Using Spatial Statistics Tools on Remote-Sensing Data to Identify Fire Regime Linked with Savanna Vegetation Degradation

Anne Jacquin, UMR 1201 DYNAFOR, INPT - Ecole d’Ingénieurs de Purpan, Université de Toulouse, Toulouse Cedex 3, France
Michel Goulard, UMR 1201 DYNAFOR, Institut National de la Recherche Agronomique, Auzeville, Castanet-Tolosan, France

ABSTRACT
Fire is acknowledged to be a factor for explaining the disturbance of vegetation dynamics interacting with other environmental factors. In this study, the authors want to clarify the importance and the role of fire on the dynamics of savanna vegetation. The study area is the Marovoay watershed located on the north-west coast of Madagascar. In this site, burning herbaceous cover is the main practice in the extensive grazing system. They analyzed the relationship between two indicators, one related to vegetation activity changes and one about fire regime that results from a combination of fire frequency and seasonality. All indicators were measured between 2000 and 2007 using a time series of MODIS images. In this work, the authors implemented two approaches of spatial analysis. The first one analyzes the spatial structure of the residuals of a per-pixel non-spatial GLM model. In the second approach, a spatial GLM model is directly computed. In both approaches, the authors proposed two levels of stratification for the study area according to the spatial variations of the relationship established between vegetation activity changes and fire regime. The use of spatial statistical tools produced parsimonious models which they found to be consistent with expert knowledge. The authors demonstrated that a statistical analysis based on spatial GLM is able either to stratify an area when non ancillary data on land use exist or to validate an existing stratification.

Keywords: Fire Regime, General Linear Model (GLM Model), Remote Sensing, Spatial Statistics, Vegetation Dynamics

INTRODUCTION
Fire is a common management tool in African tropical and sub-tropical savanna. It is acknowledged to be a factor for explaining the disturbance of vegetation dynamics. Depending on the fire regime more specifically the occurrence and the seasonality of the fires, the vegetation cover of the savanna changes in terms of biomass quantity and structure (Eva & Lambin, 2000). But these fire effects vary widely according to local conditions because of many interactions.

DOI: 10.4018/jaeis.2013010105
with other environmental factors such as the rain regime, the stockbreeding pressure, the soil properties or the human activities (Borak et al., 2000). As a consequence, there is no general agreement on the conditions under which fires should be used to ensure the sustainability of the savanna (Jeltsh et al., 2000). "The problem of savanna tree-shrub-grass equilibrium appears to be extremely varied: there is not one savanna problem, but several savanna problems" (Schnell, 1971). Based on this assumption, clarifying and quantifying the importance and the role of fire on savanna vegetation cover taking into account the specificities of the local conditions is a major issue to provide accurate information to local managers while they build their management strategy.

Given the elements presented above, to analyse space-time variations of the plant cover dynamics of savanna together with space-time variations of the ways of using fires is the most appropriate approach (Eva & Lambin, 2000; Ehrlich et al., 1997; Bucini & Lambin, 2002; Devineau et al., 2010; Jacquin, Chéret, Sheeren, & Goulard, 2010). In the present work, issues on the importance and the role of the fire factor in the changes for a given savanna ecosystem are revisited at landscape scale using time-series of medium spatial resolution images to measure vegetation activity trend and fire regime over almost ten years. This is addressed through the implementation of spatial statistical tools. Our aim is not to produce strong thematic conclusion about fire regime and landscape management, but to suggest methodological tools and to test them on a real dataset.

From a methodological point of view, this study presents two interests compared to previous works (Eva & Lambin, 2000; Bucini & Lambin, 2002).

First, we used a time-series of images as input data. This kind of data enables to use temporal decomposition methods which are recognised to be more adapted than traditional change analysis technics to detect abrupt as well as subtle changes on vegetation cover (Verbesselt et al., 2009). These time series allows producing information on fire that combines seasonality and occurrence; occurrence can be including into the analysis as it is recognized to play a significant role in the explanation of vegetation changes. Using these time series, fire regime and vegetation changes are calculated at the same spatial resolution and in the same timing as recommended by Bucini and Lambin (2002).

Second, the relationship between fire regime and vegetation changes is usually studied on homogeneous environmental conditions. These are defined through a stratification technique. Quality of the data used for the stratification highly influences conclusions (Buicini & Lambin, 2002; Jacquin, Chéret, Sheeren, & Goulard, 2010). In this paper, we investigated how to examine the relationship between fire regime and vegetation changes with and without data on environmental factors. To this end, we compared two statistical approaches in which we directly or indirectly consider the existence of a spatial effect due to environmental factors.

The research was conducted at Madagascar, in the framework of the Madagascar national program for preventing soil from erosion risk (PLAE; http://www.plae-mada.com). The project aims at improving a sustainable use of the natural vegetation resources in the savanna areas surrounding rice production perimeters. The research activities are concentrated on the relations between the use of fire and the degradation observed of the savanna vegetation cover, as fire is recognized to be the most common practices to manage grassland ecosystems (Kull, 2002).

**Background**

At Madagascar, 25% up to 50% of non-forested and non-cultivated areas are assumed to be burnt each year during the dry season, from April to October (Kull, 2000). Estimations of burned areas in savanna are highly variable depending on the source: from 435000ha/year (Langrand & Wilme, 1995) to 650000ha/year (Rakotoarjaona, 2004). These figures highlight a very common usage of fire. Almost all fires observed in savanna ecosystems are supposed to
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