Available online at www.sciencedirect.com

SciVerse ScienceDirect

Polar Science 7 (2013) 125–135

http://ees.elsevier.com/polar/

Seasonal changes in camera-based indices from an open canopy black spruce forest in Alaska, and comparison with indices from a closed canopy evergreen coniferous forest in Japan

Shin Nagai [a,*], Taro Nakai [b], Taku M. Saitoh [c], Robert C. Busey [b], Hideki Kobayashi [a], Rikie Suzuki [a], Hiroyuki Muraoka [c], Yongwon Kim [b]

[a] *Research Institute for Global Change, Japan Agency for Marine-Earth Science and Technology, 3173-25 Showa-machi, Kanazawa-ku, Yokohama 236-0001, Japan*

[b] *International Arctic Research Center, University of Alaska Fairbanks, 930 Koyukuk Drive, Fairbanks, AK 99775-7340, USA*

[c] *River Basin Research Center, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan*

Received 29 June 2012; revised 2 November 2012; accepted 5 December 2012
Available online 20 December 2012

Abstract

Evaluation of the carbon, water, and energy balances in evergreen coniferous forests requires accurate in situ and satellite data regarding their spatio-temporal dynamics. Daily digital camera images can be used to determine the relationships among phenology, gross primary productivity (GPP), and meteorological parameters, and to ground-truth satellite observations. In this study, we examine the relationship between seasonal variations in camera-based canopy surface indices and eddy-covariance-based GPP derived from field studies in an Alaskan open canopy black spruce forest and in a Japanese closed canopy cedar forest. The ratio of the green digital number to the total digital number, hue, and GPP showed a bell-shaped seasonal profile at both sites. Canopy surface images for the black spruce forest and cedar forest mainly detected seasonal changes in vegetation on the floor of the forest and in the tree canopy, respectively. In contrast, the seasonal cycles of the ratios of the red and blue digital numbers to the total digital numbers differed between the two sites, possibly due to differences in forest structure and leaf color. These results suggest that forest structural characteristics, such as canopy openness and seasonal forest-floor changes, should be considered during continuous observations of phenology in evergreen coniferous forests.

Keywords: Evergreen coniferous forest; Gross primary productivity; Phenology; Red; Green; Blue

1. Introduction

Comprehensive, long-term, and continuous in situ and satellite observations are required to accurately evaluate the spatio-temporal characteristics of terrestrial ecosystem structure and function, and this has become a particularly important task within the modern context of global climate change (Muraoka et al., 2012).

* Corresponding author. Tel.: +81 45 778 5594; fax: +81 45 778 5706.

E-mail addresses: nagais@jamstec.go.jp (S. Nagai), tnakai@iarc.uaf.edu (T. Nakai), taku@green.gifu-u.ac.jp (T.M. Saitoh), rcbusey@alaska.edu (R.C. Busey), hkoba@jamstec.go.jp (H. Kobayashi), rikie@jamstec.go.jp (R. Suzuki), muraoka@green.gifu-u.ac.jp (H. Muraoka), kimyw@iarc.uaf.edu (Y. Kim).

1873-9652/$ - see front matter
http://dx.doi.org/10.1016/j.polar.2012.12.001

Previous in situ and satellite observations indicate that the timing of leaf expansion has advanced in Europe (Menzel et al., 2006) and boreal Eurasia (Delbart et al., 2008). These studies mainly targeted deciduous vegetation, as this exhibits clear phenological changes such as leaf expansion, color development, and leaf fall. However, evergreen coniferous forests show more subtle phenological changes. Detecting these changes is important because these forests are found throughout the world's cool-temperate and boreal regions, where carbon, water, and energy balances are expected to be strongly influenced by global warming (DeFries and Townshend, 1994; Kawamiya et al., 2012).

Previous studies indicate that seasonal variations in gross primary productivity (GPP) in evergreen coniferous forests follow a bell-shaped curve (increasing in spring and decreasing in autumn) in response to seasonal variations in temperature and photosynthetically active radiation (PAR) (Saitoh et al., 2010; Thomas et al., 2009). In addition, the color of the canopy surface changes in accordance with seasonal variations in the photosynthetic pigments in leaves, even when the plant area index (PAI) remains constant throughout the year, as is the case in many coniferous forests (Han et al., 2003; Hughes, 2011; Nagai et al., 2012; Saitoh et al., 2010). These studies suggest that long-term continuous phenological observations of evergreen coniferous forests, from plot to global scales, are required if we are to accurately evaluate the carbon, water, and energy balances of these forests, because seasonal and interannual variations of phenology have a critical effect on these systems (Richardson et al., 2010).

Recent studies indicate that daily images obtained using digital cameras can be used to evaluate the relationships among seasonal changes of vegetation, GPP, and meteorological parameters throughout the year (Ahrends et al., 2009; Richardson et al., 2009; Saitoh et al., 2012b). Digital cameras are relatively inexpensive to operate, and have small labor requirements, allowing the detection of subtle seasonal changes at a higher frequency than is possible with satellite observations, which are often influenced by cloud and aerosol contamination (Saitoh et al., 2012b; Sonnentag et al., 2012; Zhao et al., 2012). Such cameras have also been used to ground-truth satellite observations (Graham et al., 2010; Hufkens et al., 2012; Ide and Oguma, 2010; Nagai et al., 2010, 2012), and Saitoh et al. (2012b) evaluated the temporal and spatial distribution of potential photosynthetic capacity from the relationship between seasonal variations in camera-based indices and GPP on sunny days.

In previous studies, seasonal variations in the digital number of red, green, and blue (RGB) values have been used as a camera-based index that can be extracted from digital camera images. These indices were examined in spruce (*Picea* spp.) and pine (*Pinus* spp.) forests in North America (Bater et al., 2011; Richardson et al., 2009; Sonnentag et al., 2012), and in a cedar (*Cryptomeria japonica*) forest in Japan (Saitoh et al., 2012b). However, these studies were somewhat restricted by the following factors:

(1) the relationship between GPP and the camera-based index was not described (Bater et al., 2011; Sonnentag et al., 2012);
(2) the target site was a single evergreen coniferous forest (Richardson et al., 2009; Saitoh et al., 2012b); and
(3) multiple camera-based indices were not investigated (Bater et al., 2011).

To obtain data regarding the general or specific characteristics of phenology in evergreen coniferous forests, and to apply these data at regional to global scales, it is necessary to examine the relationships among daily canopy surface images, GPP, and meteorological parameters at multiple sites, where different forest structural characteristics and climate conditions occur, and where these differences affect the results.

In this study, we examine the relationship between seasonal variations in camera-based indices extracted from daily canopy surface images (obtained with digital cameras), and eddy-covariance-based GPP derived from field studies in an open canopy black spruce (*Picea mariana*) forest in Alaska and in a closed canopy cedar forest in Japan. Our aim is to ground-truth the diagnostic attributes of the ecological characteristics that can be detected in canopy surface images from evergreen coniferous forests with different forest structural characteristics.

2. Materials and methods

2.1. Study sites and observation period

The study sites were located in a boreal evergreen coniferous forest (65°07′24.10″N, 147°29′14.80″W, 250 m a.s.l.) in the Poker Flat Research Range, Alaska, USA, and in a cool–temperate evergreen coniferous forest (36°08′23.00″N, 137°22′15.00″E, 800 m a.s.l.) in Takayama, Japan. Carbon dioxide fluxes and concentrations, as well as micrometeorological parameters, have been monitored continuously at these sites since 2010 and 2005, respectively (Saitoh et al., 2010; Sugiura et al., 2011). Table 1 summarizes the