International Journal of Applied Earth Observation and Geoinformation 13 (2011) 357–367

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Broad-scale spatial pattern of forest landscape types in the Guiana Shield

Valéry Gond[a,*], Vincent Freycon[a], Jean-François Molino[b], Olivier Brunaux[c], Florent Ingrassia[c], Pierre Joubert[c], Jean-François Pekel[d,1], Marie-Françoise Prévost[e], Viviane Thierron[f], Pierre-Julien Trombe[c], Daniel Sabatier[b,**]

[a] CIRAD, UPR B&SEF, F-34398 Montpellier, France
[b] IRD, UMR AMAP, F-34000 Montpellier, France
[c] ONF, Direction Régionale de Guyane, F-97300 Cayenne, France
[d] ENGE, Université catholique de Louvain, B-1348 Louvain la Neuve, Belgium
[e] IRD, UMR AMAP, F-97300 Cayenne, France
[f] WWF, F-97300 Cayenne, France

ARTICLE INFO

Article history:
Received 18 June 2010
Received in revised form 5 January 2011
Accepted 7 January 2011

Keywords:
Forest landscape types
Spatial pattern
Remote sensing
Tropical rainforest
Guiana Shield

ABSTRACT

Detecting broad scale spatial patterns across the South American rainforest biome is still a major challenge. Although several countries do possess their own, more or less detailed land-cover map, these are based on classifications that appear largely discordant from a country to another. Up to now, continental scale remote sensing studies failed to fill this gap. They mostly result in crude representations of the rainforest biome as a single, uniform vegetation class, in contrast with open vegetations. A few studies identified broad scale spatial patterns, but only when they managed to map a particular forest characteristic such as biomass. The main objective of this study is to identify, characterize and map distinct forest landscape types within the evergreen lowland rainforest at the sub-continental scale of the Guiana Shield (north-east tropical South-America 10° North-2° South; 66° West-50° West). This study is based on the analysis of a 1-year daily data set (from January 1st to December 31st, 2000) from the VEGETATION sensor onboard the SPOT-4 satellite (1-km spatial resolution). We interpreted remotely sensed landscape classes (RSLC) from field and high resolution remote sensing data of 21 sites in French Guiana. We cross-analyzed remote sensing data, field observations and environmental data using multivariate analysis. We obtained 33 remotely sensed landscape classes (RSLC) among which five forest-RSLC representing 78% of the forested area. The latter were classified as different broad forest landscape types according to a gradient of canopy openness. Their mapping revealed a new and meaningful broad-scale spatial pattern of forest landscape types. At the scale of the Guiana Shield, we observed a spatial patterns similarity between climatic and forest landscape types. The two most open forest-RSLCs were observed mainly within the north-west to south-east dry belt. The three other forest-RSLCs were observed in wetter and less anthropized areas, particularly in the newly recognized "Guianan dense forest arch". Better management and conservation policies, as well as improvement of biological and ecological knowledge, require accurate and stable representations of the geographical components of ecosystems. Our results represent a decisive step in this way for the Guiana Shield area and contribute to fill one of the major shortfall in the knowledge of tropical forests.

1. Introduction

At a time when Amazonian tropical rainforests are undergoing profound and rapid changes (Laurance et al., 2001), characterizing their spatial organisation is of major importance for analysing land-use changes and promoting sustainable management of forest resources. From a conservation point of view, the question arises as to how far large protected areas actually encompass the diversity of forest ecosystems. Landscape is a key concept at a key scale for sustainable management, but is not fully taken into consideration by ecologists and managers.

* Corresponding author at: CIRAD, UR 105 Forest Ecosystems Goods and Services, TA-C105/D, Campus de Baillarguet, 34398 Montpellier Cedex, France. Tel.: +33 4 67 59 37 87.
** Corresponding author at: IRD, UMR AMAP, TA-A51/PS2, Bd de la Lironde, 34398 Montpellier Cedex, France. Tel: +33 4 67 61 65 83.
E-mail addresses: valery.gond@cirad.fr (V. Gond), daniel.sabatier@ird.fr (D. Sabatier).
[1] Current address: Joint Research Centre of the European Commission, Global Environement Monitoring Unit (GEM), Via E. Fermi, 2749 I-21027 Ispra (Va) Italy.

0303-2434/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jag.2011.01.004

A landscape is an area that is spatially heterogeneous in at least one factor of interest (Turner, 2005). Consequently, landscape elements may be defined as homogeneous areas with respect to a set of factors of interest. Following Forman and Godron (1986), we define landscape types as a recognisable combinations and proportions of landscape elements. The mapping of such landscape types across large areas allow to detect what we call here the spatial pattern of landscape types. Our study focuses on the forest landscapes types of the Guiana Shield area.

At local scale, many authors have described an impressive number of landscape elements with specific typologies according to their structure (i.e. density and size-frequency distribution of stems, canopy structure, and floristics) either from field observations (Pires and Prance, 1985), quantitative measurements (Clark and Clark, 2000) or from high or very high spatial resolution satellite imagery (Lu et al., 2003; Johansen et al., 2007). All these studies involved a context-dependent typology and a fine scale resolution, both inaccurate for the mapping of large trends in the variations of vegetation cover.

At regional scale, maps of forest landscape types have been based on broad environmental classes rather than on actual vegetation characteristics. The pioneering RADAMBRASIL and its improvements (Veloso et al., 1991; IBGE, 1992) was the first attempt to map the spatial distribution of native landscape types in Brazil, mostly based on proxies of their determinant factors such as altitudinal classes. Similar approaches have been used in the Guiana Shield countries (Guyana: ter Steege, 2001; Huber et al., 1995; Suriname: Ravillous, 2000; French Guiana: Girou, 2001), combining in so different ways high resolution remote sensing (typically 30 m spatial resolution from Landsat imagery) and field data that they are mostly not compatible and unable to produce a global view of the spatial pattern of forest landscape types.

At continental scale, according to remote sensing, the forest is clearly distinguished from other biomes (e.g. savannas, wetlands, shrubland, and agriculture; Friedl et al., 2002; Bartholomé et al., 2004) but the resulting vegetation maps display tropical rainforests as a uniform broad-leaved evergreen forest class and fail to distinguish any distinctive forest landscape type within (South America: Eva et al., 2004; Asia: Stibig et al., 2007; Africa: Mayaux et al., 2004). On the contrary, studies based on scattered, but detailed field measurements identified clear patterns of species diversity, (ter Steege et al., 2000), life traits (ter Steege et al., 2006), or aboveground biomass (Malhi et al., 2006; Saatchi et al., 2007), thus strongly suggesting the existence of such distinctive types. Therefore, depicting such geographical structure in the forest vegetation cover from continuous data is of major interest, because it would provide key elements to support forest conservation and management policies. The objective of this study is to identify, characterize and map distinct forest landscape types within the evergreen lowland rainforest at the sub-continental scale of the Guiana Shield.

2. Materials and methods

2.1. Location

The Guiana Shield covers 2.3 million km^2 and is located on the north-eastern part of continental South America. The study area lies between latitude 11° North and 4° South, and between longitude 48° and 58° West. The climate is tropical with annual precipitation ranging from 1500 to 4000 mm and mean annual temperatures ranging from 25 °C to 30 °C (Hammond, 2005). The number of consecutive months with less than 100 mm precipitation varies from 0 to 7 (Sombroek, 2001). The altitude ranges from 0 to 3000 m (average altitude 270 m). Cristallophyllous substratum is found in two larges domes (East and West) where very little sedimentary rock remains. On the edges, alteration deposits cover large areas (Roraïma white sands and the Guianan coastal plains). The relief comprises a hill system within a dense hydrographic network. Vegetation types are of natural or anthropogenic origin (forests, swamps, savannas and agricultural crops). Rainforests cover almost all the study area. Biodiversity and endemism are very high (ter Steege et al., 2000).

2.2. Remote sensing data

This study is based on the analysis of a 1-year daily data set (from January 1st to December 31st, 2000) from the VEGETATION sensor onboard the SPOT-4 satellite. The data set was extracted from daily global acquisitions covering a period of 12 months (VGT, 2000). The main characteristics are listed below.

Data were pre-processed in daily synthesis at a 1-km spatial resolution (Mayaux et al., 2000). Four channels were used: blue [0.43–0.47 μm]; red [0.61–0.68 μm]; near infra-red (NIR) [0.78–0.89 μm]; and shortwave infra-red (SWIR) [1.58–1.75 μm]. A processing chain transformed digital numbers into luminance, then into reflectance (Meygret, 2004). Data were geo-referenced in Plate Carrée projection using the WGS84 geodesic system. The geometric accuracy of VEGETATION data from day to day was between 300 and 465 m (positioning error) in absolute location and from 325 to 625 m for multi-temporal superimposition, less than half a pixel (Sylvander et al., 2000). Atmospheric corrections were made using the simplified 6S model (named SMAC) for the four channels (VITO, 2004). Surface reflectance (top of canopy) was then obtained.

SPOT-4/VEGETATION data could not be processed directly because of the presence of clouds that hide large portions of the ground. The blue channel was only used to filter cloudy and hazy pixels, whereas the three other channels were the input data of our analysis. A yearly synthesis was considered the best way to compensate for the lack of information due to cloud cover and to take climatic seasonality into account. The annual synthesis was done to generate a mean composite image as proposed by Vancutsem et al. (2007).

2.3. Spectral analysis of the annual synthesis

The annual composite image was analyzed using the ISODATA unsupervised classification scheme (Tou and Gonzalez, 1974; ENVI 4.3 software, Research Systems Inc.), resulting in pixel clusters hereafter referred to as remotely sensed landscape classes (RSLC). Two parameters were selected: a maximum of 10 iterations to free the positioning of the gravitational centre of classes and a maximum range of 50 resulting classes. A previous study (Mayaux et al., 2000) had already shown this algorithm to be useful in such investigations.

2.4. Interpretation of forest RSLC

We interpreted the main types of RSLC (water, swamp, forest, savanna, agriculture, etc.) by matching them with the IBGE (1992, 2004) and Eva et al. (2004) maps. We paid a special attention to the RSLC corresponding to the forest type and interpreted them through a study carried out on 21 French Guianan sites. The latter were chosen because they were well documented and scattered throughout an area that included all these RSLC. These sites hosted a variety of forest and non-forest landscape elements, including areas disturbed to varying extents by human activities (Fig. 1).

For each site, we selected and georeferenced several high-resolution aerial photographs from the French National Geographic Institute (IGN) to match the area covered by the available control data. Aerial photographs acquisition dates ranged from 1955 to 2001 (for the sites not disturbed by human activities) and