MONITORING HUMAN-INDUCED LAND USE AND LAND COVER CHANGES IN THE CAMPOS AMAZÔNICOS NATIONAL PARK (BRAZIL) AND ADJACENT AREAS USING NDVI TRAJECTORIES

Daniel Borini Alves[123], Fernando Pérez-Cabello[12] and Marcos Rodrigues Mimbrero[12]

1. University of Zaragoza, Department of Geography and Spatial Management, Zaragoza, Spain; dborini@unizar.es, fcabello@unizar.es, rmarcos@unizar.es
2. Aragon Institute of Environmental Science (IUCA), Zaragoza, Spain;
3. CAPES Foundation, Brasília, Brazil.

ABSTRACT

The object of the analysis is the human-induced land use and land cover (LULC) changes in the Campos Amazônicos National Park (Brazil), monitoring and distinguishing trajectories in NDVI (Normalized Difference Vegetation Index) variations. The study area (26604 km²) includes the National Park and adjacent areas, has been subject to significant LULC dynamics associated mainly with the deforestation process and use of fire. Four Landsat images mosaic was created for each year between 1984 and 2013. NDVI values were generated for each mosaic and then the initial and the final years of the time series were classified into five categories (water, forest, secondary/degraded forest, savannah/pasture and crop/bare soil), using a maximum likelihood supervised process. The NDVI trajectories were analysed using a random points sample for the whole study area and pixel by pixel in a selected upscaling area. The main regressive trajectory was the transition “forest to crop/bare soil", which shows that 2003 was the year of the greatest drop in NDVI values associated with growing of the deforested areas. Splitting the years into two periods 1984-2002 and 2003-2013, the average of "forest-crop/bare soil" NDVI values changed from 0.819 to 0.570. The results indicate distinct trajectories associated with LULC changes that contribute to better understanding the human impacts operating in the area.

INTRODUCTION

The southern Brazilian Amazon has experienced significant human-induced land use and land cover (LULC) changes during the last decades mainly associated with deforestation, degradation processes and using fire as a main management instrument to the agro-pastoral practices (1, 2). As a response to these pressures on biodiversity, a major government policy established the creation of conservation units, contributing to mitigate human impacts on this important biome of the planet (3, 4, 5).

To monitor and better understand these LULC changes, remote sensing data is an essential source allowing to generate systematic information at different spatial and temporal scales (6). Regarding remote sensing techniques, the generation of vegetation indexes calculated from the combination of spectral bands stands out from the other techniques. Also, the NDVI is one of the most used index, relating spectral information of the red and near infrared to generate a variable to estimate the quantity, quality and development of vegetation (7).

To calculate this index, it is possible to count on lifting decades of satellite sensor information, which highlights the potential of the Landsat time series (8, 9, 10). This series provides free access to an extensive gallery of relevant temporal and spatial resolution images, which are widely used and validated in scientific research on remote sensing.

In this context, this work aims to explore and enhance comprehension of the human-induced LULC changes during the last three decades in the Campos Amazônicos National Park and the adjacent areas applying a multi-temporal analysis of NDVI trajectories, supporting to understand the importance of this area in biodiversity conservation process in local and regional scales.

Study area

The study area (26604 km^2) (Figure 1) includes the Campos Amazônicos National Park, created in 2006, and adjacent areas. The area is located in the south of the Brazilian Amazon, covering municipalities in the states of Amazonas, Rondonia, and Mato Grosso. The adjacent areas consist of several regions of agro-pastoral activities and indigenous lands, where pastures for cattle grazing and grain crops predominate, using fire as the main tool for land management. The upscaling area (36 km²) is located in the southwest sector of the study area, which corresponds to a representative area relating human-induced LULC changes with high rates of deforestation in recent decades.

The area has a savannah vegetation enclave in predominant Amazon biome (11). The savannah area, locally identified as *cerrado*, displays grassland and shrubs vegetation domain, while the Amazon area presents tree species from rain forests (12). The region have high annual average temperatures, ranging between 24°C and 28°C and the annual rainfall of up to 2000 mm. The dry period extends from May to October. However, the dry season varies in certain years, due to the effects of different regional climate phenomena El Niño, Pacific Decadal Oscillation and Atlantic Multidecadal Oscillation (13, 14). During the dry period, hot pixel detections show an intensive use of fire for the management of agro-pastoral practices (15).

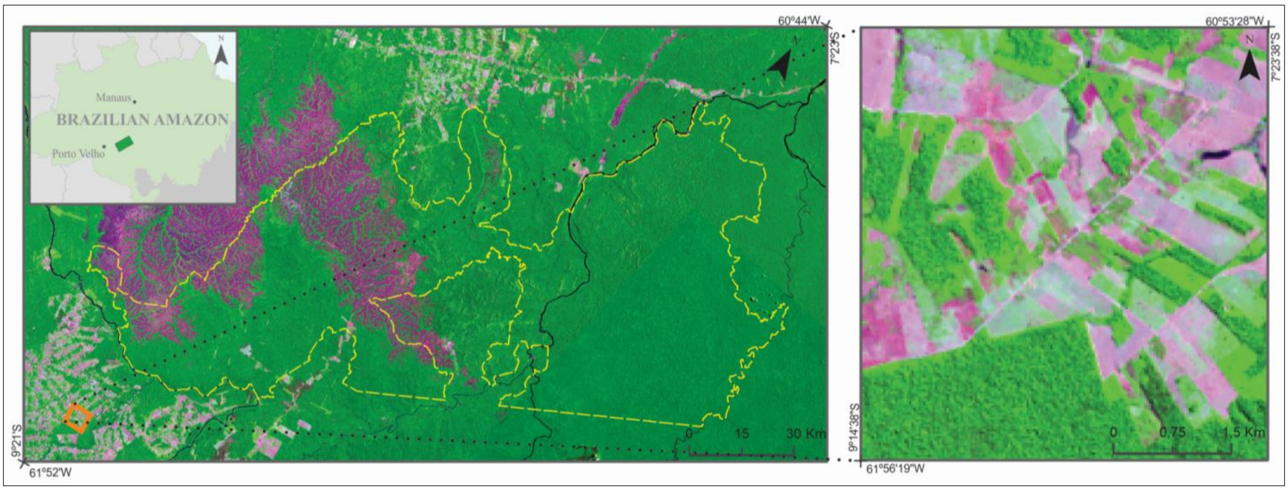

Figure 1. Campos Amazônicos National Park (yellow polygon) and the adjacent areas, in the southern of Brazilian Amazon, displayed over a Landsat OLI mosaic image (RGB-754) from August, 2013. The right image is a detailed fragment, which shows an agro-pastoral activities area.

METHODS

The methodological procedure starts with data preparation and pre-processing, selecting and downloading four images per year (Table 1), from 1984 to 2013, derived from the Landsat series (TM, ETM+ and OLI). In this case, an atmospheric corrected product (Landsat Surface Reflectance) was used, available at http://earthexplorer.usgs.gov, processed by USGS. These four images were merged giving priority to the paths/rows 231/66 and 231/65 which covers approximately 70% of the study area. All images belong to the same period of years, June to September, associated with the dry season in the study area.

During the image selection process, was prioritized pixel quality (based on the information provided by the supplier), low percentage of cloud cover (lower than 20%) and proximity to the end of the dry season (seeking the maximum of the dynamic information in a given year and reducing stationary phenological effects of multi-temporal analysis). Closer images to the early dry season record more vigorous vegetation stages most often associated with high rainfall rates in the remaining months of the year (16).

Table 1: The selected Landsat TM/ETM+/OLI images by path/row.

Year	Landsat sensor/Julian date				Year	Landsat sensor/Julian date			
	231-66	231-65	230-66	230-65		231-66	231-65	230-66	230-65
1984	TM/217	TM/217	TM/258	TM/226	1999	ETM+/218	ETM+/218	TM/219	ETM+/227
1985	TM/219	TM/219	TM/212	TM/228	2000	TM/197	TM/197	TM/206	TM/206
1986	TM/222	TM/222	TM/167	TM/167	2001	ETM+/223	ETM+/223	ETM+/216	ETM+/216
1987	TM/193	TM/193	TM/186	TM/186	2002	ETM+/178	ETM+/162	ETM+/187	ETM+/187
1988	TM/196	TM/196	TM/189	TM/221	2003	TM/205	TM/205	TM/182	TM/198
1989	TM/182	TM/182	TM/159	TM/255	2004	ETM+/232	ETM+/232	ETM+/209	ETM+/177
1990	TM/185	TM/185	TM/194	TM/194	2005	TM/242	TM/210	TM/203	TM/219
1991	TM/188	TM/220	TM/197	TM/229	2006	TM/197	TM/197	TM/190	TM/190
1992	TM/175	TM/207	TM/184	TM/200	2007	TM/216	TM/216	TM/209	TM/209
1993	TM/177	TM/177	TM/202	TM/170	2008	TM/219	TM/219	TM/212	TM/212
1994	TM/196	TM/196	TM/221	TM/221	2009	TM/253	TM/253	TM/246	TM/246
1995	TM/215	TM/215	TM/160	TM/192	2010	TM/208	TM/208	TM/201	TM/201
1996	TM/186	TM/186	TM/195	TM/195	2011	TM/211	TM/227	TM/204	TM/204
1997	TM/204	TM/204	TM/197	TM/197	2012	ETM+/222	ETM+/222	ETM+/215	ETM+/215
1998	TM/175	TM/175	TM/184	TM/184	2013	OLI/216	OLI/216	OLI/225	OLI/193

NDVIs values were generated for each mosaic. The mosaics of 1984 and 2013 were classified into five categories, using a maximum likelihood supervised process as follows:

* Forest (F) – areas of dense rain forest or open rain forest. The open rain forest associated with forest drainage channels galleries in the savannah's enclave area;

* Secondary/degraded forest (Fs) – regenerated forests or in advanced process of regeneration, as well as areas of degraded rainforests areas. It also includes savanna areas with denser shrub domain;

* Savannah/pasture (SP) – grassland and shrubby areas largely used as areas of creation of extensive cattle on pastures;

* Crop/bare soil (CB) – ranching and croplands, with large harvested zones, viewed as bare soil. It also includes burned areas to crop/pastures usage;

* Water (W) – rivers and small water reservoirs, which is located in certain pastures and agricultural areas.

The classification was validated using the Cohen kappa index, based on a database of control points comparison. Cloud, shadows and smoke masks were applied associating a 'nodata' value to these pixels. The trajectories in NDVI variation values were analysed in a sample of random points for the whole study area (covering 3%, with a total of 969850 points) and pixel by pixel for the upscaling area. For each NDVI trajectory average, standard deviation and coefficient of variation were calculated according to the intersection of thematic classes. Additionally, a change point detection was calculated for the trajectories following a non-parametric approach (17) and using a 'changepoint' package of R software (18).

RESULTS AND DISCUSSION

The results of the classification process (Figure 2) allow a spatial configuration of the dynamics of the LULC in recent decades. Validation with a Cohen kappa index shows values of 0.82 and 0.84 to 1984 and 2013 classifications respectively. Among the LULC changes, we mainly identify the loss of forest areas associated with the advancement of agricultural areas and pastures in the southwest and north sectors. The analysis records the loss of 2120 km² of forest between 1984 and 2013, in areas predominantly outside of the limits of the National Park. In quantitative terms, 883 km² of forest became crop/bare soil in 2013, and 706 km² became savannah/pasture.

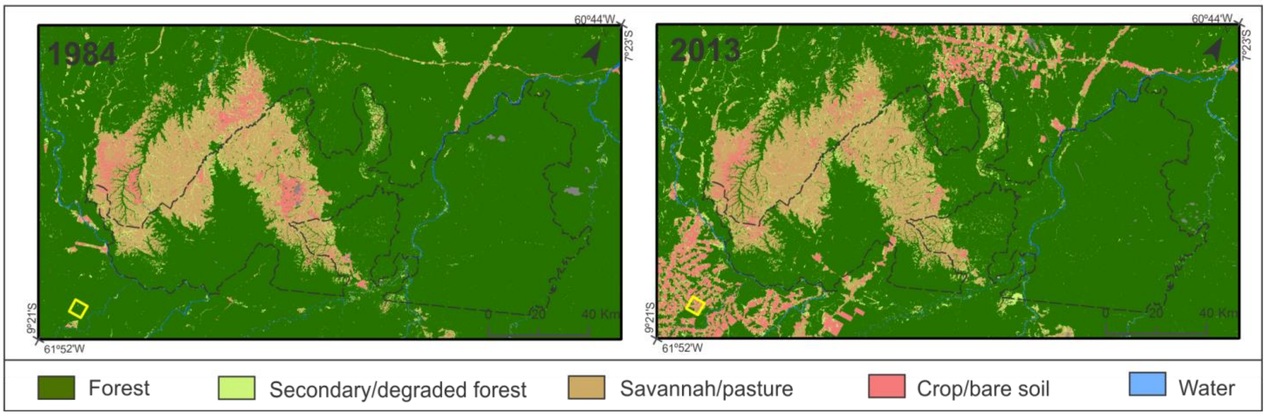

Figure 2. LULC classification of 1984 and 2013.

This LULC dynamics can be analyzed through the NDVI trajectories (Figure 3). F-F displayed the most stable trajectory of NDVI values, with an average value of 0.830 and a coefficient of variation of 2.99%. While the pixels of SP-SP, which was periodically affected by fire, had an average NDVI value 0.560 and coefficient of variation 17.02%. The transition of F-CB trajectory revealed that during the first 13 years average values stand close to those from the F-F trajectory (mean values of 0.828). In 1999, identified as break point of the trajectory (17), the average NDVI values begin to distance themselves from the F-F values. This detachment is consolidated in 2003, following gradually, provided with increased participation of CB class of pixels associated with deforestation. The average NDVI values are 0.488 in 2013, associated with the CB class values. Splitting the years into two periods 1984-2002 and 2003-2013, F-CB NDVI values changed respectively from 0.819 to 0.570. The F-SP trajectory follows the same logic established in the F-CB transition, with a steeper decline in the second half of the review period. The breakpoint of this trajectory is set in 2002, where the descents gradually expand in the following years and presents a final average of 0.631 in 2013.

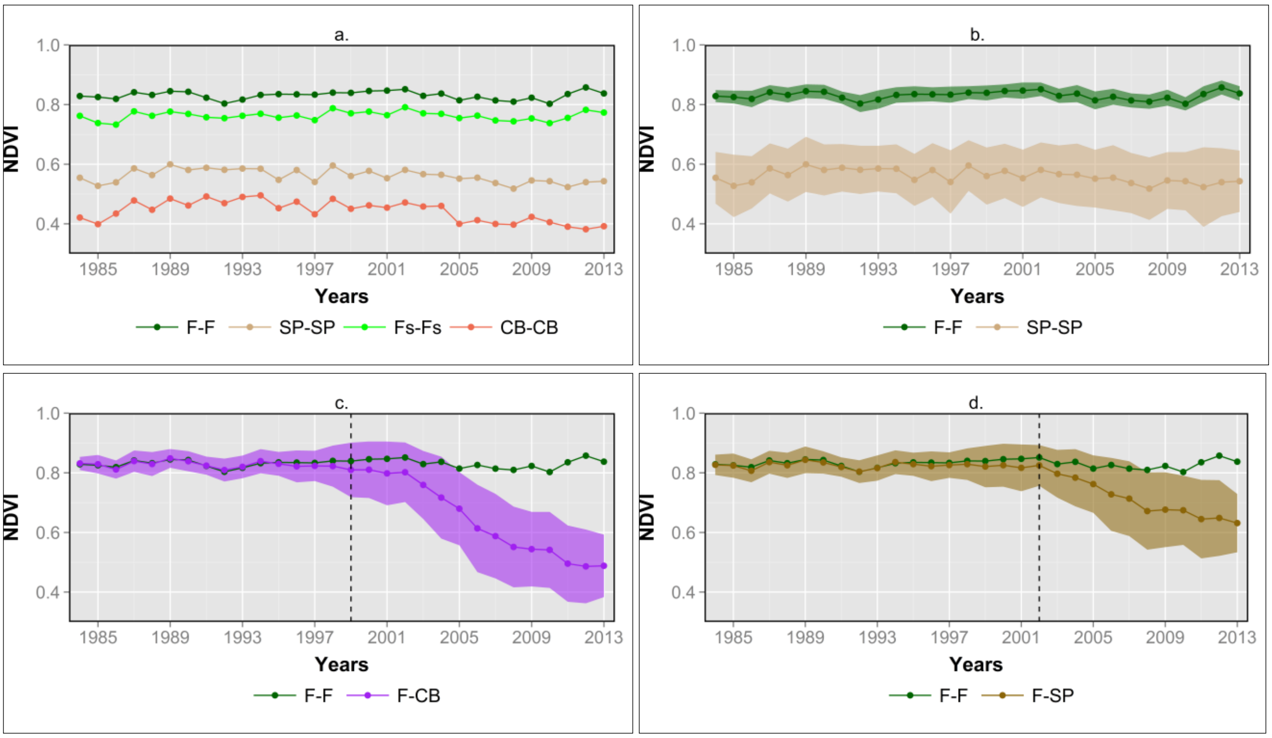

Figure 3. NDVI trajectories of each classified class (a); Variability of F-F and SP-SP trajectories; (b); F-CB trajectory compared to F-F trajectory (c); F-SP trajectory compared to F-F trajectory (d). Maximum and minimum limits of the filled areas are the average added and subtracted to their respective standard deviations. Break points (17) are assigned in the transition trajectories (F-CB and F-SP).

The deforestation and degradation processes can be seen in more detail by analysing the trajectories of NDVI along the upscaling area (Figure 4). A change point analysis applied pixel by pixel shows that losses of forest were more intensive in the last 15 years. 84% of the classified points changed between 1999 and 2013, highlighting the year of 2003 (24% of changed points).

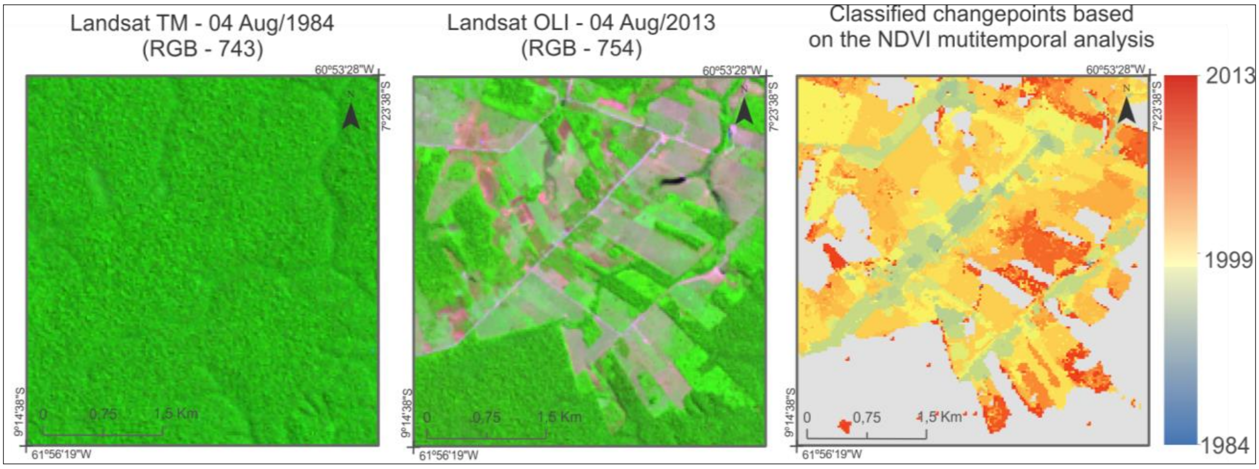

Figure 4. Deforestation and degradation process analysed based on the NDVI trajectories, identifying change points pixel by pixel (finding at most one change point – AMOC) in the upscaling area.

CONCLUSIONS

NDVI multi-temporal analysis was proved that it is a useful tool allowing detecting and monitoring LULC changes. In this particular case, combining NDVI monitoring and change point detection process made possible to identity an increase in the deforestation, mainly in rain forest communities, starting 15 years ago and becoming more intense over time.

The results shows that the human-induced LULC changes has a considerable effect on the adjacent areas of the Campos Amazônicos National Park, which highlights the importance of this protected area in the context of the biodiversity conservation in local and regional scale. Nevertheless, is important to invest in the existed protected areas, in addition to create a new ones, facing the dilemmas associated with the conservation policy of Brazilian Amazon (4).

It is worth to highlight the current potential of Landsat products since Landsat 8 satellite, launched in 2013, guarantees their continuity. This fact allows enhancing valuable multi-temporal analysis and monitoring of remote areas.

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