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Conference Paper · April 2009

Anais XIV Simpósio Brasileiro de Sensoriamento Remoto, Natal, Brasil, 25-30 abril 2009, INPE, p. 2523-2530.

Using Landsat images combined with field data for landscape evaluation in the Amazon

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Abstract. Long term studies using on a network of forest plots have generated significant insights into the spatial and temporal dynamics of forest carbon cycling in Amazonia. However, bias in plot location within landscapes may be influencing the values obtained for the forest parameters. Here we use land cover maps and the spectral signature of each class generated based on Landsat data to evaluate the heterogeneity of the landscape within which the plot is embedded. In addition, we evaluate the regional variation in wood productivity, wood specific density and biomass revealed by the RAINFOR network taking into account the forest physiognomy mapped. Our methodology consisted of aggregating remote sensing data covering 24 field plots and generating landscape maps to identify the specific forest physiognomy of the plots. Then, we evaluated the spectral signature of the land cover classes. Finally, we analyzed three forest parameters to assess their representativeness with respect to the type and area of the landscape surrounding the plot. Our results showed that a great range of forest types were distinguishable in the Landsat data. We also showed that when you take into account the total area of the forest physiognomy in order to consider the data representativeness of the region, it is essential to consider the landscape, as the more heterogeneous the region, the more influence in the total calculation it presents. Finally, the spatial patterns of the forest biophysical parameters published by the RAINFOR are consistent with our results that take into account the landscape variability.

Keywords: Landsat/ETM+, Landscape, above ground biomass, wood density, wood productivity, Amazon.

1. Introduction

The Amazon is an important part of the global biosphere, playing a major role in influencing climate systems (Andreae et al., 2004; Malhi et al. 2008), and providing vital ecosystem services such as carbon cycling (Houghton et al., 2001) and water cycling (Marengo, 2005).

One of the main sources of information about the carbon dynamics and forest ecology of Amazonia is widely dispersed networks of permanent forest inventories plots such as the RAINFOR network (Malhi et al., 2002).

The picture emerging from RAINFOR network studies suggests that slow growing forests from central and eastern Amazonia, where soils are poorer, have significantly higher above ground biomass (AGB), higher wood density and larger seeds than stands in northwest and southwest Amazonia that are situated on more fertile soils (Baker et al., 2004, Malhi et al., 2006, ter Steege et al., 2006). However, nearly all of these findings rest on the assumption that the permanent forest plots are a representative sample of the part of the Amazon in which they are based. The implicit assumption is that a 1 hectare field plot provides a reasonable reflection of regional forest structure, species composition and dynamics (Chave et al., 2004).

However, to effectively and accurately scale-up these field data it is fundamentally important to consider the landscape mosaic structure, defined by Zonneveld (1989) as the “landscape unit”. This sampling unit relies on spatially locating and mapping homogeneous areas in the landscape based on the available data that drives the vegetation characteristics for a region and has already been used with success (Franklin and Woodcock, 1997, Asner and Wessman, 1997, Aragão et al., 2005).

In this study, we use land cover maps and the spectral signature of each class generated based on Landsat ETM+ data to evaluate the heterogeneity of the landscape within which the field plot is embedded. In addition, we evaluate the regional variation in wood productivity, wood specific density and biomass revealed by the RAINFOR taking into account the forest physiognomy mapped.

2. Methodology

2.1 Study area

We evaluated the landscape and field data, such as wood productivity (WP), wood density (WD) and above ground biomass (AGB) of four sites (24 field plots in total) covering western, central and eastern Amazonia, which have been used in intensive studies (e.g. Laurance et al., 1998, Malhi et al., 2004, Phillips et al., 2004, Lewis et al., 2004, Baker et al., 2004). Sites were chosen on the basis of the number and availability of the field plot data and on the availability of cloud free remote sensing data (Table 1).

Table 1. Study site characteristics.

Site	Number of Plots	Country	Central coordinate	Landsat Path/Row	Image date
Allpahuayo	5	Peru	73°25´W, 3°56´S	06/63	23/09/2003
Caxiuanã	2	Brazil	51°27´W, 1°43´S	225/61	20/08/2002
Manaus	11	Brazil	60°01´W 2°28´S	230/62	08/09/2002
Tambopata	6	Peru	69°17´W 12°50´S	02/69	23/08/2001

2.2 Landsat ETM+ data processing

The spectral bands 1 to 5 and 7 of four Landsat 7 /ETM+ scenes were used in this study. These images were acquired during the dry season (August and September) due to the higher availability of cloud free atmospheric conditions. The images were imported into a dataset in a Geographic Information System (GIS) for image processing and spatial data integration. The projection used was geographic, datum WGS84. The images were geographically rectified using the methodology suggested by Richards, 1993. The image-to-image rectification was performed using the NASA GeoCover[1] product, with 14,5m spatial resolution. The root mean square error (RMSE) was less than two pixels and normally less than one, depending on the number of control points possible in each scene (mainly roads or rivers).

2.3 Topographic data processing

The topographic data used in this study was the Shuttle Radar Topography Mission (SRTM) version 2[2], which generated a complete high-resolution digital topographic database, with 90m spatial resolution. The elevation data was then resampled to 30 m spatial resolution using a simple matrix division for the data aggregation with the Landsat 7 ETM+ images. The elevation data was used to further characterize the vegetation types.

[1] https://zulu.ssc.nasa.gov/mrsid
[2] ftp://e0srp01u.ecs.nasa.gov/srtm/version2

2.4 Generating the Landscape maps

To select the region to be analyzed in each scene, the field plots data were firstly located in the images using the Global Position System (GPS) punctual data acquired in field campaigns by our group and other investigators. Based on the location of the field plots, a region of 10 km x 10 km with the field plots located in the center was established for defining the landscape region to be mapped and analyzed. For the Manaus site a larger areas was selected to include all the plots.

The image classifications performed in this study were generated using image segmentation coupled with a region-based algorithm, followed by non-supervised classification algorithm based on clustering techniques (Camara et al., 1996). For a better result, manual edition was ultimately carried out to correct omission and commission errors due to spectral similarity among targets.

The land cover type classes' were defined based on the spectral and textural image's properties, field data information and image interpretation, as described in Table 2. In the literature, the Western Amazonian rain forests have traditionally been divided into two major forest types: inundated forests and non-inundated (*Terra Firme*) forests (Salo et al., 1986). Here, we propose an alternative classification and divide the forest into *Terra Firme* and *Paleovarzea*. The *Paleovarzea* are land cover types located in Holocene/Pleistocene alluvial soils, and this feature, unlike inundated forest, is easily recognized in Remote Sensing imagery. This landscape forest physiognomy differentiation is an effective way to characterize the heterogeneous mosaic of forest composition and structure in *Terra Firme* areas due to differences in edaphic site conditions, especially soil properties (Table 2).

Table 2. Land Cover types description.

Land Cover Classes	Description
Land use	Bare soil, pasture areas, croplands and roads
Disturbed forest	Disturbed forest, secondary forest and logging areas
Clouds/ Cloud shade	Clouds, cloud shadow
Water	Rivers and water bodies
Terra Firme	Typical *Terra Firme* area, with the elevation data showed
Terra Firme 3	*Terra Firme* area with the spectral characteristic between *Terra Firme* and *Terra Firme* 2; presence of palm trees, with sandy soil
Paleovarzea	Forest physiognomy of *Terra Firme*, however located in Holocene/Pleistocene alluvial formations
Bamboo	Bamboo monodominant physiognomy; spectrally was possible to differentiate 2 types
Swamp	Constant flooded area
Seasonally inundated	Seasonally inundated area over streams

2.5 Wood Productivity, wood specific density and AGB of the field plots in the landscape context

To assess the regional pattern of the forest biophysical measurements, we used mean values for forest productivity, wood specific density and AGB data (Malhi et al., 2004, Baker et al., 2004) to calculate the influence of the forest type on the total area where the field plot is located (provided by the landscape map). Specifically, we use the relative area within the landscape of the physiognomy/ies that characterizes the plots within a site to calculate a weighted average for the three biophysical variables (Equation 1). Any discrepancy in the regional pattern in a different way from the already published data would indicate a degree of landscape bias.

$$y = \frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} \qquad (1)$$

Where y is the weighted mean, of a number of variables x_i with weights w_i.

3. Results

3.1 Landscape maps classification

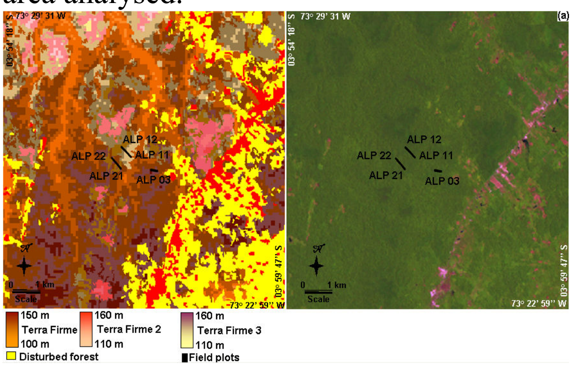
The landscape maps generated are presented in Figure 1.

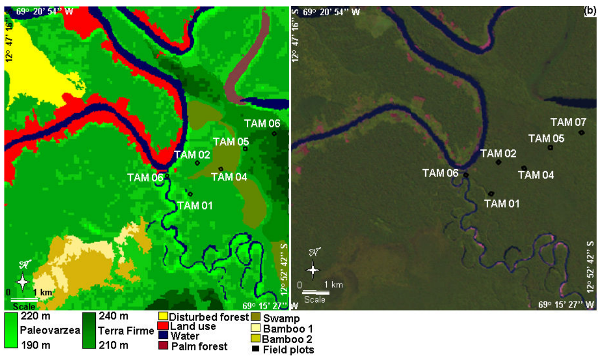
In the Allpahuayo site, in western Amazon, three distinct areas can be distinguished by the classification algorithms in the map generated for the Allpahuayo site: land use, anthropogenic disturbed forest, and primary forest (Fig. 1a). In this site there are four plots and their and if we consider the three basic forest physiognomies, the field plots are representative of two of them, *Terra Firme* and *Terra Firme* 3, varying in between 130m to 150m elevation, functioning as a sample of 50.8% of the natural landscape units mapped in this study.

The Tambopata landscape map has 2 anthropogenic classes (land use and disturbed forest) and 9 pristine forest classes: 3 *Paleovarzea* 2 classes, 3 *Terra Firme* classes, a Palm tree forest, *Bamboo* area and a swampy region. The classification algorithms separated the following classes: Bamboo 1 and Bamboo 2, palm forest, land use, disturbed forest, *Paleovarzea* 2 and *Terra Firme* (Fig. 1b). The swamp area was manually generated based on field experience and textural properties in the image not captured by the algorithm.

The landscape map generated for the Central Amazon (Manaus region) has 12 *Terra Firme* classes in addition to the following classes: seasonally inundated, land use, disturbed forest and a blow down (Fig. 1c). It was possible to separate spectrally all the land cover classes using the classification algorithms. The *Terra Firme* class was further characterized when combining with the altimetry data, varying from 40m to 160m elevation. The most representative classes are *Terra Firme* varying from 80m to 120m elevation. The land use area and the disturbed forest correspond to 2% and 7% of the mapped area, respectively.

The eastern Amazon site, Caxiuanã, presented a land cover map with two anthropogenic classes (land use and disturbed forest), a river and one single forest physiognomy: *Terra Firme* (Fig. 1d). There is also the presence of clouds and clouds shade, and in these areas the ground information were masked. The cloud and cloud shade class represents 22% of the study area. Combining the land cover map with the altimetry data, seven *Terra Firme* classes were generated varying from sea-level to 70m elevation. The most representative forest physiognomy in this area is the *Terra Firme* 40-50 meters altitude, covering 24% of the total area analysed.





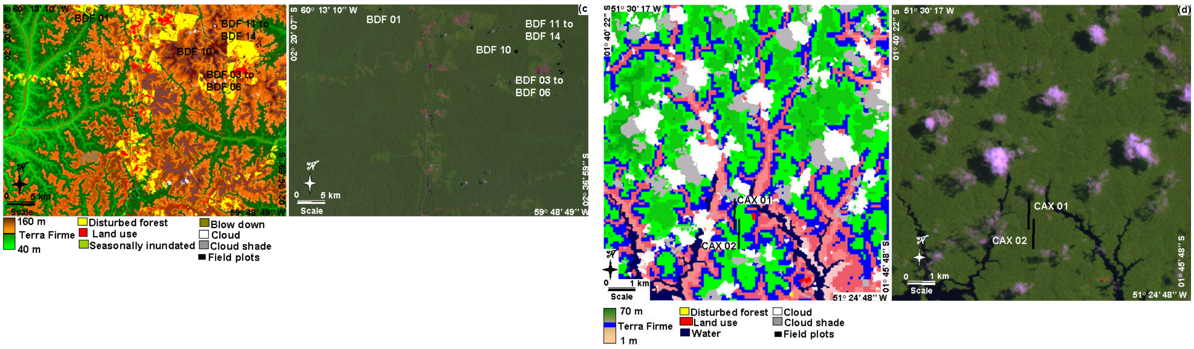


Figure 1. Landscape maps generated for each one of the sites showing the location of the field plots.

In this study, a radiometric normalization of the data was not carried out. Therefore, a direct comparison among the values for land cover classes common for the four sites could not be performed. Here we presented a general evaluation of the spectral variability for each land cover type (Figure 2).

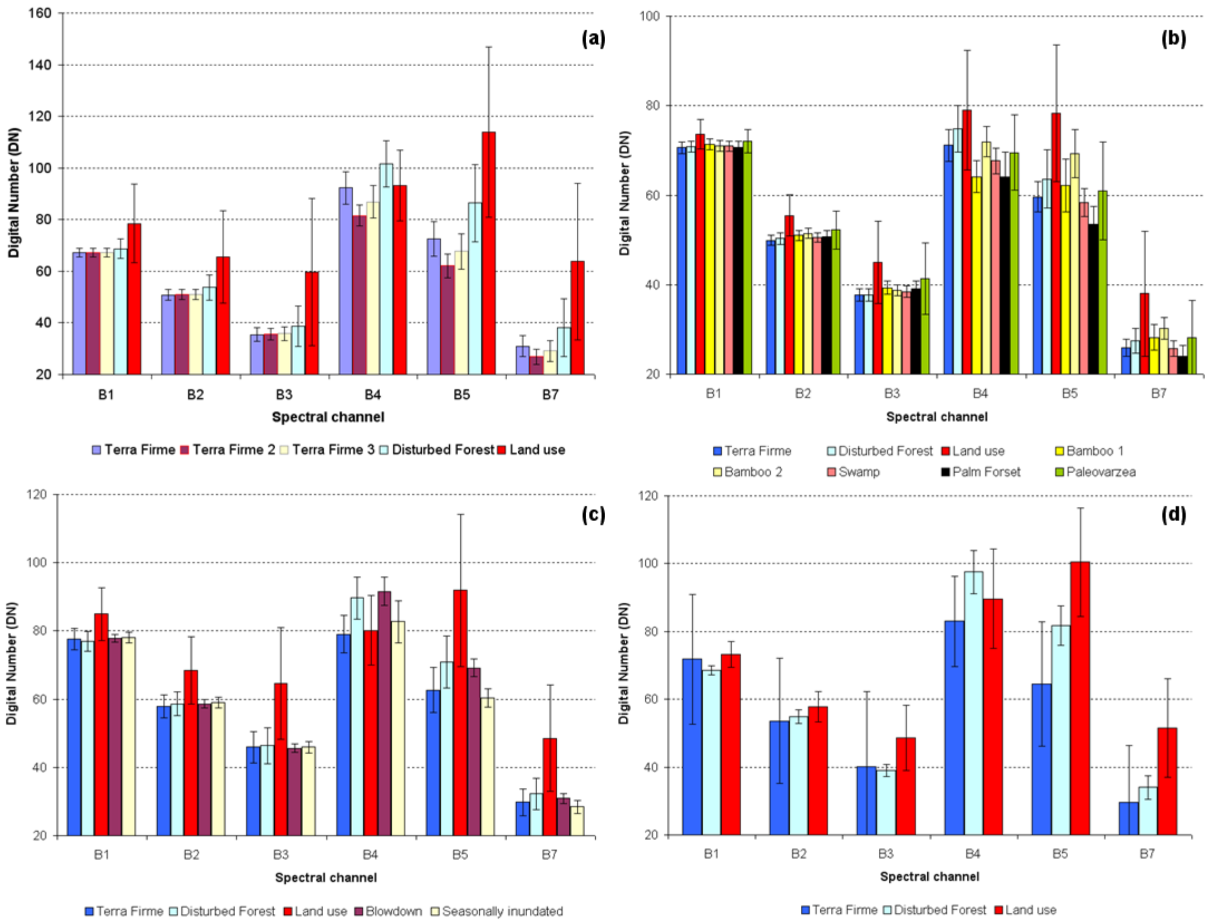


Figure 2. Spectral characterization for the land cover classes for (a) Allpahuayo, (b) Tambopata, (c) Manaus and (d) Caxiuanã.

The *Terra Firme* classes in all sites showed a high variability in channels 4, 5 and 7, reflecting the cell structure and water content of this forest physiognomy. The chlorophyll absorption (channels 1 and 3) and the vegetation reflectance in channel 2 were less scattered in all sites. Disturbed forests presented an intermediate degree of variability for all sites, presenting high variability in channels 3 to 7. Oppositely, the blow down and seasonally inundated forest classes presented a very consistent and poorly scattered data in all channels. The land use class presented a high level of variability, as it included not only vegetated areas but also bare soil patches and agricultural lands.

3.2 Weighted analysis taking into account the landscape maps

Using the weighted values that take into account the landscape area mapped for Allpahuayo, we estimate that, relative to the published studies (Malhi et al. 2004; Malhi et al. 2006; Baker et al. 2004), the mean value of the productivity is 5% higher, and the mean values for wood specific density and biomass of 1.7% and 3.1% lower.

For the Tambopata weighted analysis, it was estimated an ~8% decrease in wood productivity and wood specific density and 6.9% decrease for the AGB relative to published data. The plots TAM 01 and TAM 06 give the highest wood productivity in this physiognomy. Both of them are located in the *Paleovarza* physiognomy and also are less than 50m away from water bodies. In contrast, the lowest and the highest AGB for this site are found in TAM 01 and TAM 06 respectively. The TAM 04, (located in the swamp) gives a mean value higher then the overall mean for this site.

The Manaus field plots have been intensively studied and described in the literature evaluating AGB, wood productivity (Chambers et al., 2001) and forest edge effects (Laurance et al., 1997). In the Manaus site, the forest wood productivity and wood specific density' weighted analysis did not show major variations relative to the published literature. Considering the field sites that can be affected by edge effects (Laurance et al., 1997), three plots are located in less than 500m from a disturbed or anthropogenic area. These plots show a mean wood productivity and biomass of 2.33 Mg C ha^{-1} $year^{-1}$ and 273.81 Mg C ha^{-1}, respectively. These values are higher than the mean values for the other plots in this site suggesting that forest disturbance significantly affects these biophysical parameters. However, due to the low number of sampled plots close to disturbed areas, this does not substantially change the overall mean result for the site.

The weighted analysis suggests that none of the three biophysical variables in the Caxiuanã plots are more than 1% than any of the published mean values

The regional variation in wood productivity, wood specific density and above ground biomass after taking into account the new values that consider the forest physiognomy representativeness through the weighted analysis did show a distinguishable trend in differentiating western from eastern Amazon forest biophysical parameters, but not from Central and Eastern Amazon. Moreover, the western plots (Allpahuayo and Tambopata) did not show clear differences between *Terra Firme* and *Paleovarzea* measurements, but presented significant difference between *Paleovarzea* and *Terra Firme* 3 (Figure 3).

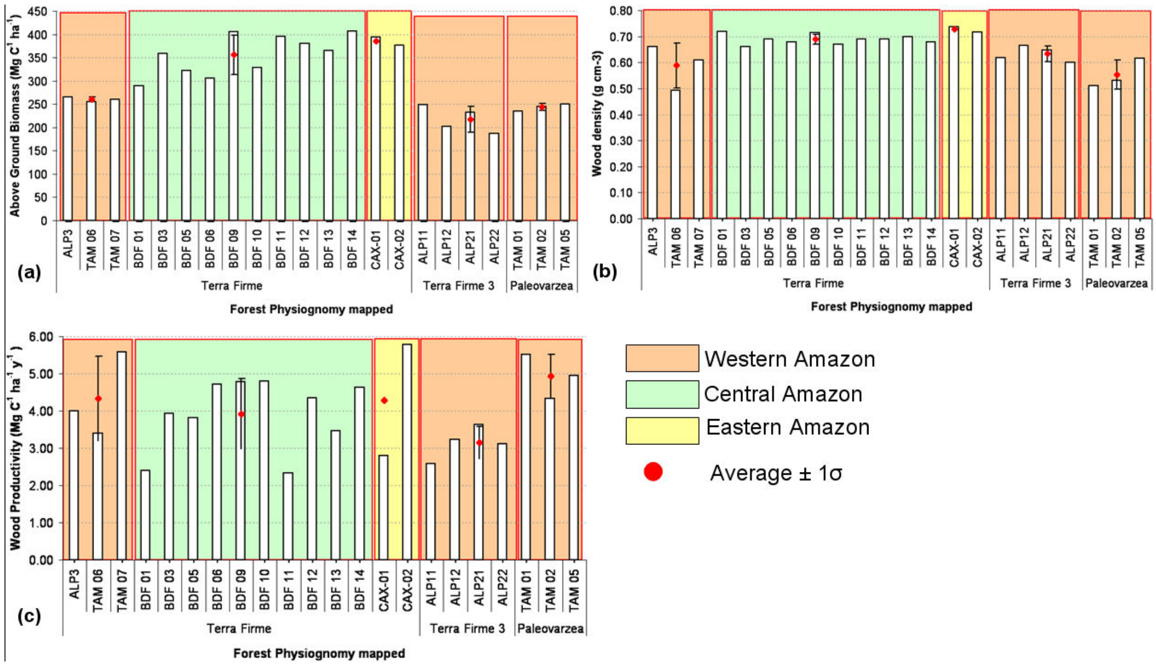


Figure 3. Forest biophysical measurements divided by forest physiognomy mapped in the 3 different regions in the Amazon. (a) Above Ground Biomass, (b) Wood density and (c) Wood productivity. The mean value per region ± 1 standard deviation is also shown.

4. Conclusion

In this study we evaluated the use of Landsat images to asses the landscape variability and forest biophysical parameters in three distinct regions in the Amazon.

Firstly, a great range of forest physiognomies were spectrally distinguishable by the classification algorithms, including different types of *Terra Firme* forests, two types of Bamboo forests, palm tree forest, disturbed forests, blow down area and seasonally inundated regions.

Secondly, we can conclude that when you take into account the total area of the forest physiognomy in order to consider your data representative of the region, it is essential to take into account the landscape, as more variable the region, the more influence in the total calculation it presents (e.g. Tambopata site).

Finally, the spatial patterns of wood productivity (WP), wood density (WD) and above ground biomass (AGB) showed by publications of the RAINFOR network is consistent with these results that consider the Landscape variability: higher AGB and WD in Eastern and Central Amazon, and higher WP in Western Amazon.

Acknowledgments. Liana Anderson would like to thanks the Brazilian Government for her PhD studentship (CAPES, grant BEX 4018052) and the financial support of BECA-IEB (grant B/2006/01/BDE/04). Luiz Aragão would like to thanks the NERC Research Fellowship.

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