Spatial Statistics 13 (2015) 90–105

Contents lists available at ScienceDirect

Spatial Statistics

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

Spatial pattern development of selective logging over several years

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ARTICLE INFO

Article history:
Received 20 April 2014
Accepted 4 March 2015
Available online 21 May 2015

Keywords:
Selective logging
Point pattern
Inhomogeneous J-function
Geyer's saturation process
The area-interaction process

ABSTRACT

Selective logging gives currently a major contribution to ongoing deforestation in the Brazilian Amazonia. On satellite images, log-landing sites (LLS) are well visible, and they serve as a proxy to selective logging activities. In this study we analysed the spatial patterns of the LLS collected during the years 2000–2009 in a part of the Brazilian Amazonia, using spatial statistical methods. The purpose was to reveal important spatial and temporal characteristics of selective logging. After the spatial analysis, the patterns formed by the LLS were modelled using the higher-order Gibbs interaction models due to their suitability to model clustered patterns. The area-interaction model and Geyer's saturation model proved effective in modelling the clustered patterns in the absence of information about covariates. Results of both models conform closely to each other. We conclude that spatial statistical methods are powerful tools for analysing and interpreting the spatial patterns formed by selective logging.

1. Introduction

In the Brazilian Amazonian forests, selective logging for timber is a major source of forest degradation (Uhl et al., 1991). Adverse effects of selective logging on the Amazonian forests include damages to forest phenology (Koltunov et al., 2009), increasing vulnerability of a forest to fire (Gerwing, 2002; Fearnside, 2005), forest fragmentation (Broadbent et al., 2008) and wide spread of deforestation (Uhl

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http://dx.doi.org/10.1016/j.spasta.2015.03.001

et al., 1991; Fearnside, 2005). An important challenge faced by forest researchers is to detect and analyse the locations and patterns of forest perforations caused by selective logging for timber. Selective logging operations are almost impossible to monitor as much of the Amazonian region is inaccessible. Remote sensing, due to its synoptic view and fast coverage, may serve as a viable source for the purpose. Log-landing sites (LLS), the locations where the collected timber is stored, can be detected from the remote sensing images and may serve as a proxy for the selective logging activities in a surrounding area (Anwar and Stein, 2012).

There has been intensive work on analysing the deforestation patterns and processes in the Brazilian Amazonia. Efforts have been made to model the deforestation processes using different spatial analytical tools (Apan and Peterson, 1998; Alvis et al., 1998). Spatially explicit analysis and modelling of the locations of forest degradation caused by selective logging is, however, lacking. As logging operations vary in time, location and intensity (Matricardi et al., 2005), a spatial–temporal statistical analysis of the detected LLS may reveal important spatial and temporal characteristics of selective logging distribution. Due to small spatial extent of the LLS, it is natural to represent them as points in the maps derived from remote sensing images. Spatial point pattern statistics, then, may serve as appropriate tools for analysing and modelling the process that determines the LLS positions.

Different types of spatio-temporal data require different modelling approaches. The LLS maps generated from the remote sensing images are examples of the discrete-time spatio-temporal point process data. Discrete-time spatio-temporal point process data can arise in two ways; either the underlying process genuinely operates in discrete-time, or an underlying continuous-time process is observed at a discrete sequence of time-points (Diggle, 2005). LLS data may serve as an example of the latter as they are generated from the Landsat images acquired annually with almost the same time interval.

New logging activities grow from previously logged areas and thus extend more deeply into the interior core of remaining intact forest areas (Broadbent et al., 2008). LLS may thus exhibit interaction. Considering the interaction is important to understand the selective logging dynamics, whereas ignoring it can result in misleading conclusions about the spatial LLS distribution (Turner, 2009). If the LLS data are found to be of an inhomogeneous structure then different ecological and geographic factors may be responsible for the LLS distribution pattern. Modelling of such a nonstationary process is done using Monte Carlo Markov Chain (MCMC) methods. In the presence of interaction among LLS, such methods may become computationally extensive as they need to incorporate interaction terms as well as the spatially varying LLS intensity (Baddeley et al., 2000). When the LLS patterns exhibit interactions, pairwise interaction point processes are suitable choice. Pairwise interaction point processes are perhaps the most widely used sub-class of Markov point processes also known as Gibbs point processes. In a pairwise point process the configuration interacts only via pairs of points. Pairwise interaction models are good models for repulsive (regular) patterns but they do not sufficiently describe clustered patterns (Law et al., 2009). The lack of pairwise Markov models for clustered patterns led to the development of higher-order interaction processes such as Geyer's saturation and the area-interaction processes. These processes have infinite-order interactions and thus are well suited for modelling a clustered pattern.

The present study focuses on the assessment of spatial patterns formed by the LLS. Whereas the purely spatial aspects of selective logging have been dealt in Anwar and Stein (2015), the objective of this study is to discover important spatial–temporal characteristics of selective logging in the south-western part of the Brazilian Amazonia and then modelling the LLS patterns using a Gibbs model suitable for clustered patterns. By using patterns of several years, it is intended to better understand and quantify the spatial characteristics of the LLS distribution in the area and to reveal its temporal dynamics.

2. Study area and data description

The study area (Fig. 1) covering 30,000 km^2 is located in the south-western Brazilian Amazon. It constitutes the northern Rondônia state, north-western Mato Grosso state, and south-eastern Amazonas state — three of the five top timber-producing states which account for about 95% of the region's deforestation. The terrain of the region is undulated, ranging from 100 to 450 m above sea