International Journal of Applied Earth Observation and Geoinformation 52 (2016) 527–531

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Analysis of the pattern of potential woody cover in Texas savanna

Xuebin Yang[a,*], Kelley A. Crews[a], Bowei Yan[b]

[a] Department of Geography and the Environment, The University of Texas at Austin, Austin, TX 78731, USA
[b] Department of Statistics and Data Science, The University of Texas at Austin, Austin, TX 78731, USA

ARTICLE INFO

Article history:
Received 2 December 2015
Received in revised form 19 July 2016
Accepted 26 July 2016
Available online 3 August 2016

Keywords:
Texas savanna
Potential woody cover
Woody plant encroachment
Nonlinear quantile regression
MODIS VCF

ABSTRACT

While woody plant encroachment has been observed worldwide in savannas and adversely affected the ecosystem structure and function, a thorough understanding of the nature of this phenomenon is urgently required for savanna management and restoration. Among others, potential woody cover (the maximum realizable woody cover that a given site can support), especially its variation over environment has huge implication on the encroachment management in particular, and on tree-grass interactions in general. This project was designed to explore the pattern of potential woody cover in Texas savanna, an ecosystem with a large rainfall gradient in west–east direction. Substantial random pixels were sampled across the study area from MODIS Vegetation Continuous Fields (VCF) tree cover layer (250 m). Since potential woody cover is suggested to be limited by water availability, a nonlinear 99th quantile regression was performed between the observed woody cover and mean annual precipitation (MAP) to model the pattern of potential woody cover. Research result suggests a segmented relationship between potential woody cover and MAP at MODIS scale. Potential biases as well as the practical and theoretical implications were discussed. Through this study, the hypothesis about the primary role of water availability in determining savanna woody cover was further confirmed in a relatively understudied US-located savanna.

1. Introduction

Savanna ecosystems are characterized by the coexistence of woody and herbaceous vegetation (Frost et al., 1986). They exist across a wide range of conditions in terms of climate (e.g. rainfall), soil nutrient content, fire regimes and herbivory level, covering about 20% of the Earth's terrestrial surface (Ramankutty and Foley, 1999). Mainly found in tropics and subtropics, savannas are home to a large proportion of human population, livestock and wildlife of the world. Moreover, savanna ecosystems play a critical role in global land-atmosphere energy balance, as well as carbon, nutrient, and water cycles (Scholes and Walker, 1993; Lal, 2004).

Many theories have been advanced to explain the coexistence and relative abundance of woody and herbaceous components in savannas, which can be categorized into two broad classes (Walter et al., 1971; Van Langevelde et al., 2003; Higgins et al., 2000). While one is based upon the competitive interactions between the two contrasting life forms, the other focuses exclusively on tree establishment and persistence restricted by demographic bottlenecks (Sankaran et al., 2004). However, both positive and negative evidence exists for each category of those theories, and none of them is generalizable across all types of savannas (Scholes and Archer, 1997; Jeltsch et al., 2000). Other than that, savanna dynamics have been debated with regard to equilibrium, non-equilibrium, and disequilibrium dynamics (Ellis and Swift, 1988; Sullivan and Rohde, 2002). As for savanna modeling community, the validity of traditional succession models versus state-and-transition models needs further investigation (Fowler and Simmons, 2008).

Furthermore, the phenomenon of woody plant encroachment, defined as the directional increase of woody plants at the expense of herbaceous vegetation, commends the relevance of illuminating the above 'savanna questions'. This is because that the encroachment has been observed in southern United States (Archer et al., 1995; Creamer et al., 2013) and many other parts of the world (Cabral et al., 2003; Coetsee et al., 2013; Soliveres and Eldridge, 2014). And it has adversely affected the ecosystem production and function, and largely reduced species diversity (Hughes et al., 2006; Van Auken, 2009; Alofs and Fowler, 2010). A thorough understanding of the aforementioned alternative mechanisms and dynamics is urgently required for woody encroachment management, especially in consideration of changing climate and land use patterns anticipated to worsen the scenario (Sala et al., 2000; House et al.,

* Corresponding author.
E-mail address: yxbfuture@utexas.edu (X. Yang).

http://dx.doi.org/10.1016/j.jag.2016.07.021

2003; Field et al., 2014). Potential woody cover – the maximum realizable woody cover that a given site can support – would provide insights into these 'savanna questions'.

2. Background

During the past several decades, substantial increase in woody plants has been observed on the Edwards Plateau of Texas, USA (Archer, 1989; Taylor, 2008; Alofs and Fowler, 2010). The encroachment was attributed to the expansion of existing woody species and establishment of new woody species, accompanied by a significant amount of temporal and spatial heterogeneity in fire regimes and herbivory level (González, 2010; Alofs and Fowler, 2013). Being unfavorable to the dominant herbivores in this region (domestic livestock and deer), the encroaching species of Ashe juniper and red berry juniper now dominate much of the plateau, largely reducing livestock production and regional plant diversity (Fowler and Simmons, 2008; Creamer et al., 2013).

Facing the huge encroachment, both conservation managers and research ecologists are concerned about the potential woody cover (the hypothetical degree of encroachment), as well as the alternative of succession models and state-and-transition models for savanna dynamics modeling. If potential woody cover is well below canopy closure, woody plant encroachment will be a bounded process (Sankaran et al., 2005). Otherwise, savannas may switch to a wooded state as a result of the encroachment, and disturbances such as fire and herbivory will be necessary for the persistence of woody and herbaceous vegetation. While succession models emphasize an ordered series of states during the development of savannas (Fowler and Simmons, 2008), the state-and-transition models consider reversible stable states (Briske et al., 2005; Bestelmeyer et al., 2009). If succession models fit Texas savanna dynamics, the encroachment will persist and the savanna will develop toward a more and more woody state. Otherwise, if the state-and-transition models fit better, the encroachment will be a reversible process with or without human manipulation, and it will be a much easier task to combat with the encroachment.

It is hypothesized that the potential woody cover that a given site can support is predominantly limited by water availability (Frost et al., 1986; Sankaran et al., 2008). Research also suggests that, if water availability plays the primary role in determining woody cover in savannas, the potential woody cover would show a gradual increasing trend with mean annual precipitation (MAP) (Walker and Noy-Meir, 1982; Sankaran et al., 2004, 2005). But if factors such as fire and herbivory play the primary roles, an abrupt increase in potential woody cover would be observed over rainfall gradient. That is, a dominance of grassland will be found in areas below a MAP threshold, while woody canopy closure would occur in areas above that threshold sufficient for woody plant growth (Frost et al., 1986; Jeltsch et al., 2000).

Sankaran et al. (2005) analyzed the potential woody cover in African savannas applying the above MAP-based scheme. However, analogous research in other savanna regions has been rarely seen. And the pattern of the potential woody cover of other savanna ecosystems remains to be established, which could be different from that of the African savannas due to the relatively unexplored factors such as soil characteristic and climate seasonality (Kulmatiski and Beard, 2013). Given so, this study was designed to investigate the potential woody cover across broad environmental gradients in Texas savanna. While field sites were restricted to a fine scale of 0.25–0.5 ha in the African research, a coarse scale study would enrich the theory of scale-dependency of woody cover observation (Gillson, 2004; Wiegand et al., 2006).

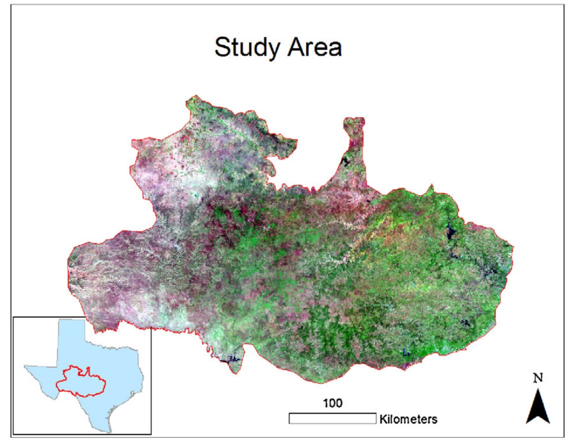

Fig. 1. The study area in Texas, USA.

3. Methods

3.1. Study area

This study was tested on the Edwards Plateau of Texas, USA (Fig. 1). The plateau is a unique ecoregion of Texas, characterized by juniper-oak savanna and mesquite-Acacia savanna with middle to short herbaceous vegetation (Küchler, 1964; Fowler and Simmons, 2008). It is adjacent with dry plains on its western border, and with moist prairies and woods to the east. The plateau is roughly an oblong region in which a large rainfall gradient is present, with mean annual precipitation ranging from ~360 mm to ~950 mm in the west-east direction. It has thick and mostly flat bedrock, mainly consisting of hard early Cretaceous limestone. Due the origin of limestone, soil in this region is generally shallow (less than 10 inches) and rich in clay content (Schmid, 1969). The study area is displayed with Landsat GeoCover Mosaics of 2000, under band combination of 7, 4 and 2 for a natural-like rendition (Fig. 1).

3.2. Data acquisition

MODIS Vegetation Continuous Fields (VCF) is an annual product that estimates the proportion of tree cover, non-tree vegetation and bare ground of global land surface at MODIS pixel level (DiMiceli et al., 2011). The VCF product has been widely used in a variety of research and application (Bucini and Hanan, 2007; Song et al., 2014). As the only large scale and proportional tree cover dataset available, the MODIS VCF tree cover layer is able to provide us a very large sample to examine the pattern of potential woody cover over broad environmental gradients that is difficult to discern by a small number of observations. The latest MODIS VCF tree cover of 2013 (250 m resolution) was utilized in this research.

Precipitation data was acquired from Southern Regional Climate Center. MAP from 1981 to 2010 was calculated in millimeters for 51 rain gauge stations within this study area. Thereafter, a continuous MAP surface was created at 250 m resolution. The interpolation method of Kriging was applied, which proves more realistic compared to other methods (Ly et al., 2013). The MAP surface and MODIS tree cover layer are displayed in Fig. 2.

3.3. Data sampling

Spatial random sampling was performed across the study area with the MODIS VCF tree cover layer in ArcGIS 10.3, creating a total of 10,000 random pixels. Corresponding proportional tree cover and MAP values were extracted for the sample. Pixels with tree cover values greater than 100% (due to water, cloud, shadow, or