Monitoring temporal vegetation changes in Lao tropical forests

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Abstract. Studies on changes in vegetation are essential for understanding the interaction between humans and the environment. These studies provide key information for land use assessment, terrestrial ecosystem monitoring, carbon flux modelling and impacts of global climate change. The primary purpose of this study was to detect temporal vegetation changes in tropical forests in the southern part of Lao PDR from 2001-2012. The study investigated the annual vegetation phenological response of dominant land cover types across the study area and relationships to seasonal precipitation and temperature. Improved understanding of intra-annual patterns of vegetation variation was useful to detect longer term changes in vegetation. The breaks for additive season and trend (BFAST) approach was implemented to detect changes in these land cover types throughout the 2001-2012 period. We used the enhanced vegetation index (EVI) data from the Moderate Resolution Imaging Spectroradiometer (MODIS) (MOD13Q1 products) and monthly rainfall and temperature data obtained from the Meteorology and Hydrology Department, Ministry of Agriculture-Forestry, published by Lao National Statistical Centre in this research.

EVI well documented the annual seasonal growth of vegetation and clearly distinguished the characteristic phenology of four different land use types; native forest, plantation, agriculture and mixed wooded/cleared area. Native forests maintained high EVI throughout the year, while plantations, wooded/cleared areas and agriculture showed greater inter-annual variation, with minimum EVI at the end of the dry season in April and maximum EVI in September-October, around two months after the wet season peak in rainfall. The BFAST analysis detected abrupt temporal changes in vegetation in the tropical forests, especially in a large conversion of mixed wooded/cleared area into plantation. Within the study area from 2001-2012 there has been an overall decreasing trend of vegetation cover for native forests and mixed wooded/cleared lands, and by contrast an increase in EVI of plantations after 2008.
1. Introduction
Information on spatial and temporal changes in vegetation at local, regional and global scales is important for improving our understanding of human - environment interactions [1, 2] including alterations in terrestrial ecosystems, carbon fluxes and global climate [3]. Satellite-based studies on vegetation phenology provide information for environmental risk assessment and land use change monitoring. This information is also useful for detecting and monitoring global environmental change as vegetation response is associated with temperature, soil moisture, and human activity [2]. Moreover, monitoring and forecasting changes in phenology is useful to understand the response of vegetation related to changing climatic conditions [4]. However, acquisition of such information from on-ground studies is difficult.

The use of information captured by earth-observing remote sensing instruments provides opportunities to overcome this challenge [5]. Information from space is essential for analysing the spatial and temporal patterns of vegetation from local to regional and continental scales [6-9]. Changes in vegetation can be analysed using remote sensing data time series, such as NDVI [7, 9, 10] and EVI [11, 12].

Several remote sensing approaches have been tested and successfully applied to study changes in vegetation composition, cover and structure. They have used a diversity of satellite datasets, with varying spatiotemporal resolutions, and have employed a range of statistical methods [9]. Amongst these, the BFAST approach is a powerful analysis to detect gradual and abrupt changes in satellite data time series [8, 13]. It has been successfully tested in south eastern Australia and South Somalia.

However, there is little known about the performance of BFAST in tropical forests. Monitoring vegetation in this region using satellite remote sensing is challenging due to atmospheric effects such as frequent cloud cover and high levels of aerosols. These factors have an influence on analysis of temporal signals of remote sensing data. As a result, vegetation phenology in tropical forests is not well documented [12]. Therefore, the primary purpose of this study was to attempt to detect intra and inter-annual changes in the vegetation of tropical forests across the study area, the southern part of Lao PDR, through analysis of MODIS satellite vegetation index data. The response of vegetation phenology to monthly average precipitation and temperature was investigated, providing understanding of intra-annual response, against which longer term changes in vegetation could be detected. The BFAST approach was used to detect vegetation changes in land cover types between 2001 and 2012.

2. Material and method
2.1. Study area
The study area was situated in Champasack Province, in the south of Lao PDR. It covers an area of 15,415 km², from 13°55'00"N to 15°22'00"N latitude and from 105°13'00" E to 106°55'00" E longitude (figure 1). It is bordered by Salavan and Sekong Provinces in the north and northeast respectively, while the east is bordered by Attapeu Province. The province adjoins Thailand to the west and Cambodia to the south. About 58% of the Champasack Province is covered by native forests and it includes two of the largest Laotian national biodiversity conservation areas, Xepian and Dong Houa Sao. A range of natural ecosystems cover the region including savanna, dry, moist or mixed deciduous tropical forests, and semi-evergreen dry dipterocarpus forests. Champasack has relatively flat terrain comprising two different landscapes; 26% of the area is high altitude upland and 74% is low altitude, flat lowland. The altitude ranges from 75 - 1,284 m, but the majority of land is between 75 - 120 m above sea level. There are two distinct seasons: rainy (May-October) and dry (November-April). During the rainy season it is often windy, humidity is high and most of the 2,279 mm average annual rainfall occurs. In the dry season, conditions are mostly sunny, average temperatures are 28°C - 31°C and there is little rainfall.
2.2. Data
The research made use of the MODIS 16 days EVI composite product (MOD13Q1) time series from 2001-2012, with a spatial resolution of 250m. Both NDVI and EVI have been used to study changes in vegetation in tropical regions. In this study, we used EVI because it is better captures vegetation dynamics rather than NDVI [11], and it reduces sensitivity to soil and atmospheric effects but remains sensitive to a wide range of variation in canopy density [2]. The study area was covered by MODIS tile h28v07. Data was downloaded from the National Administration and Space Aeronautics (NASA) using a “MODISTools” package in R\(^1\). Data were reprojected to WGS84, UTM projection and zone 48 (MODIS reprojection tool version 4.01). Additionally, we also used monthly average rainfall and temperature data (2001-2012), from the Lao Meteorology and Hydrology Department, Ministry of Agriculture-Forestry, published by the Lao National Statistical Centre in this study.

2.3. Data Analysis
Our aim was to investigate the dynamics of EVI in different land uses from 2001-2012. EVI for four dominant land uses was first compared and contrasted, and then examined in the context of the monthly average precipitation and temperature. We also applied the BFAST approach to detect temporal changes in tropical forests. EVI time series (2001-2012) were extracted for four different land use covers using a standard randomization approach. Samples were randomly computer generated within land use polygons digitized from high resolution satellite imagery available through Google Earth. The land uses represented native forest, plantation, mixed wooded/cleared area and agriculture. 250 samples for each land use were extracted and the average EVI for each 16-day composite date calculated from the 2001-2012 records. This provided average annual EVI profiles of the four major land uses. These were compared with monthly rainfall and temperature patterns for the same period. Secondly, inter-annual changes in vegetation of four different land uses were examined using the BFAST approach. In total, 1,000 random samples representing the four land uses were used in the model. The BFAST algorithm decomposes input time series datasets into three components: trend, seasonal and remainder components. Its formula is:

\[ Y_t = T_t + S_t + e_t \]  \hspace{1cm} (1)

\(^1\)http://cran.fhcrc.org/web/packages/MODISTools/index.html
Where \( Y_t \) is the observed data at time \( t \); \( T_t \) is the trend component; \( S_t \) is the seasonal component; and \( e_t \) is the remainder, or residual component.

3. Results and discussion

3.1. Seasonal patterns of vegetation

The seasonal pattern of vegetation response was well represented by the spatial averages of MODIS EVI for the four land use types (native forest, plantation, mixed wooded/cleared area and agriculture) (figure 2). Native forest had highest overall EVI with least variation throughout the year, but a minor peak in July and slightly higher EVI maintained though to December. Plantations also had high overall EVI, but with greater seasonal variation: lower than the native forests from January-June, and higher from August-November. The wooded/cleared areas showed even greater intra-annual range of EVI; much lower than the forests and plantations January-July, but with similarly high EVI in the latter half of the year. Both plantations and mixed wooded/cleared areas showed evidence of two peaks in EVI in August and October. By contrast, the agricultural lands had overall lower EVI, but with greater variation between seasons, with a maximum in September-November.

EVI dynamics exhibited systematic differences based on vegetation cover, species and management practices in the four land uses. A high canopy cover is maintained throughout the year for forests and plantations, with the plantation species showing more evidence of seasonal variation. In mixed wooded/cleared areas more deciduous trees and shrubs are prevalent, resulting in a pronounced seasonal contrast in EVI. Agricultural areas displayed a pronounced annual cycle of land clearance/preparation (Jan-April), followed by crop planting and growth (Jun-Oct) and harvest (Nov-Dec). During land preparation, the greater soil exposure results in very low EVI, which gradually increases during growth of the crops (predominantly rice), reaching a maximum in October.

![Figure 2](image-url)

**Figure 2.** A long term average of EVI profile across four land use types; native forest, plantation, agriculture and mixed wooded/cleared area, from 2001-2012.

3.2. EVI responses to monthly precipitation and temperature

The vegetation response in relation to monthly average rainfall and temperature (2001-2012) is shown in figure 3. The annual vegetation growth cycles for all vegetation/land cover types closely followed the precipitation pattern with a lag of two-three months but were inversely related to temperature. From January to April average rainfall was less than 250 mm (figure 3A), while average temperatures climbed from a low of 26°C in January to the annual high of 31°C in April (figure 3B). During this period, vegetation cover and/or photosynthesis was lower, resulting in lower EVI for all land uses. However,
when rainfall increased from late May through September (300-400 mm), the greenness of vegetation started to increase and peaked in October, two months after the July peak of rainfall. This EVI signal still remained high almost two-three months after the end of rainfall, and then gradually declined in Nov-Dec. Soil moisture was still available to the deep-rooted perennial trees and shrubs of the forests, plantations and wooded/cleared areas during this period. It is evidence that intra-annual variations of average EVI are strongly influenced by seasonal rainfall.

Figure 3B shows an inverse relationship between monthly average temperature and EVI within all four land-use covers. Although the minimum of EVI seemed to synchronize with higher temperatures in the dry period (Mar-April) and the different vegetation types appeared to actively response to a mid-range of temperature during June-Nov, temperature was not directly influencing EVI. From these two figures, it could be concluded that the rainy season (Jun-Nov) until the beginning of dry season is the best for vegetation growth in this region because of relatively suitable temperatures (26°C-28°C) and availability of soil moisture.

3.3. Detecting temporal changes of vegetation with BFAST model
Temporal changes in vegetation in the study area were detected using the BFAST model. Verbesselt, Hyndman (7) suggested that the trend component indicates gradual and abrupt change in vegetation, while the seasonal component indicates phenological changes. Results here showed that BFAST had a capability to detect abrupt changes in vegetation dynamics, especially when a large area of mixed wooded/cleared area was converted to plantation. This was confirmed by visual interpretation of two dates of Google Earth images (2006 and 2012). The 1,000 random samples were all examined, with combined samples for each land use illustrated and described here. Figure 4A shows the temporal
changes in plantation area detected by the BFAST algorithm. The examination of the BFAST trend component for plantation suggests that clearing for plantations commenced from the beginning of 2004 to late 2007, followed by maturation and increase in plantation canopies from 2008 until 2011. Their EVI value dropped in early 2012, and then continued to increase.

The overall trend of vegetation in mixed wooded/cleared area was downward, with two abrupt changes detected by the BFAST algorithm: in 2005 and early 2010 (figure 4B). Although EVI in native forests remained stable from 2001-2011, there was an abrupt decrease in its response in 2012 (figure 4C). Figure 4D shows an overall gradual downward trend and the annual seasonality of vegetation of agriculture areas.

4. Conclusion
This study aimed to detect temporal changes in tropical forests across the study area in southern Lao PDR using enhanced vegetation index (EVI) time series data of MODIS. Firstly, the intra-annual response of vegetation in different land covers was investigated to provide an understanding of typical seasonal patterns. Secondly BFAST was applied to examine inter-annual changes in vegetation responses over the 2001-2012 periods. EVI well documented the annual seasonal growth of vegetation and well distinguished the characteristic phenological patterns of four different land use types; native forest, plantation, agriculture and mixed wooded/cleared areas. The maximum vegetation growth occurred two
months after the peak of annual precipitation, coinciding with mid-range monthly temperatures. This suggests that typical seasonal patterns of vegetation growth appeared to be primarily determined by water availability, but not directly by temperature. This study has provided key information on vegetation seasonality, long term trends and land clearance and re-planting for the first time in a tropical forest of Lao PDR. The BFAST analysis revealed an overall trend of decreasing vigour for all land covers since 2001, with the exception of plantations. It demonstrated to be capable of detecting known clearance and revegetation, supported by independent evidence (Google Earth image interpretation), and a possible disturbance event in the native vegetation class in 2011. The BFAST analysis of MODIS EVI appeared as a promising tool to assess tropical land cover type changes.

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6. References
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