to estimate fractional coverage. Plant functional types (PFT) were estimated from the photos throughout the growing season. This was the only feasible method for detecting the changes in coverage – destructive sampling (e.g., biomass or leaf area index analysis) was not possible as the plots were continuously measured and the natural phenology could not be disturbed.

A 10 × 10 cm grid was laid on top of each image and examined visually to estimate the vertically projected fractional cover for each PFT every 2–3 weeks corresponding to the dates of spectroscopy measurements. Fractional cover measurements were all made by the same person for the overall consistency. An arithmetical mean of four plots was calculated for the PFT coverage determination. Plot-specific values were used to relate the cover data to spectral data. In addition to the stand parameters, all herbaceous species in the intensive study plots were also identified to provide an extensive overview of the stands (Table 2).

Measurements of understory spectra

The vegetation growing period usually lasts 175–180 days in Estonia, from mid-April to October (Hallik et al., 2009). In 2013, the vegetation period started abruptly in April when the monthly average temperature reached 4 °C (Estonian Environment Agency, 2014). The growing period was then already under way when the first measurements were taken (9 May).

The understory spectra were measured under diffuse light conditions with fiber input supplied FieldSpec-Pro VNIR spectrometer by Analytical Spectral Devices (ASD), Inc., covering 350–1050 nm region. The sampling interval was 1.4 nm with the resolution 3 nm at full width half maximum (FWHM) at 700 nm. The instrument was controlled by a laptop carried by the instrument operator. Sufficient warm-up time (approximately 30 min) was allowed for the spectrometer, regular dark current measurements were taken and the white reference panel was kept clean to achieve the best results.

All measurements were taken when the sun was completely blocked by the clouds or direct solar radiance was totally attenuated by the long path length in tree crown layer at low solar elevation near sunset. Diffuse irradiation conditions are needed for two reasons: to eliminate the effect of incidence angle on the measured reflectance signal and to reduce spatial variation in the incident radiation field. In addition the high anisotropy of vegetation scattering was also reduced by using diffuse light conditions (Rautiainen et al., 2011).

The downward-pointed spectroradiometer was held by the outstretched hand of the operator. Due to the fact that the instrument has a 25° field of view the area sampled during each spectral measurement corresponded approximately to a circle with a diameter of 50 cm. No fore-optics was used. The understory spectra was measured every 2 m along transect, resulting in 50 measurements per transect. Three spectra above a 10-inch Spectralon SRT-99–100 white panel were recorded at the beginning and end of each transect and also along it after every four understory spectra measurement points (every 8 m). Regarding the four intensive study plots, each 1 m × 1 m square was divided into quarters (area 0.25 m^2) and the spectrum of each quarter was measured separately. The white reference panel was measured three times before and after the understory measurements to obtain the incident spectra measurements.

Table 1
A general description of tree-layer vegetation of the study sites.

Study site	Dominant tree species	Mean tree height, m	Mean breast height diameter, cm	Effective leaf area index
Herb-rich	*B. pendula* Roth	22(5.5)	18(6.2)	2.9(0.35)/0.8[a]
Transitional bog	*P. sylvestris* L.	16(1.5)	18(4.4)	1.8(0.15)
Sub-xeric/mesic	*P. abies* (L.) Karst/ *B. pendula* Roth	19(5.2)	17(7.3)	3.8(0.62)

In brackets is the standard deviation of a measure.

[a] LAI_{eff}(July)/LAI_{eff}(November).