Monitoring a pioneer front using SPOT-VEGETATION time series

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A farm in Maçaranduba study area. Note the extensive pasture, the forest edge and the swamp pasture on both sides of the road.
Photo V. Gond.

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RÉSUMÉ

DE L'UTILISATION DES SÉRIES TEMPORELLES SPOT-VÉGÉTATION POUR SURVEILLER UN FRONT PIONNIER

Depuis les années 1960, la forêt amazonienne se réduit face à l'extension des surfaces commerciales agricoles. Ce phénomène a été renforcé par l'augmentation de la population due à l'immigration vers ces nouveaux secteurs défrichés. Le phénomène a alors tendance à s'amplifier aux dépens de la forêt. Dans ce contexte, il devient essentiel de surveiller ces fronts pionniers afin de caractériser les changements rapides qui s'y opèrent. Les satellites à haute résolution ne sont pas adaptés pour surveiller ces milieux très dynamiques car leur résolution temporelle est faible et leur traitement reste compliqué. Inversement, les données satellitaires à basse résolution semblent être plus adaptées pour ce genre d'analyses. En se basant sur des données à basse résolution obtenues à partir du satellite SPOT-VEGETATION cette étude propose une méthode de surveillance adaptée à des fronts de déforestations de petites étendues. La méthode peut être extrapolée à d'autres fronts pionniers afin de les surveiller et d'établir des diagnostics sur les dynamiques temporelle des transformations paysagères.

Mots-clés : front pionnier, déforestation, SPOT-VEGETATION, surveillance par télédétection, Amazonie.

ABSTRACT

MONITORING A PIONEER FRONT USING SPOT-VEGETATION TIME SERIES

Since the 1960s, the Amazonian forest has been shrinking with the advance of primarily commercial cultivated areas. The pattern is being strengthened by high population growth and the migration of populations towards these newly deforested pioneer fronts. These trends are causing space to be appropriated to the detriment of forested areas. It has become essential to be able to locate areas on the pioneer front quickly and systematically in order to characterize new phases in advancing deforestation as they occur. However, satellite tools with high spatial resolution are not suited to monitoring of this type, as their temporal resolution is too broad and data processing is characteristically complex. Although low–resolution satellite images therefore seem more appropriate to these analyses, they can raise major problems when the target areas are very specific. In order to use imagery with low spatial resolution, such as SPOT-VEGETATION images, this study proposes a monitoring methodology based on a deforestation front of very small size. The method could be extrapolated to other deforestation fronts to investigate new areas to be monitored and thus establish diagnoses of the temporal dynamics of landscape transformation.

Keywords: pioneer front, deforestation, Spot-VEGETATION, remote sensing survey, Amazonia.

RESUMEN

SEGUIMIENTO DE UN FRENTE PIONERO MEDIANTE SERIES TEMPORALES DE SPOT-VEGETATION

Desde los años 60 la selva amazónica se reduce debido a la extensión de áreas comerciales agrícolas. Dicho fenómeno se ha visto intensificado por el incremento de población que emigra hacia estas nuevas áreas roturadas, acentuando el proceso a expensas de las zonas selváticas. En consecuencia, resulta indispensable supervisar dichos frentes pioneros para caracterizar los rápidos cambios que se producen. Los satélites de alta resolución no están adaptados para el seguimiento de estos medios tan dinámicos debido a su baja resolución temporal y a la dificultad que entraña el procesamiento de los datos. Por el contrario, los datos de satélites de baja resolución parecen más adaptados para este tipo de análisis. Basándonos en datos de baja resolución obtenidos a partir del satélite SPOT-VEGETATION, este estudio propone un método de seguimiento adaptado a frentes de deforestación de pequeña extensión. El método puede extrapolarse a otros frentes pioneros para realizar su seguimiento y establecer diagnósticos sobre las dinámicas temporales de las transformaciones del paisaje.

Palabras clave: frente pionero, deforestación, SPOT-VEGETATION, seguimiento por teledetección, Amazonía.

Landscape mosaic with forest on the background, burned forest, pasture and palms on the foreground. On the foreground, note the young bushland. Photo J. Oszwald.

Introduction

Deforestation has been the subject of many studies for the last thirty years (Davidson *et al.,* 2012; Soares-Filho *et al.,* 2006). Since the beginning of the 1990's, deforestation monitoring has been carried out through the collection of data with the purpose to quantify cleared areas (Laurance *et al.*, 2011). Satellite techniques were usually developed and used to observe deforestation processes (Achard *et al.*, 2007). This trend is now proving true and is being intensified by the increasing use of high resolution satellite information, thus multiplying regional and local studies (Oszwald *et al.,* 2011). Satellites such as Landsat-TM or SPOT-HRV have quite a high spatial resolution, respectively of 20 to 30 meters, and of 10 meters for SPOT 5, but the temporal repetitivity is low (16 days for Landsat TM and 26 days for SPOT). Therefore, the use of these images provides accurate information of the deforestation front at a given time *t* to the detriment of a global vision, from both a spatial and temporal point of view. Moreover, the presence of a persistent nebulosity and of a regular cloud cover due to the humidity of the forest make the acquisition of usable images difficult, even during the dry season (Asner *et al.,* 2009). They generate a theoretical limit to remote sensing methods in tropical landscapes with forest and agricultural land use.

Transformation of landscapes is considered to be one of the main drivers behind species loss, regionally and globally, but if many ecological studies focus on how the effects of spatial landscape structure on biodiversity are being impacted (Gibson *et al.*, 2011), very few deal with the temporal dimension of landscape change. The ability to map the temporal dynamics of landscape change would represent a valuable tool to deal with one of the most critical issues in biological conservation: assessing the effect of temporal scale of the biodiversity response to ongoing landscape transformation (Foster, 2002).

In order to improve the temporal monitoring of the land cover, the use of spatial information with high temporal resolution appears to be relevant. Indeed, addressing these issues require low spatial resolution satellite images from 250 to 1,000 m which are optimized for vegetation monitoring (Colditz *et al.,* 2011). Deforestation fronts generally refer to wide geographical areas, especially with regard to the Amazonian deforestation front. Nevertheless, local dynamics are very limited since the clearing systems are managed by actors from the world timber economy or intensive farming (Carrero, Fearnside, 2011).

Thus, the purpose of this study is to test the use of low spatial resolution data to monitor local dynamic of a pioneer front.

Material and Methods

Study area

The region of Maraba covers 30,000 km², located on the Tocantins River, 500 km south of Belém, in the federal state of Para (figure 1). The historical context of this region has great resonance because it modelled and is still modelling the land cover dynamics. Before 1974, the populations used to support themselves by harvesting and picking during the rainy season, which is also the time to collect latex from rubber trees and the annual crop of Para nuts. It is during this period that gold and diamond prospecting started in the area. The forest was mainly accessible from the river, for there were no real trails yet.

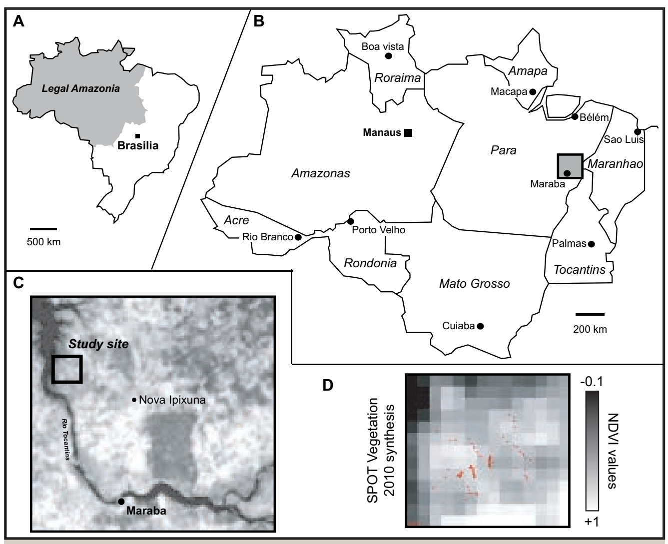

Figure 1.
Location of the study area, Nova Ipixuna Municipality (the pixel size on the satellite map is 1 km²).

A swamp area close to the lake. During rain season the pasture is temporary flooded causing strong change in the ecological functioning of this landscape.
Photo V. Gond

At the forest edge, different invaded pastures by palms. In front, pasture is clean and reversely on the back the pasture is completely closed by palms.
Photo J. Oszwald

In 1974-1975, an important milestone came with the completion of the trans-Amazonian highway to Maraba. It enabled many migrants to reach bordering forest areas. Then, settlement policies were implemented along the trans-Amazonian highway, in particular by the INCRA (Instituto Nacional de Colonizaçao e Reforma Agrària), which entailed the appearance of the first food crops, such as rice or manioc plots. Moreover, new farmers came in growing numbers, attracted by the discovery of the Carajas mines, south of the study site. This discovery implied the creation of road services to the mines, with the Carajas-Maraba-Sao Luis railroad (Maranhao), but also with the construction of asphalt roads, such as the Carajas-Belém road, for instance. Finally, the coming of numerous miners greatly increased the cities' needs for energies, which hastened the development of new policies to build the Tucurui hydroelectric dam (2,500 km²).

During this period, the world market prices for latex and Para nuts dropped, compelling the large farm operations, as well as the small family farms to turn to cattle rising. Today, the progression of the deforestation front on the study site aims at building grasslands dedicated to intensive cattle rising. In this context, the Nova Ipixuna study site which is a focal point of the AMAZ project[1] was investigated (figure 1).

Remote sensing data

A ten-day NDVI synthesis ("S10-composite") images data set from SPOT-VEGETATION (VGT) were used to produce temporal NDVI profiles for the test site from 1998 to 2010. The S10 composites have spatial resolution of 1 km and are corrected for radiometric, geometric and atmospheric effects (Mayaux *et al.*, 2000). The combination of spectral range, spatial resolution, and exceptional geometric fidelity with a pixel-to-pixel registration across different dates within 500 m (Vegetation, 2004) are well suited to regional vegetation studies. NDVI is a combination using red [0.61-0.68 µm] and near infra-red [0.78-0.89 µm] channels. It is devoted to evaluate the photosynthetic activity of the Earth surface.

Certain periods of the year were not usable because of the strong nebulosity and frequent precipitations, which characterize the equatorial environment during the rainy seasons. During these periods NDVI is very perturbed. The study was limited to the driest months, *ibid est* for the Nova Ipixuna area: June, July and August from 1998 to 2010.

[1] AMAZ (Services écosystèmiques des paysages agrosylvopastoraux amazoniens : analyse des déterminants socio-économiques et simulation de scénarios, 2006-2010) is a French research project within which the present study takes place for study eco-efficient landscapes in deforested area.

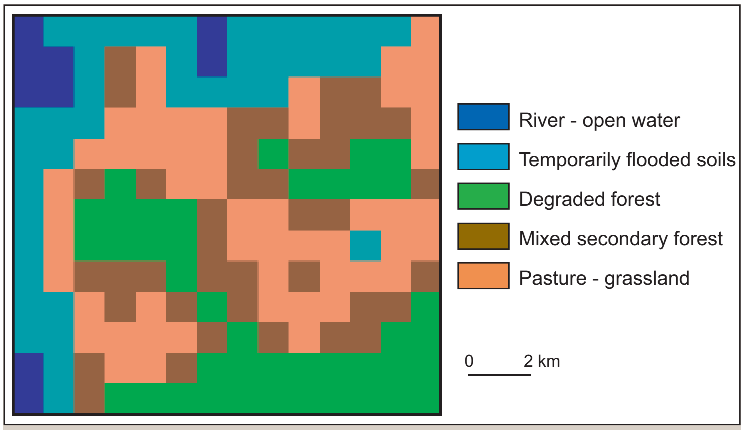

Figure 2.
Land use map developed from the NDVI/SPOT VEGETATION synthesis imagery (computed over the decades of June, July and August 2010; the pixel size on the satellite map is 1 km^2).

Field measurements

The ground survey was carried out in March 2007 and aimed at helping in the differentiation of the various landscape units so as to carry out a multi-temporal analysis of low resolution satellite images. Tropical forest areas are very complex, vertically (multi-layer vegetation) and horizontally (landscape heterogeneity). Before the beginning of the ground survey, a colour composite of a Landsat-TM image taken in 2006 was produced. Structures are identified according to the colour, the texture, the shape of the geographic object analysed. This preliminary analysis makes it possible to develop a sampling strategy for the vegetation areas surveyed. These areas are then visited and described to enable the radiometric identification *in fine* of the of landscape components.

This ground survey enabled to gather the coordinates of about 168 known ground control points, which give an overall picture of the elements of the landscape. The resulting database is used to identify the different landscape units, and to spectrally characterize those units in order to monitor them in the long term. A supervised nearest neighbours classification trained by field data base was applied to the NDVI three month time series.

Results and discussion

The classification of the Nova Ipixuna using the NDVI synthesis computed over the period of June to August 2010 is presented figure 2. The 2010 classification reveals that 99% of the pixels are correctly classified with a Kappa index of 0.96. This classification identified pixels corresponding to forest areas and to grasslands. These pixels were extracted from the multi-temporal data base, and the average NDVI was calculated from the arithmetic mean in order to determine an average spectral profile of forests and grasslands between 1998 and 2010 (figure 3). During this same period, temporal dynamics of the average NDVI of forest and grassland areas show a quite similar trend as for the dry season months. Indeed, the shape of the two curves is nearly identical, the only difference being the NDVI signal strength in the forest areas, which rates higher, particularly in 1999 and 2000, with a maximum of 0.9 for forest and 0.8 for grassland. Based on the above statements, it is thus possible to identify a shift in the dynamics of the pixels that from forest turn into grasslands, with a change in the intensity of the signal resulting in a drop in NDVI values: from -0.03 to -0.1 (figure 3).

Therefore, a statistical thresholds was identified revealing any sudden change in the surface quality, such as the settlement of grasslands through burnt clearing or cut clearing (Achard *et al.*, 2001; Richard, Poccard, 1998). To that end, the spectral profile was extracted in the NDVI between 1998 and 2010 of each grassland pixel identified in 2010. These data were compared to the average spectral profile of forests (figure 4). The comparison of these spectral profiles enables to identify a break date in the trend line, which appears in the signal strength. It reveals that some pixels identified as grasslands in 2010 were already grasslands before 1998; (pixels 1 and 2). On the contrary, the conversion dates of the other pixels, which characterize the main dynamics identified in the whole data base, are subsequent to 1998 (pixel 3: 2000; pixel 4: 1999; pixel 5 and 6: 2003; pixel 7: 1999 and regrowth then June 2005; pixel 8: 2005; pixel 9: 2008 and pixel 10: 2009).

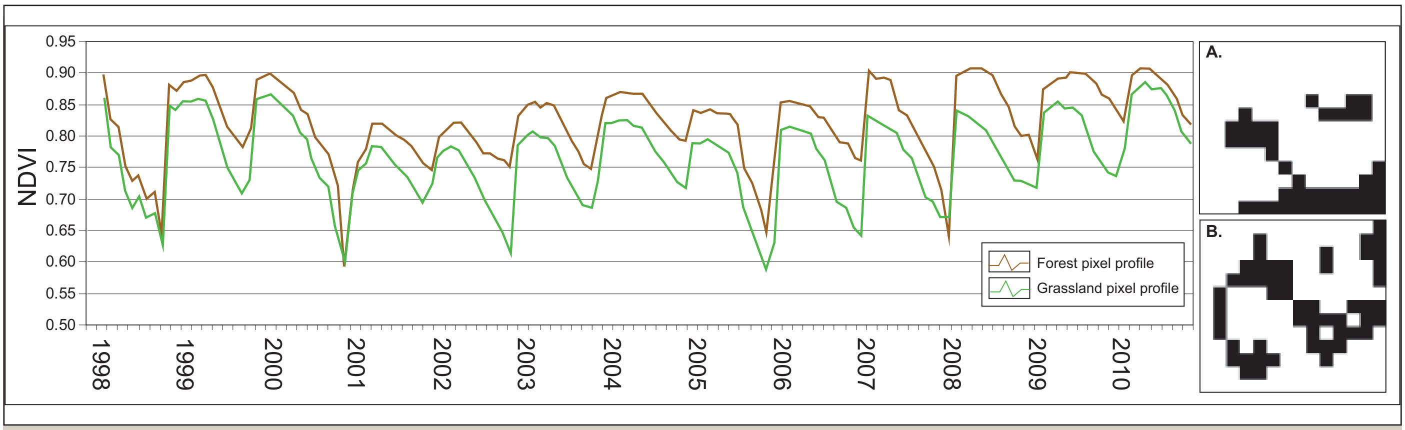

Figure 3.
Forest and grassland mean spectral signatures of Nova Ipaxuna study site between 1998 and 2010 (for three month: June, July, August). These means are calculated from the arithmetic average of all the pixels identified as forests and grasslands during the classification.
A. pixels classified as forests (fig. 2). B. pixels classified as grasslands (fig. 2)

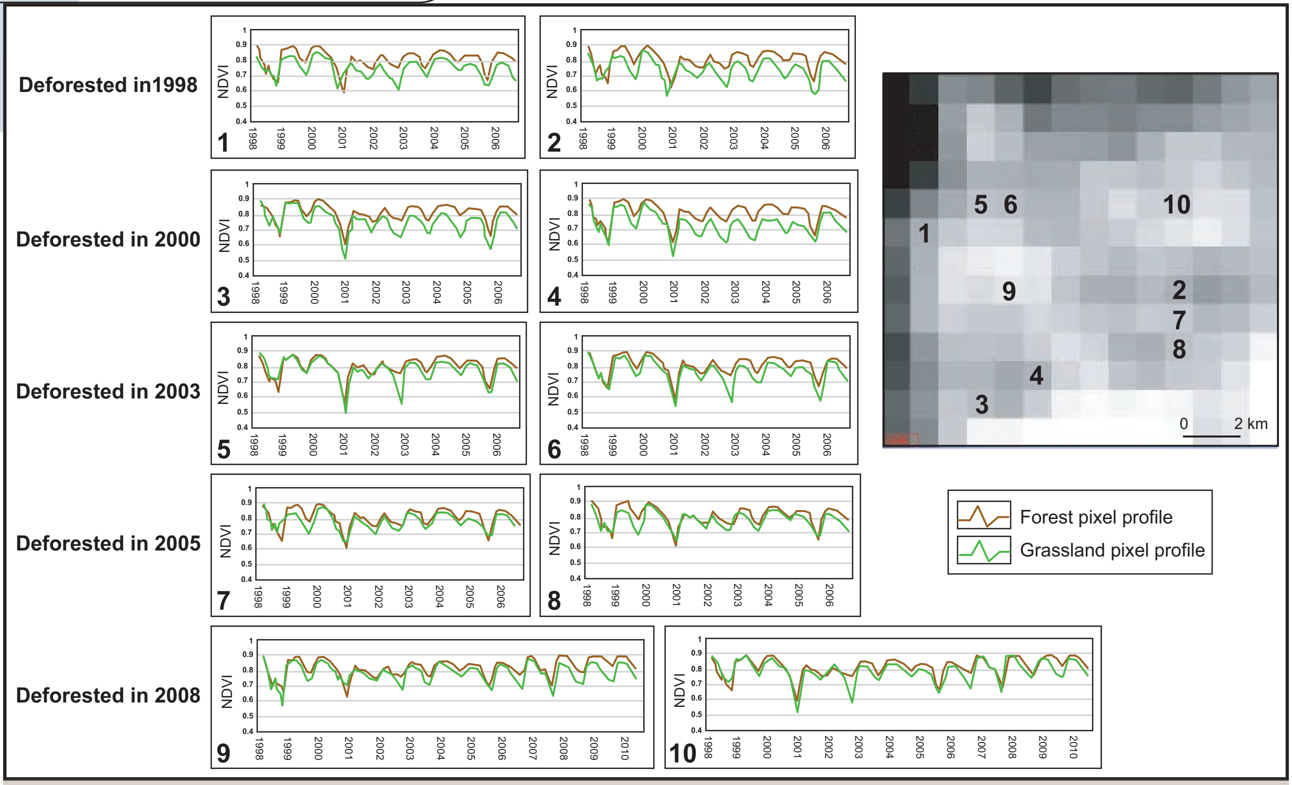

Figure 4.
Spectral dynamics of some pixels identified as grasslands in 2010 on Nova Ipixuna study site between 1998 and 2010.
This curve is compared to forest mean spectral signatures.

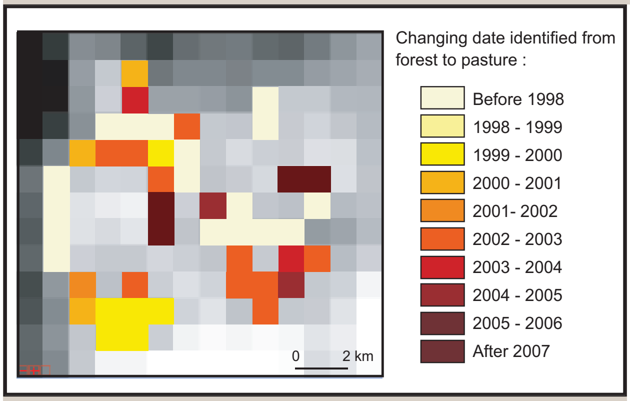

Figure 5.
Dynamic mapping of the pioneer front between 1998 and 2010 on Nova Ipixuna study site.

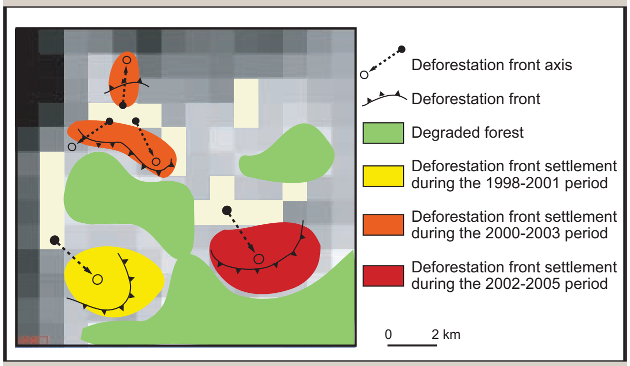

Figure 6.
Map illustrating change dynamics identified on Nova Ipixuna study site between 1998 and 2010.

This identification enables to construct an evolutionary map representative of the spatial composition of the pioneer front in the study site of Nova Ipixuna between 1998 and 2010 (figure 5). The geographic analysis and interpretation of the various dates indicating land use changes emphasize a part of the deforestation phenomena in Nova Ipixuna. This interpretation generates a synthesis map of the spatial dynamics of land use changes between 1998 and 2010 (figure 6). This synthesis map illustrates the local dynamics of the deforestation front, as well as the sectors that have been more vulnerable to the extension of grasslands over the past few years. This map shows the formation of small forest islands, particularly in the south-central part of the study site. As the deforestation front set up between 2002 and 2005 continues to spread, the small forest islands in the western-center of the study site might suffer of many threatened (Briant *et al.*, 2010; Laurance *et al.*, 2011) and finally completely disappear to become grasslands in the years to come.

The deforestation front that started before 1998, focused especially on the west of the river shoreline, and near easily accessible trails located in the North-East and East-Central regions. But today, it tends to spread southwards, towards still “intact” forest areas. Forest clearance for grasslands has major implications not only on biodiversity and hydrology but also on traditional farming, agro-extractivism based on cropping and adding value to the Para nut. The tool presented here points the usefulness of such technique to analyse precisely the complexity of the deforestation front fragmentation. Export this method to other deforestation front could be important for scientific or management purposes. The use of standardized SPOT-VEGETATION data is a crucial advantage to the repeatability of the process proposed here.

Conclusion

The methodological approach of this study is particularly relevant within the broad context of the Amazon deforestation monitoring. Landscapes are highly fragmented into fields, grasslands, forest islands, but also into fallow lands and new forests. Remote sensing is an efficient way to study the speed and dispersion related to the quality of the land cover dynamics. The technique developed here enables to identify locally the temporal trends of the landscape dynamics by using the temporal repetitivity of the VEGETATION sensor. The vision shows how relevant the development of indications is, providing major information to the actors and decision makers in charge of land management and planning. Governance being at the heart of the current environmental issues, remote sensing appears as a fundamental tool for the characterization and understanding of land cover dynamics.

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This paper is dedicated to the memory of Zé Carlos and Maria who were killed in 2011 within the study site of Nova Ipixuna.

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