Global Ecology and Conservation 13 (2017) e00366

Contents lists available at ScienceDirect

Global Ecology and Conservation

journal homepage: http://www.elsevier.com/locate/gecco

Original Research Article

# Climate change and its effects on vegetation phenology across ecoregions of Ethiopia

Tenaw Geremew Workie [a, *], Habte Jebessa Debella [b]

[a] *Entoto Observatory and Research Centre (EORC), Ethiopia*
[b] *College of Natural Sciences, Department of Zoological Sciences, Addis Ababa University, Ethiopia*

## ARTICLE INFO

*Article history:*
Received 18 August 2017
Received in revised form 11 December 2017
Accepted 21 December 2017
Available online xxx

*Keywords:*
Phenology
Phenophase
NDVI
Rainfall
Temperature
Ecoregions

## ABSTRACT

Vegetation phenology is an integrative environmental indicator of climate change and long-term observations of the changes in plant phenology using remote sensing technologies help us to understand climate change trends over space and time. However, such trends and their implications for ecosystem health have been poorly explored in Ethiopia. In this paper we examine the temporal changes in the phenology of vegetation in relation to climatic drivers across Ecoregions in Ethiopia using satellite images. To do this, the MODIS 8-day NDVI product, MODIS surface temperature and emissivity, and pentad based rainfall data from Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) for the 14 year period 2002–2015 were used. The aggregated time series NDVI, temperature and rainfall data were generated for each Ecoregion in the Google Earth Engine (GEE) Environment followed by Fourier smoothing to overcome various noises. The phenology of each Ecoregion was constructed using the intra-annual NDVI variability. Major events in the vegetation cycle or phenophases were identified using sigmoid vegetation growth functions and inflection point detection techniques. The relationships between rainfall and NDVI and between temperature and NDVI were investigated and multiple regression models were developed as regressors to NDVI. Our results indicated that, over the 14 years, the start of the growing period became earlier, and the growing period elongated for most of the Ecoregions in Ethiopia, except for the Somali Acacia-Commiphora bushlands and thickets (SACBT) Ecoregion, in which the start of the growing period was delayed. The widening of the growing period indicates an increase in ecosystem productivity, increment of evapo-transpiration, and disturbance to the water and energy balance of the region. Rainfall and NDVI were positively and strongly correlated but with one-month lag time, whereas temperature and NDVI were negatively correlated for all the Ecoregions. This appears to be due to the variation in timing of the high rainfall season and the decreasing trends of temperature with respect to the variation in the angle of the sun and the subsequent movements of the ITCZ in the region. The overall study indicates that climate variability is affecting the phenology of vegetation across all Ecoregions in Ethiopia. Shifts in crop growing seasons should be considered to efficiently utilize the summer rain for crop production.

---

* Corresponding author. Entoto Observatory and Research Centre, P.O.Box:33679, Addis Ababa. Ethiopia.
*E-mail address:* tenaw.geremew@ecsu.edu.et (T.G. Workie).

https://doi.org/10.1016/j.gecco.2017.e00366

## 1. Introduction

Phenology is the study of the recurring time of vegetation events, the biotic and abiotic drivers, and the relationship between same or different species. Information about the environment can be derived by tracking phenological cycles and identification of phenophases. Phenophases are observable stages or phases in the seasonal cycle of vegetations such as onset of greenness and senescence (Leith, 1974). Phenology is one of the simplest and most effective indicators of climate change (IPCC. Climate Change, 2007), (Adole et al., 2016). Tracking the phenology of vegetation also helps to track the changes in ecosystem function and species composition (Xiaa et al., 2015a), provide baseline data from which to monitor changes in vegetation associated with events such as fire, drought, land use conversions, climate fluctuations, and directional climate change (Justice et al., 1986). However, such trends and their implications on ecosystem health were poorly explored across ecoregions of Ethiopia.

Vegetation responds to climate change by changing their phenological patterns such as, (a) shifting the timing of the life cycle events, (b) shifting range boundaries resulting in areas of extirpation and colonization, (c) changing morphology, reproduction or genetics, or (d) extinct. These processes lead to change in the phenological profile of an ecosystem as the mix of species changes, or as individual species adapt to the changing climatic conditions (McCloyKeth, 2010). Such changes lead to abrupt changes in ecosystem functions and species composition (Penuelas et al., 2004).

Phenological events are sensitive to temperature, rainfall, and human activities affecting vegetation growth, canopy structure and functions (Zhang et al., 2005a), (Kartschall et al., 1995). The sensitivity to rainfall and temperature differs from region to region. Temperature is the major factor for controlling the seasonality of vegetation growth in humid temperate climate. Consequently, clearly identifiable phenological responses to global warming in temperate regions are observable. In tropical regions vegetation is less sensitive to temperature changes (Zhang et al., 2005b). However, annual growth trends of some tropical rainforest trees in West Africa were rather related to solar radiation than rainfall (Polansky and Boesch, 2013).

Phenological studies can be conducted using small scale ground based or in situ field study (Chmielewski et al., 2004) and large scale remote sensing or land surface phenology (LSP) (Dash et al., 2010). The ground based studies can be conducted using, a) visual observation and recording of the different states of plant life cycle (Chmielewski et al., 2004), b) in-situ spectral measurement and near surface remote sensing from laboratory made sensors (Hufkens et al., 2012); and c) gas exchange measurements from flux towers (Jin et al., 2013). Large scale remote sensing technique is based on deriving vegetation indices (VIs), Leaf Area Index (LAI), fraction of Absorbed Photosynthetically Active Radiation (fAPAR) from satellite based sensors (Huete et al., 2002).

The overall remote sensing studies are based on two groups of phenological studies: a) drawing the trends in VI data, and b) deriving the phenophase time or status which can be used to detect the changes in the phenological patterns over space and time. Drawing the trend VI data involves smoothing to overcome noises caused by cloud cover, mixed pixel effects and sensor anomalies which can be done using, i) statistical, ii) curve fitting and iii) data transformation techniques (Atkinson et al., 2012). The phenological parameter estimation or phenophases detection, on the other hand, are often made using, i) threshold, ii) curve derived and iii) functional model fitting methods (de Beurs and Henebry, 2010).

Despite the paramount importance of studying the phenology of vegetations, globally, most of the studies conducted are concentrated in the temperate regions. Given the fact that Africa constitutes 17% of the global forest cover and diverse vegetation types, little is known about the phenology across the continent and the factors regulating vegetation growth dynamics (Adole et al., 2016). Phenology of Africa and its drivers are known to be poorly studied (IPCC. Climate Change, 2014). As the summary of the phenological studies conducted in Africa indicates, most of the studies are concentrated in South Africa (Adole et al., 2016). Ethiopia, being a home for diverse range of vegetation types, its vegetation phenology is among the least studied. Ethiopia's economy is largely reliant on agriculture which is known to be one of the most vulnerable sectors to climate change. Accordingly, understanding how vegetations respond to changing climate helps to devise better natural resources management and climate change adaptation strategies. The aim of this study was to track phenological changes and their drivers across ecoregions in the country over the past 14 years by coupling remotely sensed datasets.

### *1.1. Study area*

The study was conducted in Ethiopia, located between latitude 3.30°–15°N and, longitudes 33°–48°E, which has three major climatological seasons: June–September (Locally called “Kiremt”), October–January (locally called “Bega”), and February–May (locally called “Belg”) (Korecha and Barnston, 2007). Specifically, the units of analysis were the ecoregions of Ethiopia, derived from Terrestrial Ecoregions of the World (TEOW). TEOW is a biogeographic regionalization of the Earth's terrestrial biodiversity. Ecoregions are defined as relatively large units of land or water containing a distinct assemblage of natural communities sharing a large majority of species, dynamics, and environmental conditions (Olson et al., 2001). These regions exhibit homogeneous ecosystem processes and, so it is important to develop public policies that include appropriate spatial scales and that consider environmental dynamics (Biodiversity and Mexican. ww, 2016). Fig. 1 indicates the ecoregions that constitutes Ethiopia.

Among these ecoregions, Somali Acacia-Commiphora bushlands and thickets constitutes about 40% of the country. The Ethiopian montane forest (EMF) and montane grassland and woodlands (EMGW) account for about 41% of the country. The remaining 9 ecoregions, all combined, cover the remaining 19% of the country (Table 1).