RESPONSES OF TROPICAL DECIDUOUS FOREST PHENOLOGY TO CLIMATIC VARIATION IN NORTHERN THAILAND

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ABSTRACT

Vegetation phenology is sensitive to climate variability, and understanding of changes in phenology is necessary to evaluate the impacts of climate change and variability. Although a number of research have been done on quantifying the phenology changes of deciduous forest (DF) using time series of vegetation indices, there is still limited effort to evaluate the change and trend of DF phenology and its relation to climatic variation in tropical Monsoon areas. In this study, time series of Normalized Difference Vegetation Index (NDVI) extracted from Moderate Resolution Imaging Spectroradiometer (MODIS) from 2001 to 2014, reconstructed using linear interpolation methods and the Savitzky-Golay algorithm, was used to investigate the pattern and changes of DF phenology in responses to climate variation. The start date of growing season (SOS), end date of growing season (EOS) and length of growing season (LOS) were derived from time series data by threshold-based method for each pixel. The results show that LOS of DF ranged mainly between 280 and 320 days, starting mainly from March to May (104-136 DOY) and ending from February to March (51-75 DOY) of following year. In overall, there was no clear trend in changes of tropical DF phenology over this period. However, variations in phenological in short time scale were found to correlate with climate factors. SOS was positively correlated with maximum temperature and negatively correlated with precipitation in March-May. EOS was positively correlated with minimum temperature in December. LOS varied according to the maximum temperature and precipitation during March to May. The significant correlation of phenological parameters to climate factors in this study implies that future variability in meteorological variables under climate change would affect to forest ecosystem functioning.

Keyword: Deciduous forest, Phenology, Normalized Difference Vegetation Index (NDVI), Climate variability.

INTRODUCTION

The tropical deciduous forest areas are estimated to be larger than that of temperate deciduous forests and play an important role in global carbon cycles [1]. In temperate zone, the annual temperature seasonality is the main controlling factor to timing of leaf flushing [2]. In tropical forest, leaf flushing varied among species and associated with changing in photoperiod, soil moistures and the timing of rainfall [3]. Study at forest species level showed that annual growth of tropical forest is strongly determined by both temperature and rainfall [4].

With decades of remote sensing imagery, it is possible to monitor the phenology changes in long term through space at local, regional and global scale [5-7]. Moderate Resolution Imaging Spectroradiometer (MODIS) provides valuable data for monitoring the ecosystem and it addresses spatial limitation associated with *in situ* observations from phenological networks. Among remotely sensed surface parameters, Normalized Difference Vegetation Index (NDVI) has been widely used as an indicator of vegetation growth status, distribution and phenology [7-13]. Many studies have derived quantitative phenological metrics from NDVI to assess the spatial pattern of forest phenology such as start date of season (SOS), end date of season (EOS), and length of growing season (LOS) as well as to assess the response of forest to climate variation [14-15].

Deciduous forest (DF) occupies about 52.9% of total forest areas in Thailand [16]. Yoshifuji (2006) reported that the inter-annual variations of canopy duration in tropical deciduous forest spanned between 40 and 60 days. This was much larger than the inter-annual variations reported previously in temperate deciduous forests, implying a profound potential impact of such variations on surface energy balance and canopy-atmosphere water and carbon exchange on an annual time scale [17]. The information on long term phenological observation in temperate regions are available for number of trees for example, the Pan European Phenological Network (www.dow.wau.nl/msa/epn/) and United States of America National Phenology Network (https://www.usanpn.org/). However, the information on the impacts of climate changes on the vegetation of the tropical zone, particularly Southeast Asia, is still limited [18]. Although a number of remote sensing methods have been developed to quantify vegetation seasonal cycles using time-series of vegetation indices, there is limited effort to explore and monitor trends of vegetation phenology in the Monsoon Southeast Asia [5, 19-20]. There are needs to increase our understanding of the impact of climate variation on this important forest ecosystem.

This study was performed to determine the pattern of tropical deciduous forest phenology and its relationship to climate variability. Our specific objectives were: to characterize the spatial and temporal variation of tropical DF phenological parameters as start, end and length of growing season in long term periods; and to assess how the DF phenological responses to climate variation in Northern Thailand. This study was conducted based on time series of Normalized Difference Vegetation Index (NDVI) extracted from Moderate Resolution Imaging Spectroradiometer (MODIS) from 2001 to 2014. We focused on the tropical deciduous forest because its seasonality is well-defined that would serve as good entry point to improve our understanding of influences of climate variability on phenological changes.

DATA AND METHODOLOGY

Study area

Total area of northern part of Thailand is about 169.644 square kilometer. Most areas of this part are hilly and mountainous. The climate in this region is influenced by monsoon wind and is of seasonal character such as southwest monsoon and northeast monsoon. The southwest monsoon which starts in May brings a stream of warm moist air from the Indian Ocean towards Thailand causing abundant rain over the country. The northeast monsoon which starts in October brings the cold and dry air from the anticyclone in mainland China over major parts of Thailand [20]. Deciduous forests are widely distributed in most of northern Thailand, covering about 52 percent of forest areas in this region [21]. Forest type in Northern Thailand includes mixed deciduous forest, dry dipterocarp forest, pine forest, swamp forest, evergreen forest and bamboo forest. The current study focuses only on the mixed deciduous forest (Fig. 1).

Data

MODIS Data: Surface Reflectance MOD09Q1 of MODIS product providing band 1 (Red) and band 2 (NIR) at 250-meter resolution and MOD09A1 at 500 meter resolution in an 8-day period (Product V5, downloaded from: https://reverb.echo.nasa.gov/reverb/) were used in this study. Cloud cover is presented in band 1 and band 2 of MOD09Q1 images, which limits the potential of images for ground information extraction. Removing and replacing cloud contaminated pixels is necessary in phenology extraction. All series of 644 images period 2001-2014 was applied with cloud removal method which bases on linear interpolation method [22] to provide free cloud data sets of band 1 and band 2 for calculating the vegetation index. The Savitzky-Golay filter was then applied for smoothing to remove the remaining noise through the entire time series of NDVI. This filter method has been proven applicable for phenology study [5, 23-25].

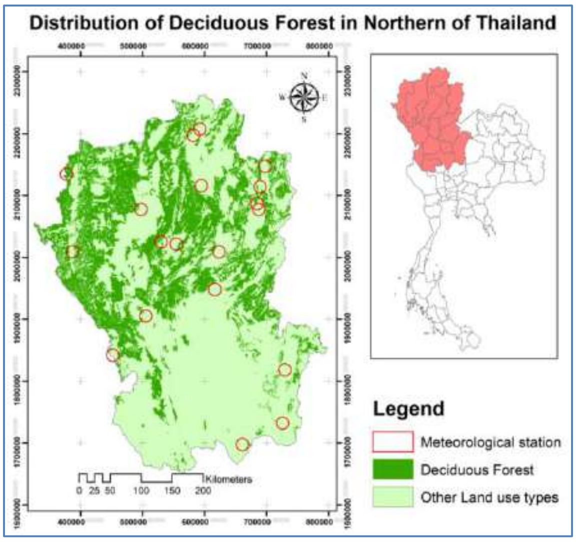


Fig 1. Distribution of deciduous forest in Northern of Thailand. Red dots are location of meteorological stations from which climate factors were derived.

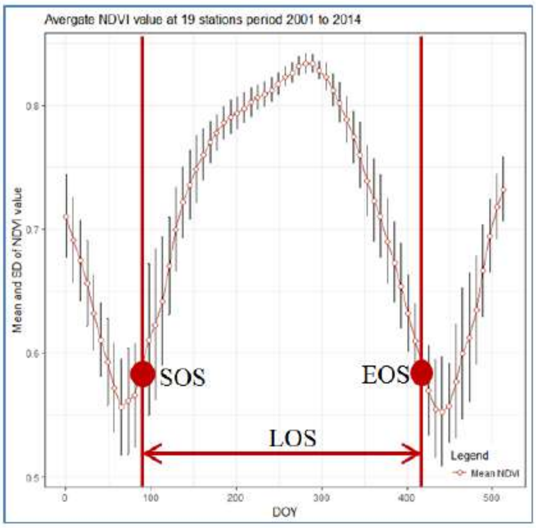


Fig 2. Seasonal variation in mean NDVI of DF in at 19 stations period 2001-2014

Meteorological Records: Climate data used in this study was obtained for the period 2001-2013 from Thai Meteorological Department. The 13-year variation (2001–2013) of the maximum and minimum temperature, and the precipitation were analyzed and aggregated into a yearly, seasonal and monthly period. Season was defined as summer (March to May), raining (June to October) and winter (November to February)

Forest map: The deciduous forest mask was created using forest database of Royal Forest Department, Thailand for the year 2007/08. This forest mask was used throughout the analysis to extract deciduous forest pixels from NDVI imagery. The current study focuses on the phenological shift, so the changes in forest pixels over time were not considered.

Determination of deciduous forest phenological parameters

At a pixel scale (250 × 250 meter), 64 points of NDVI time series revealed seasonal growth of DF (Fig. 2). Savitsky-Golay as discussed by Jonsson and Eklundh [26] in TIMESAT software package was used to fit the curve of time series data following second order polynomial and to extract the phenological parameters mentioned below [5, 25-30].

- Start of growing season (SOS): This is defined as the date of leaf unfolding (day of year, DOY) and this study considered SOS as a date when NDVI increases to 20% of the amplitude during the beginning period of the NDVI time series (measured from the left minimum level). For the series of NDVI in a given year, $\mathrm{NDVI_{Max}}$ is the maximum of NDVI and $\mathrm{NDVI_{min}}$ is minimum of NDVI in the first half of the year. SOS was calculated as follows;

$$SOS = NDVI_{\min(left)} + \left(NDVI_{max} - NDVI_{\min(left)}\right) \times 0.2 \qquad \text{Equation 1}$$

- End of the season (EOS): This is defined as the dates leaf discoloration (day of year, DOY) and leaf fall at the end of season. This study considered EOS as a date when NDVI decreases to 20% of the amplitude during the ending period of the NDVI time series (measured from the right minimum level). EOS was calculated as follows;

$$EOS = NDVI_{\min(right)} + \left(NDVI_{max} - NDVI_{min(right)}\right) \times 0.2 \qquad \text{Equation 2}$$

- Length of the season (LOS) is the duration (number of days) from the start to the end of the season.

The extracted phenological parameters of DF in Northern Thailand during 2001-2014 were implemented per year and per pixel, and then aggregated over the whole area to analyze the trend of phenological parameters.

Trend analysis of phenological parameters

The linear regression method was use to analyze the trend of phenological parameters [5]. The spatial trends of phenology were exanimated by applying the simple linear regression model with time as independent variable and phenological parameters as dependent variable.

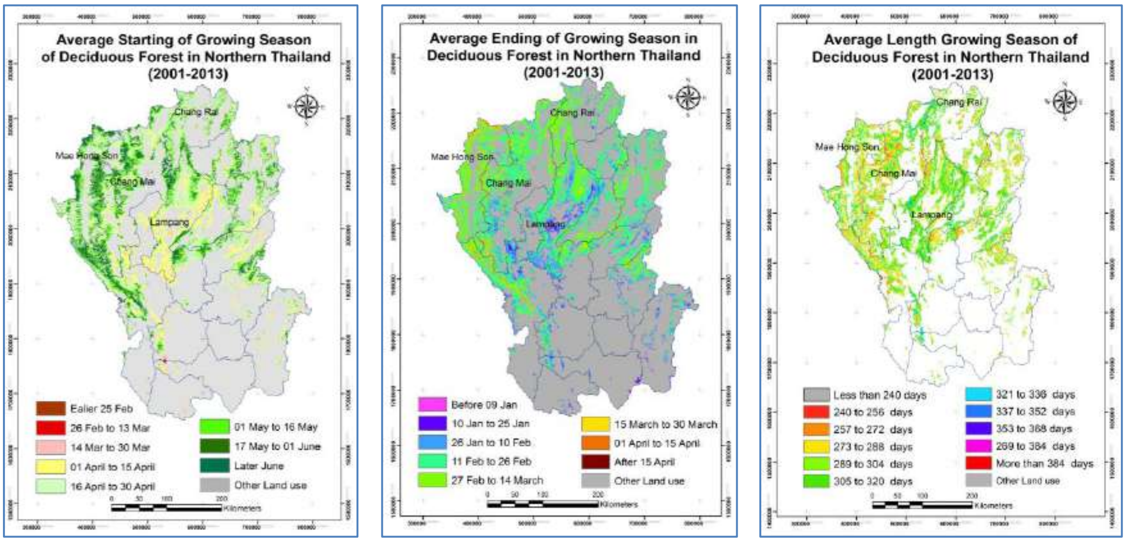
Relationship between phenological parameters and meteorological data

To understand how DF phenology is associated with climate variation, the relationships between phenological parameters and climatic factors of each month, season and year were examined. The phenological parameters around each meteorological station were represented by the average value in 10-kilometer buffer from center of the meteorological stations.

RESULTS AND DISCUSSION

SOS, EOS and LOS of deciduous forest

At each pixel, the mean value of 13 points time series for each year (2001-2013) was extracted to demonstrate the overall distribution of phenological parameters of DF in northern Thailand. In general, analysis from histogram of phenology parameters shows that LOS of DF ranged mainly between 280 and 320 days, mostly starting from March to May (104-136 DOY) and ending in February to March (51-75 DOY) of the following year (Fig. 3)



a) b) c)

Fig 3. Spatial distribution of average phenological parameters of deciduous forest in northern Thailand; a) Start of growing season; b) End of growing season; c) Length of growing season

Trend of deciduous forest's phenology parameters

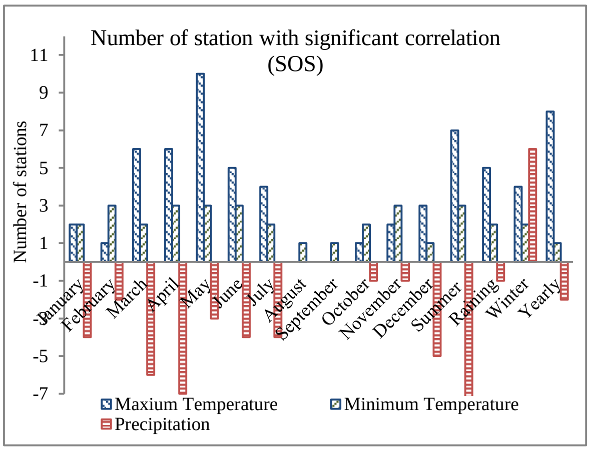
With the linear trend analysis, majority of phenological parameters of DF did not show the significant long term trend during 2001-2013. Areas of increasing and decreasing trend were fragmented.

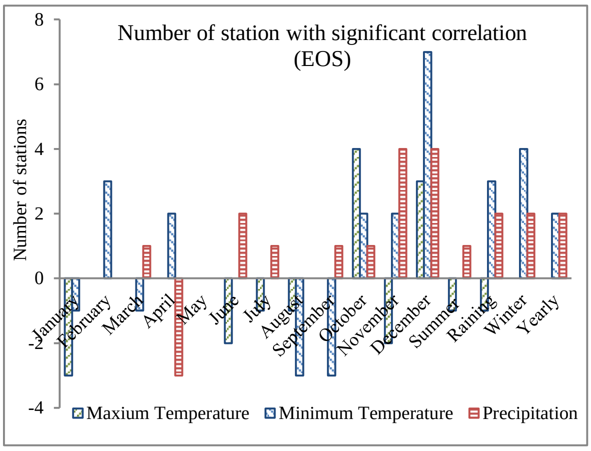
The linear trend of SOS, EOS and LOS were analyzed at 95% confident level. Over period of study, SOS trend with statistical significant change accounted for only 8.7% of all pixels and exhibited either advanced or delayed trend ($p<0.05$). Within the pixels with significant SOS trends, pixels with a positive (delayed) trend of SOS accounted for more than half. Positive SOS trends mainly occurred in Lampang province, whereas pixels with a negative (advanced) trend mainly occurred in ChiangMai and Mae Hong Son. For EOS, only 5.7% of pixels over entire area showed the significant changes ($p<0.05$), and pixels with advanced trend accounted for 79.1% of all significant pixels. The delayed EOS trend mainly occurred with DF in northwest Thailand. For the LOS, over entire areas, 5.85% of pixel displayed the significant trends.

Correlation between phenology parameters and meteorological data

The correlation between phenological parameters and yearly, seasonal and monthly climatic factors was examined at station level. The different responses of DF between western side and eastern side of the study area were observed through nineteen meteorological stations. In this study, only the stations with significant correlation were discussed.

SOS is positively correlated with the yearly and summer maximum temperature. It indicates that increases in maximum temperature during summer could lead to a delay in SOS timing. On the other hand, precipitation during March to April has a negative relationship with SOS, indicating an increase in precipitation during such period could result in advanced SOS timing. EOS was highly and positively correlated with minimum temperature in December. LOS was negatively correlated with accumulated precipitation during December to January. LOS was found positively correlated with yearly precipitation, especial during March to May and negatively correlated with maximum temperature during March to May (Fig. 4).





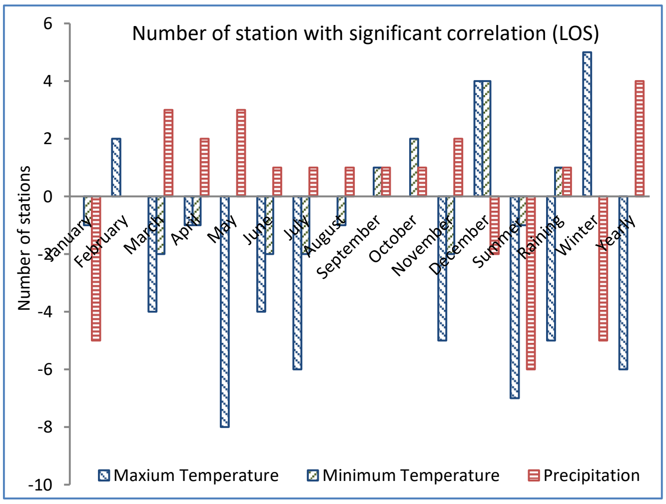


Fig 4. The number of stations with significant correlation between climate factors (monthly, seasonality and yearly maximum, minimum temperature and precipitation) and DF phenology parameters: start of season (a); end of season (b); length of season (c). The negative and positive in figure presented the negative and positive correlation coefficient.

Table 1. Results of statistical analysis of different between climate factors at 19 meteorological stations.

Parameters	Mean of non significant group	Mean of significant group	p-value	95% confidence interval
Max Temperature	32.3	33.4	0.011	-1.8 to -0.3
Min Temperature	20.7	21.9	0.034	-2.4 to -0.1
Precipitation	1433.4	1288.9	0.160	-63.1 to 352

Among these 19 meteorological stations, analysis also further reveals that the pattern of phenological responses to climatic factors could be divided into two main group; a group with a significant and with non-significant correlation between climate factors and phenological parameters. The results indicate that these two groups are significant different in maximum and minimum temperature ($p<0.05$), but not in precipitation (Table 1). Thus, we found that it is the temperature rather than the precipitation that significantly affect phenological shifts in this region. SOS in the group with significant correlation was 0.4-9.4 days earlier than the group without significant correlation. EOS and LOS were not significantly different between two groups.

In short, the results reported in this study show that the tropical deciduous forest exhibited considerable phenological variability across years during periods of this study. This variability was captured by time series of NDVI imagery using threshold-based method in TIMESAT packages. SOS has a positive correlation with maximum temperature and a negative correlation with precipitation during March-May. EOS was positively correlated with minimum temperature in December. LOS was negatively correlated with maximum temperature and positively correlated with precipitation during March to May. In addition, it was found that the length of season that determines the growing periods depends on SOS, rather than EOS. This result is consistent with those was reported by Yoshifuji et al. (2014). They found that in a seasonal tropical forest in Thailand, leaf flushing was associated with changes in soil moisture, and triggered by both temperature and precipitation [31, 4]. Water stress is the major factor driving the sequence of phenological events in tropical forests [32]. During the dry season, the DF suffers greater the water deficits, the stomata will close to avoid the loss of water and adjust the water potential to maximize soil water uptake [33]. This leads to deciduousness during dry season.

CONCLUSION

In this study, the MODIS NDVI datasets were used for evaluating the dynamic of DF phenology in Northern Thailand during 2001 to 2014. The start date of growing season (SOS), end date of growing season (EOS) and length of growing season (LOS) were derived by threshold-based method for each pixel. The response of DF phenological parameters to climate variation was also discussed. The results indicate that there was no clear trend in a long term changes of tropical DF phenology over this period. However, the variation of SOS, LOS was correlated with both temperature and precipitation in the area. The higher temperature will lead to the shortened LOS due to delayed in SOS. While, such delayed varied from station to station, detailed monitoring is needed to further improve our understanding of tropical deciduous forest responses to climate change and variability.

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