Ecological Informatics 34 (2016) 117–128

Contents lists available at ScienceDirect

Ecological Informatics

journal homepage: www.elsevier.com/locate/ecolinf

A systematic review of vegetation phenology in Africa

Tracy Adole [a,*], Jadu Dash [a], Peter M. Atkinson [b]

[a] Global Environmental Change and Earth Observation Research Group, Geography and Environment, University of Southampton, UK
[b] Faculty of Science and Technology, Lancaster University, UK

ARTICLE INFO

Article history:
Received 2 March 2016
Received in revised form 5 May 2016
Accepted 25 May 2016
Available online 29 May 2016

Keywords:
Africa
Climate change
Phenology
Remote sensing
Vegetation
Vegetation indices
Satellite sensors

ABSTRACT

The study of vegetation phenology is important because it is a sensitive indicator of climate changes and it regulates carbon, energy and water fluxes between the land and atmosphere. Africa, which has 17% of the global forest cover, contributes significantly to the global carbon budget and has been identified as potentially highly vulnerable to climate change impacts. In spite of this, very little is known about vegetation phenology across Africa and the factors regulating vegetation growth and dynamics. Hence, this review aimed to provide a synthesis of studies of related Africa's vegetation phenology and classify them based on the methods and techniques used in order to identify major research gaps. Significant increases in the number of phenological studies in the last decade were observed, with over 70% of studies adopting a satellite-based remote sensing approach to monitor vegetation phenology. Whereas ground based studies that provide detailed characterisation of vegetation phenological development, occurred rarely in the continent. Similarly, less than 14% of satellite-based remote sensing studies evaluated vegetation phenology at the continental scale using coarse spatial resolution datasets. Even more evident was the lack of research focusing on the impacts of climate change on vegetation phenology. Consequently, given the importance and the uniqueness of both methods of phenological assessment, there is need for more ground-based studies to enable greater understanding of phenology at the species level. Likewise, finer spatial resolution satellite sensor data for regional phenological assessment is required, with a greater focus on the relationship between climate change and vegetation phenological changes. This would contribute greatly to debates over climate change impacts and, most importantly, climate change mitigation strategies.

Contents

* Corresponding author.
E-mail addresses: T.Adole@soton.ac.uk (T. Adole), J.DASH@soton.ac.uk (J. Dash), pma@lancaster.ac.uk (P.M. Atkinson).

http://dx.doi.org/10.1016/j.ecoinf.2016.05.004
1574-9541/

1. Introduction

Phenology can be defined as the study of periodic life-cycle events, the impact of changes in climate and environment on the different phases of these events, and the interrelations among these phases either from the same or different species (Lieth, 1974). Vegetation phenology, which deals with the phenology of plants and their seasonal cycles, focuses on the onset of the growing season to the end of senescence in a plant's annual cycle and its relationship with climatic and non-climatic factors (Zhang et al., 2012; Zhao et al., 2013). The relationship between vegetation phenology and climatic factors has been researched since the 1950s (Schnelle, 1955). However, it was formally established in the early 1990s that vegetation phenology is strongly dependent on climatic variables, making it a sensitive marker of seasonal changes in climate variables and their manifestation on the ground (van Schaik et al., 1993; Wright and van Schaik, 1994).

An important advantage of phenological studies is the ability to carry-out long-term and broad-scale natural experiments, which can be synchronised readily with large scale climatic data (Myneni et al., 1997; Menzel et al., 2006). This has facilitated monitoring the impacts that changes in climate may have on vegetation growth (Chmielewski and Rötzer, 2001; Cleland et al., 2007) and has aided in characterising climate-related events like droughts (White et al., 1997; Brown et al., 2012; Ivits et al., 2014). Vegetation phenology also plays an important role in controlling the global carbon, water, and nitrogen cycles, especially the global carbon cycle, as the timing and duration of growing seasons greatly influences terrestrial energy budgets and atmospheric CO_2 exchange (Keeling et al., 1996; Higgins and Scheiter, 2012). This makes vegetation phenology an important factor to consider in planning and developing climate change mitigation strategies (Peñuelas et al., 2009; Richardson et al., 2013).

In the last few decades, the study of vegetation phenology has gained attention especially in relation to investigating climate change and its impacts on terrestrial ecosystem. Several studies have shown that increases in global temperature can influence photosynthetic activity, litterfall and the length of the growing-season of plants (Chmielewski and Rötzer, 2001; Chmielewski et al., 2004; Zhang et al., 2004). These studies are either ground-based or remote sensing studies or a combination of both. This increase in temperature, in particular during the spring, has been shown to increase vegetation greenness, advance the arrival of spring, and significantly alter growing season length especially in most parts of the Northern hemisphere (Myneni et al., 1997; Menzel and Fabian, 1999; Zhou et al., 2001). Similarly, other studies involving controlled experiments that simulate increases in temperature have provided further evidence of a lengthened growing season driven by changes in climatic conditions (Matsumoto et al., 2003; Wolkovich et al., 2012). This further emphasises the importance of a greater understanding of vegetation phenology and its drivers, especially in poorly studied regions. Unfortunately, one of those regions is the African continent as identified by the IPCC (2014) report on climate change.

1.1. Vegetation phenology in Africa

Despite increased interest in phenological studies, the phenology of the African vegetation has received far less attention than that of the Northern hemisphere, notwithstanding the African forest's important contributions to the global carbon cycle. Given that Africa is home to the second-largest rainforest in the world (central African rainforests) (Zhou et al., 2014), and the second and third largest wetlands in the world: the *Cuvette Centrale* of the Congo River Basin (Betbeder et al., 2014) and the Niger Delta region of Nigeria (Spiers, 1999), vegetation dynamics in this region greatly influence regional and global land-atmosphere feedbacks. Also, 17% of global forest cover (Food and Agriculture Organization of the United Nations, 2010), and approximately 12% of tropical mangroves, which are the most productive natural ecosystem and the most carbon rich forest in the world, are found in Africa (Giri et al., 2010). In addition to the abundance of forest, as shown in Fig. 1, Africa also has a diverse range of vegetation types, ranging from deserts, grasslands, savannas and scrublands to woodlands, including broadleaved evergreen, needleleaved evergreen and deciduous forest with complex vegetation dynamics (Favier et al., 2012).

The African continent has been recognised as one of the most vulnerable to climate change impacts (Niang et al., 2014). In addition, Africa's vegetation has experienced significant change over recent years. Between 2000–2010 the continent experienced a net loss of forest cover of approximately 3.4 million hectares annually (Food and Agriculture Organization of the United Nations, 2010). East Africa in particular, was shown to have increased tropical woody vegetation over grasslands (Doherty et al., 2010), while Mitchard et al. (2009) demonstrated forest encroachment into grassland areas in central Cameroon. There has also been a reported increase in vegetation greenness in the Sahel region (Olsson et al., 2005; Heumann et al., 2007).

Despite the above studies, the phenology of the African vegetation and its role in the global biogeochemical cycle are not clearly understood. Although research on African vegetation phenology is limited, more can be done by refining and integrating these studies, to identify the particular *foci* of phenological assessments that have been conducted, the specific research gaps and the appropriate approaches needed to fill these gaps. However, to date there has been no comprehensive review that summarises the phenological studies in Africa, which highlights the specific gaps in knowledge and research, and identifies the suitable research methods required. Through this review, we provide a summary of the current state of research in the continent of Africa and some recommendations for future research. This review, thus, aims to contribute to the ongoing debates over climate change in Africa and, most importantly, its effects on vegetation phenology and attempts to mitigate its effects through climate change adaptation and mitigation strategies.

2. Conceptual framework

Phenological studies have increased in number over the last decade, with studies focusing more on higher latitude regions, and including both small on-the-ground or in situ field studies (Chmielewski and Rötzer, 2001) and large scale remote sensing sometimes referred to as land surface phenology (LSP) (Dash et al., 2010; Brown et al., 2012). On-the-ground measurements are made by visual observation and recording of the different stages of a plant's life cycle (Chmielewski et al., 2004), in situ spectral measurements and near-surface remote sensing from laboratory-made sensors (Hufkens et al., 2012; Soudani et al., 2012), and gas exchange measurements from flux towers (Jin et al., 2013). Remote sensing measurement on the other hand, is based primarily on deriving vegetation indices (VIs) and other vegetation parameters like the leaf area index (LAI) or the fraction of absorbed photosynthetically active radiation (FAPAR) from satellite-based sensors (Huete et al., 2002; Boyd et al., 2011).

Based on the above two different approaches to estimating vegetation phenological parameters, a conceptual framework was developed as a systematic basis for reviewing the scientific literature on vegetation phenological studies in Africa (Fig. 2). Selected scientific literature was