CHARACTERISTICS OF VEGETATION INDICES FROM VISIBLE IMAGES FOR GROUND-BASED PHENOLOGY OBSERVATION

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ABSTRACT: Ground-based phenology observations using digital cameras are being carried out to understand the effects of abnormal weather and climate variability on vegetation. When using commercial digital cameras in phenology observations, camera settings such as white balance and the difference of camera models and illumination conditions influence the RGB digital numbers of the images. Vegetation indices used in phenology observations that are calculated from digital numbers of images, must also be put in issue. In this study, the effectiveness of 4 vegetation indices calculated from color-corrected visual images for detecting the change of leaves and flowers was investigated by comparing under different weather conditions and within the change of season. The influence of bi-directional reflectance could be reduced by using images that were taken when the direction of the sun was around 90° to the direction of the field of view of camera. Also, it is possible to detect the timing of the phenological events by using the vegetation indices, but the influence of weather remains as a problem.

1. INTRODUCTION

The timings of leaf appearance, autumn senescence, and flowering are different and shifting year by year. These phenomena are occurring because of abnormal weather in short term and climate variability in long term due to global warming [Ono et al., 2015].

The impacts of abnormal weather and climate variability on vegetation cause various problems. Examples for these are the difference of timing of events across species such as food chains and pollination [Kudo et al., 2004; Doi et al., 2008], the change of leaf appearance and autumn senescence that leads to change of turbulent exchange of water and energy [Moore et al., 1996; Sakai et al., 1997, Richardson et al., 2007], and the lengthening of growing season that leads to change of primary productivity, photosynthesis, carbon balance, and CO_2 concentration [Ide and Oguma, 2010]. To understand such impacts on vegetation, it is important to observe changes of leaves and flowers, so called phenology, day-by-day and continuously.

Phenology observations are being conducted in many countries and regions [Morris et at., 2013]. Observations of plants should be conducted in individual species and plant scale, and should be done every day, because timings of changes differ among individual plants and species, and change of color occurs in short term. Therefore, ground-based observation would be suitable. Traditional field observations have been conducted for over a century by individuals or groups of people. For example, Japan Meteorological Agency (JMA) has been observing for many years to know the overall aspect of weather. They observe index trees of more than 10 species at 102 places. Field observations can be done in detail, but it is labor intensive, subjective, and can only be done in places where people can access [Sonnentag et al., 2012].

On the other hand, observations using digital camera can solve these problems. The date of leaf appearance, autumn senescence, and flowering is detected by vegetation indices based on digital numbers of visual images derived from digital cameras mounted on towers. This observation method can be done objectively and large amounts of data can be analyzed quantitatively, and observation networks have also been constructed such as Phenological Eyes Network (PEN) [Nagai et al., 2016] and PhenoCam Network [https://phenocam.sr.unh.edu/webcam/]. However, some problems remain about observations using digital cameras and analyzing visual images. The previous studies point out that effects on the image taken at different weather and sunlight condition [Sonnentag et al., 2012; Zhao et al., 2012]. Also, only one index that shows greenness is used, so it is difficult to discriminate the changes of various colors for individual trees. There are also few studies that use and compare more than one index. Therefore, the vegetation index that should be useful in each kind of plant or its situation seems to be unclear.

The purpose of this study is to explore the effectiveness of vegetation indices for detecting the timing of change of leaves and flowers by visual image analysis. In this paper, we report the progress results of examinations about the effects of scene illumination on vegetation indices, and how vegetation indices respond to the changes of colors of leaves and flowers.

2. METHODOLOGY

2.1 Study site

The site is located at Tokyo University of Agriculture and Technology in Tokyo, Japan (35°39.94'N 139°28.37'E). The annual mean temperature is 15.0°C with an average annual precipitation of 1529.7 mm. There are usually two rainy seasons in June and September. The trees in the site are mostly deciduous broad-leaved trees and evergreen broad-leaved trees with exceptions of a few coniferous trees.

2.2 Observation

To observe the color of the leaves and flowers on trees, we used a single-lens reflex camera. The camera was installed on the roof of a four-story building with the angle of depression at 30° and the middle of the direction of the field of view at 70°. We put a grayscale board, which has about 44% reflectance, in the field of view of camera to correct the color and the brightness on images effected by different sunlight conditions. The camera has been taking photographs every 10 minutes during daytime from April 6, 2017 to present. The used camera and settings are shown in Table 1. Fig. 1 shows the view of our observation system.

Table 1 Used camera and settings

Camera model	NIKON D5100
Exposure	F/5
Shutter speed	auto
White balance	auto
File format	JPEG Fine

Figure 1. Observation system

2.3 Image pre-processing

The colors and brightness of the images are often affected by the weather, sunlight, and setting of white balance, so we corrected them using the grayscale board as pre-processing. We extracted R, G, and B digital numbers of the grayscale board and derived linear functions of RGB for each image. RGB linear functions were then applied to each image, and the corrected images were generated.

2.4 Vegetation indices

We used four vegetation indices of *2G_RBi* (Richardson *et al.*, 2007), *2rG_rRBi* (Ide and Oguma, 2010), VI_{green} (Gitelson *et al.*, 2002), and ΔNGB (Ono *et al.*, 2015) in this study. The equations and explanations are shown as follows.

2G_RBi **:** This index shown in eq.1 expresses the greenness of objects and is also called as *Excess Green Index*. *2G_RBi* is calculated by the sum of the difference in green and red and the difference in green and blue channels, so that the value of index is shown in digital number. It is widely used in phenological observations.

$$2G\_RB\mathrm{i} = (G - R) + (G - B) \tag{1}$$

Where: *G*; digital number of Green channel, *R*; digital number of Red channel, and *B*; digital number of Blue channel.

2rG_rRBi : This was modified for *2G_RBi* to reduce the effect of sunlight illumination under different weather conditions. It uses normalized RGB values instead of “raw” digital numbers (eq.2).

$$2rG\_rRBi = (rG - rR) + (rG - rB)$$
$$rR = \frac{R}{R+G+B} \ , \ rG = \frac{G}{R+G+B} \ , rB = \frac{B}{R+G+B} \tag{2}$$

VI_{green}: This index is also normalized by dividing the difference of green and red by the sum of both (eq.3). The index value can be shown from -1 to 1. The positive value closer to 1 shows greenness and the negative value closer to -1 shows redness. The value closer to 0 shows yellow.

$$VI_{green} = \frac{G - R}{G + R} \tag{3}$$

ΔNGB: This index was also developed to reduce the effect of solar radiation by using the normalized green and blue channels divided by the average of 3 channels, and expresses the greenness of objects.

$$\Delta NGB = -\frac{NG - 1}{NB - 1}$$
$$NG = \frac{G}{A_m RGB}, \; NB = \frac{B}{A_m RGB}, \; A_m RGB = \frac{B+G+R}{3} \tag{4}$$

According to these equations, it seems that we can use *2G_RBi*, *2rG_rRBi*, and Δ*NGB* to describe the greenness of the color of leaves, while VI_{green} is used to describe autumn senescence.

3. RESULTS AND DISCUSSION

Since we could not take images from April 9 to April 28 because of system problems, we used images taken from April 29 to September 11. As for precipitation in this season, there was not much rain during the rainy season in June, but had much rain in August.

To reduce the effect of bi-directional reflection, here, we only selected 13 images that were taken within 1 hour before and after the time when the sun azimuth was 160°, because the center direction of FOV is 70°. These selected images were usually taken from around 10:30 to 12:30. The main trees that can be seen in the images are shown in Fig. 2. There are 8 species shown in Table 2. In this paper, we focus on 4 deciduous trees shown by red line in fig.2, and discuss the results of our analysis. These 4 trees generally have the following seasonal changes;

Z. serrata has green leaves that turn yellow, then red in autumn senescence.
G. biloba has green leaves that turn yellow in autumn senescence.
A. x carnea has green leaves that turn yellow, then red in autumn senescence and red flowers in spring,
B. florida has yellow green leaves that turn red in autumn senescence and white flowers in spring.

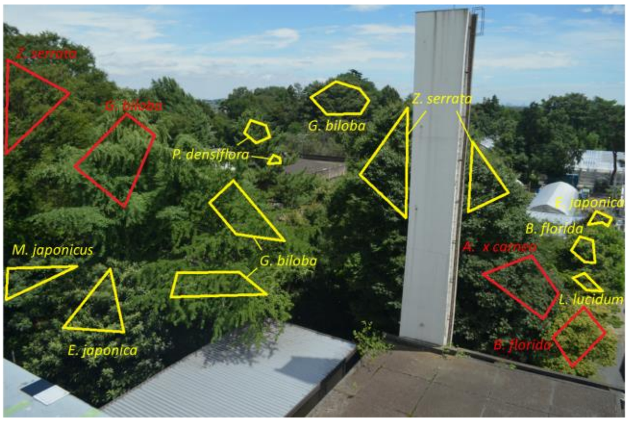

Figure 2. ROI (region of interest) of the target trees

Table 2. Species of trees in image

Species	
Zelkova serrata (Thunb.) Makino	deciduous broadleaf
Ginkgo biloba L.	deciduous broadleaf
Eriobotrya japonica (Thunb.) Lindl.	evergreen broadleaf
Mallotus japonicus (Thunb.) Muell. Arg.	deciduous broadleaf
Aesculus x carnea	deciduous broadleaf
Benthamidia florida (L.) Spach	deciduous broadleaf
Pinus densiflora Sieb. et Zucc.	evergreen conifer
Ligustrum lucidum	evergreen broadleaf

3.1 Effect of weather and sunlight

To investigate the effect of weather and sunlight on values of the vegetation indices, we compared the differences of the values of each vegetation index between clear sky, sunny, and cloudy days. We chose dates that were not in flowering, leaf appearance, or autumn senescence season, and that were close to each other. We selected the dates of July 21 for clear sky, July 27 for cloudy, and July 28 for sunny.

The differences of the vegetation indices for *Z. serrata* is shown as an example in Fig. 3 and the average with standard deviation of each vegetation index are shown in Fig. 4. The value of *2rG_rRBi* slightly increases under clear sky. It is pointed that *2G_RBi* is influenced by sunlight condition (Ide and Oguma, 2010), so it seems that this was because the direction of sunlight became closer to camera direction, which was direct-light condition in photograph. However, there was not much difference between the average values under different weather conditions (Fig.4). Most of the standard deviation was largest in clear weather. The reason seems that much leaves illuminated by direct sunlight and shadows are mixed under clear sky. Overall, there was not much difference of the average values under clear sky, sunny, and cloudy conditions, so we decided that it would not be a problem to use the selected 13 images per day as the daily averaged data under all weather conditions.

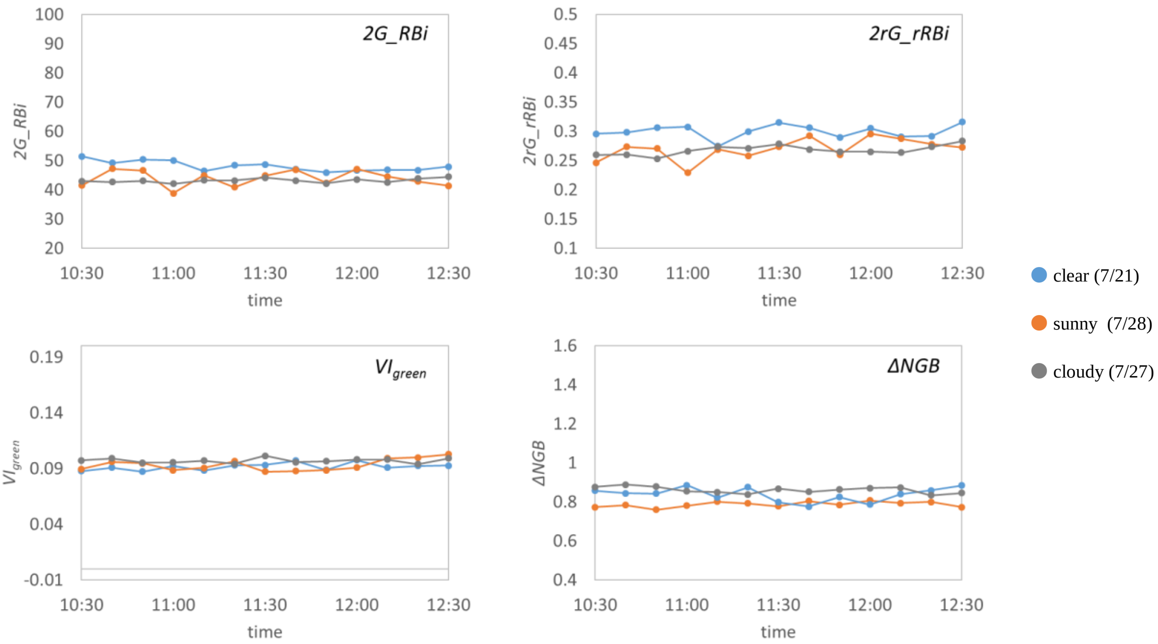

Figure 3. The differences of vegetation indices for *Z. serrata* under clear, partly cloudy, and cloudy conditions

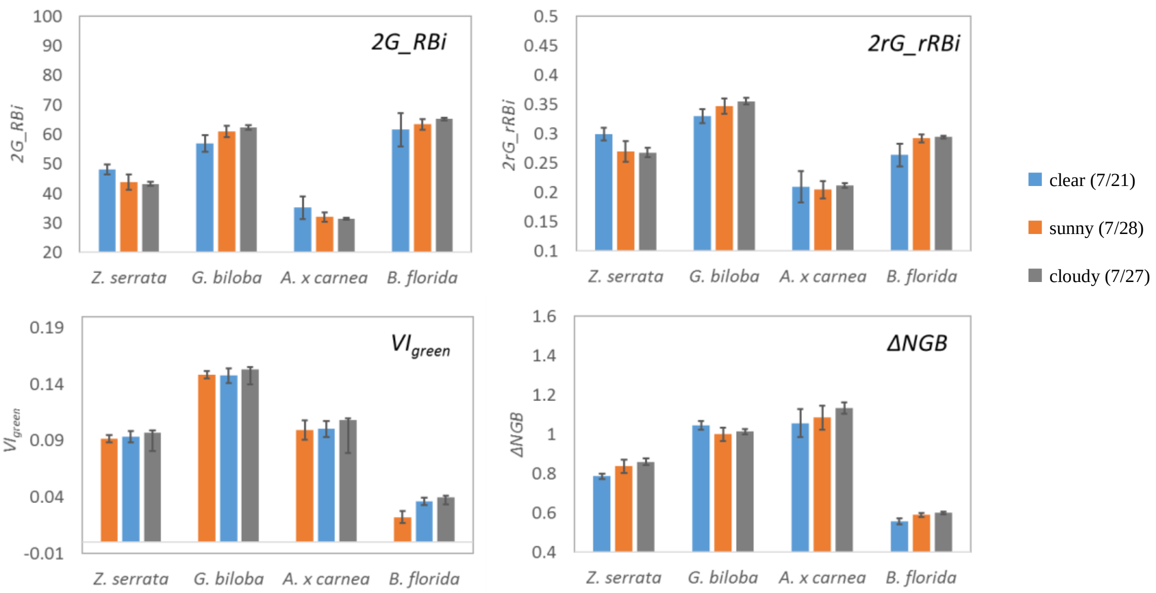

Figure 4. The average with standard deviation of vegetation indices under clear, partly cloudy, and cloudy conditions

3.2 Characteristics of vegetation indices under leaf appearance and flowering

To investigate how the vegetation indices respond to the changes of leaves and flowers of trees, we investigated the temporal patterns of the daily average of each vegetation index during this observational period. There were some days in which the camera could not take photographs because of system problems, so we only used days which had at least 9 images available. Fig. 5 shows the seasonal fluctuation of 4 vegetation indices for 4 trees. Here, we discuss about the characteristics of each tree shown by each vegetation index as follows.

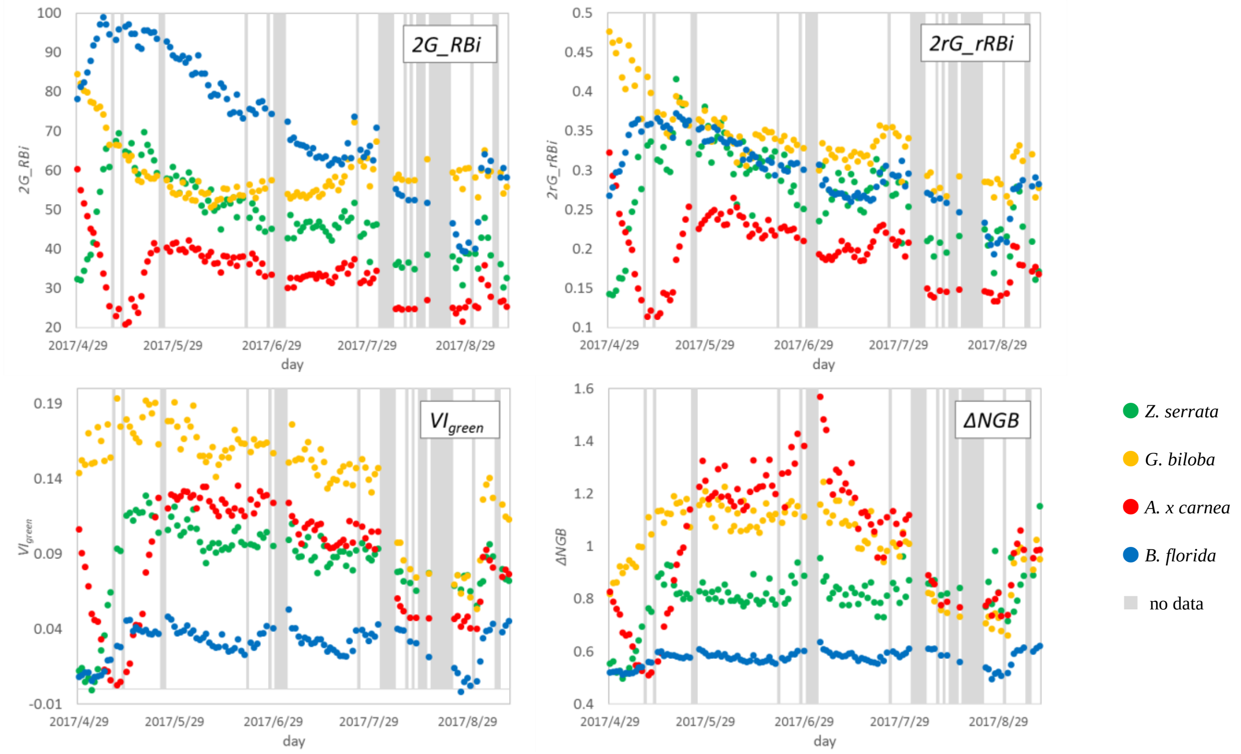

Figure 5. The seasonal fluctuation of each vegetation index for 4 trees

Z. serrata: There is one peak in all four vegetation indices in the middle of May. When the values of the vegetation indices are increasing, the tree is leafing. In the images, the canopy which started as brown, which is the color of the branches, becomes green, which is the color of the leaves. When the values of the vegetation indices gradually decrease after the peaks, the color of the leaves become darker.

G. biloba: There is an increase or decrease in the values of all four vegetation indices in May and early August, and a peak in late July for *2G_RBi* and *2rG_rRBi*. In May, the values of *2G_RBi* and *2rG_rRBi* decrease while VI_{green} and ΔNGB increase. In the images, *G. biloba* already has leaves when the observation starts on April 29, and the color of the leaves become darker green in May. The values of VI_{green} and ΔNGB responded to the color of the leaves becoming less "reddish" and "blueish", and the values of *2G_RBi* and *2rG_rRBi* responded to the color of the leaves becoming darker. There is a peak in the values of *2G_RBi* and *2rG_rRBi* in late July and a drop in all four vegetation indices in early August, but we could not find the reason for this on the images. It might be because of the long spell of cloudy weather.

A. x carnea: There is a rapid decrease and increase in all four vegetation indices in the middle May, a gradual decrease after they increase the peak in late May except for ΔNGB which has a peak on July 4, and a period with smaller values in early August like the one in *G. biloba*. *A. x carnea* starts with leaves on and no flowers, and when the values of *A. x carnea* in all four vegetation indices decrease, the red flowers bloom, and when they increase, the flowers drop. After that, the color of the leaves becomes darker, which is when the values of vegetation indices decrease. The reason for the peak of ΔNGB could not be found. We could not find the reason for the period with smaller values in early August either.

B. florida: There is a peak in the first half of May. After that, the values of *2G_RBi* and *2rG_rRBi* gradually decrease while VI_{green} and ΔNGB is decreasing and increasing. There is also a decrease and increase in late August in all four of the vegetation indices. *B. florida* already has white flowers and yellow green leaves at the start of the observation, and the flowers drop in the first half of May, which is when the values of vegetation indices are increasing. The difference of values between the start and the peak is small in ΔNGB compared to the other vegetation indices because ΔNGB is calculated by G and B, and the digital numbers of R and G do not change much. The digital numbers of B change in the period, but the digital number of B is small, so it did not affect the value of ΔNGB much. After the middle of May, the color of the leaves become darker which was when the values of *2G_RBi* and *2rG_rRBi* gradually decrease. The values of VI_{green} and ΔNGB increase and decrease in this period, but we could not find the reason for this. We also could not find the reason for the decrease and increase in late August.

We compare the fluctuation of the vegetation indices between trees. When we look at *2G_RBi*, *B.florida* has the largest value overall and *A. x carnea* is the smallest, however, when we look at *2rG_rRBi*, its difference is smaller. This was because *2G_RBi* was directly affected by the lightness of the object, but in contrast, *2rG_rRBi* was less affected because it used normalized values. As for VI_{green}, *B. florida* has the smallest value overall. This is because the color of the leaves of *B. florida* is the closest to yellow.

As for the overall of the vegetation indices, the variability of the value of *2rG_rRBi* was larger than *2G_RBi*. This was probably because of weather, so it seems that the value of *2rG_rRBi* was more affected by weather than *2G_RBi* in this study. Also, *B.florida* has the least variability. This is because it has the least shadows.

4. CONCLUSSION

In this study, we explored the effectiveness of vegetation indices for detecting the timing of leaf appearance and flowering of trees by using color-corrected images taken from visual images. We compared 2-hour fluctuation and the average with standard deviation of the values of vegetation indices in different weather conditions, and compared the seasonal fluctuation of the vegetation indices in 4 trees. As a result, we found out that by only using images taken within 1 hour before and after the time when the direction of the sun was 90° from the direction of the view of camera, the influence of bi-directional reflection on vegetation indices could be reduced. We also found out that the timing of leaf appearance and flowering could be detected by using vegetation indices. *2G_RBi* and *2rG_rRBi* detected the change of greenness and darkness of the color, while VI_{green} and ΔNGB detected the change of greenness, and especially in flowers, VI_{green} was effective. However, the problem that some vegetation indices such as *2G_RBi* and *2rG_rRBi* are affected by different weather conditions remains.

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