Estimating Central Amazon forest structure damage from fire using sub-pixel analysis

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Abstract. Surface fires cause forest degradation in the seasonal parts of Amazonia, but upland forests of the more humid Central Amazon suffer little fire damage. Seasonally flooded *igapó* forests of the central Amazon are an exception, suffering higher fire mortality than upland forest. Here we ask if spectral end members can accurately predict fire effects on forest structure. About 100 km south of Manaus a fire penetrated both forest types in 2009. We compared post-fire spectral indicators of damage against two field metrics of damage: percent loss of basal area and percent loss of individuals. We inventoried ten burned plots per forest type, each 250m x 20m. Averages of basal area and of stem density in unburned areas of both forest types provided estimates of pre-fire structure of the burned plots. Spectral data were collected from Landsat 5 pixels intersected by the 20 burned plots. Field inventories were conducted 3-4 y post-fire to include all delayed tree mortality. The Landsat 5 image was acquired 1 y after the fire, before secondary growth caused canopy greening. Using CLASLite version 2.3 we obtained sub-pixel fractions of NPV, PV and Soil from the Landsat optical bands converted to surface reflectance (6s model). Fire damage per plot ranged 0-90% losses for both basal area and for stem numbers and showed strong linear relationships with post-fire fractions of PV and of NPV (R^2 values ranging from 0.57 to 0.68).

Keywords: floodplain forests, fire damage, linear mixture model

1. Introduction

In the Central Amazon, surface fires cause high mortality in forests on black- and clear-water floodplains, but little damage in upland forests (Nelson 2001; Flores et al, 2012). Resende et al (2014) examined this phenomenon in detail and found that the same fire penetrating igapó caused an average of 57% loss of pre-fire basal area and 59% loss of stems >10 cm DBH, while upland forest plots suffered only 21% and 16% losses of basal area and stems, respectively. Higher damage in floodplains has been attributed to a larger stock of fine fuel and to floodplain forest tree roots being exposed to fire within a well-aerated surface root mat, which is thicker and more prevalent in *igapó* than on upland (Kauffman et al. 1988, Dos Santos and Nelson 2013).

Upper canopy damage caused by understory surface fires is detectable by differences in pixel color between burned and unburned areas in post-fire Landsat Thematic Mapper (TM) images. Fire scars typically disappear in these images by 2 y after the fire (Cochrane, 2003). Previous accounts of fire damage have used binary mapping of burned/unburned area (Alencar et al. 2004, 2006). Alencar et al. (2011) devised a continuous metric of burn damage based on spectral unmixing, but this index was ultimately thresholded to provide a binary burned/unburned assessment of fire scars. Here we intend to develop a quantitative relationship between the spectral pattern of forests affected by fire and field measurements of fire-induced structural damage. Such a relationship would allow mapping different degrees of fire damage across the wider landscape.

2. Methods

2.1. Stud site and forest inventories

Our study was conducted in upland and in floodplain forests (*igapó*) near Mamori Lake, about 100 km south of Manaus. Both forests were penetrated by the same fire in 2009 (Figure 1). The site presented us with a convenient natural experiment, since ignition opportunity and pre-burn rainfall were identical for both forest types. The region is a paleo-floodplain, probably deposited during the last interglacial stage, when higher sea levels impounded the Amazon 10-20m above its current high water level (Irion et al. 2010). Data from TRMM 3B43 v7 (http://disc2.nascom.NASA.gov/Giovanni/TOVAS) indicate average annual rainfall of 2375 mm with three dry months: July, August and September.

Using a time series of geo-referenced Landsat TM images (http://glovis.usgs.gov/), we delimited *igapó* and upland areas burned and not burned by the fire of 2009, taking care to exclude forests affected by a 1997 fire in the same region. (No earlier fires were detected back to 1986. Prior to 1986 the region had very low population or deforestation, thus few ignition sources.) One year after the 2009 fire, a Landsat image (Fig. 1) clearly shows that narrow dendritic igapó forests suffered greater damage than the upland forest patches between the elongate seasonally flooded valleys.

Forty inventory plots of 250m x 10m were installed: ten in burned dendritic floodplain forests, ten in unburned floodplain, ten in burned upland forest and ten in unburned upland. In each plot we measured basal area and stem density for all trees >10 cm DBH. The ten unburned plots of a particular forest type provided an average basal area and an average stem density that served as a single pre-burn estimate of each variable for all the unburned plots of that forest type. This allowed use to calculate percent loss of pre-burn basal area and percent loss of pre-burn stem density for each of the 20 burned plot (Resende et al. 2014). All field data were collected 3-4 y after the fire. This delay is necessary since a large part of post-fire basal area loss occurs up to 3 y after a fire (Barlow and Peres 2004).

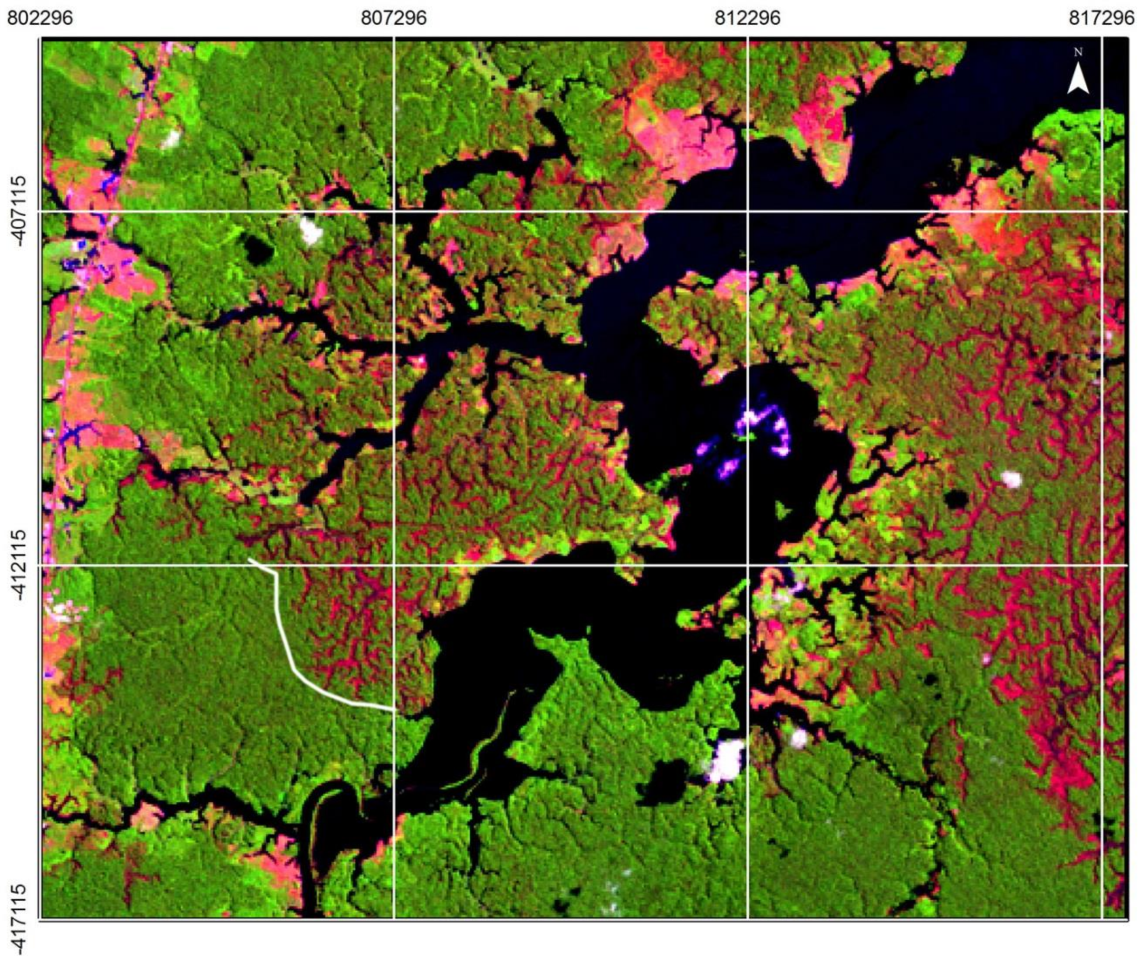

Figure 1. Landsat 5 TM false-color composite of study region with 5 km grid spacing, acquired one year after the 2009 fire. Dendritic *igapó* forest around Mamori Lake show intense fire damage while intercalated upland forest shows less damage. Curved white line is approximate limit of fire front between burned and unburned forests.

2.2. Spectral attributes

We used a Landsat 5 TM image acquired one year after the fire, before green regrowth in fire-caused gaps erased the spectral signal of damage (Cochrane and Souza Jr. 1998). Using CLASLite version 2.3 (Asner et al. 2009) we obtained sub-pixel fractions of NPV (non-photosynthetic vegetation), PV (green photosynthetic vegetation) and Soil from the six Landsat optical bands converted to surface reflectance (6s model). We used the fraction images of NPV and PV as damage indicators. We extracted the average NPV or the average PV for each burned transect and related these values to percent basal area loss or percent loss of stem density in linear regressions. Burned *igapó* (high damage) and burned upland (low damage) were combined in each graph, providing 20 observations. Each field transect intercepted about nine Landsat pixels. To properly weight the average NPV or PV from these nine pixels, we digitized a vector line connecting 11 GPS points that had been collected in the field at 25m intervals along each elongate plot's centerline. We then converted this line to 250 segments of 1m length and reconverted each segment's midpoint back points. Finally we extracted the underlying NPV or PV pixel values for these 250 points and took their average.

3. Results and Discussion

Fractions of NPV and of PV detected by Landsat in the upper canopy one year after the fire were good estimators of both percent basal area loss and percent stem loss (Figure 2). All relationships were linear, with R^2 values ranging from 0.6 to 0.7. The very broad range of field-measured damage across the 20 burned plots (0% to 90%) is of course contributing to this good fit. Residuals would be even smaller had we known the true pre-burn values of both basal area and stem density for each burned plot.

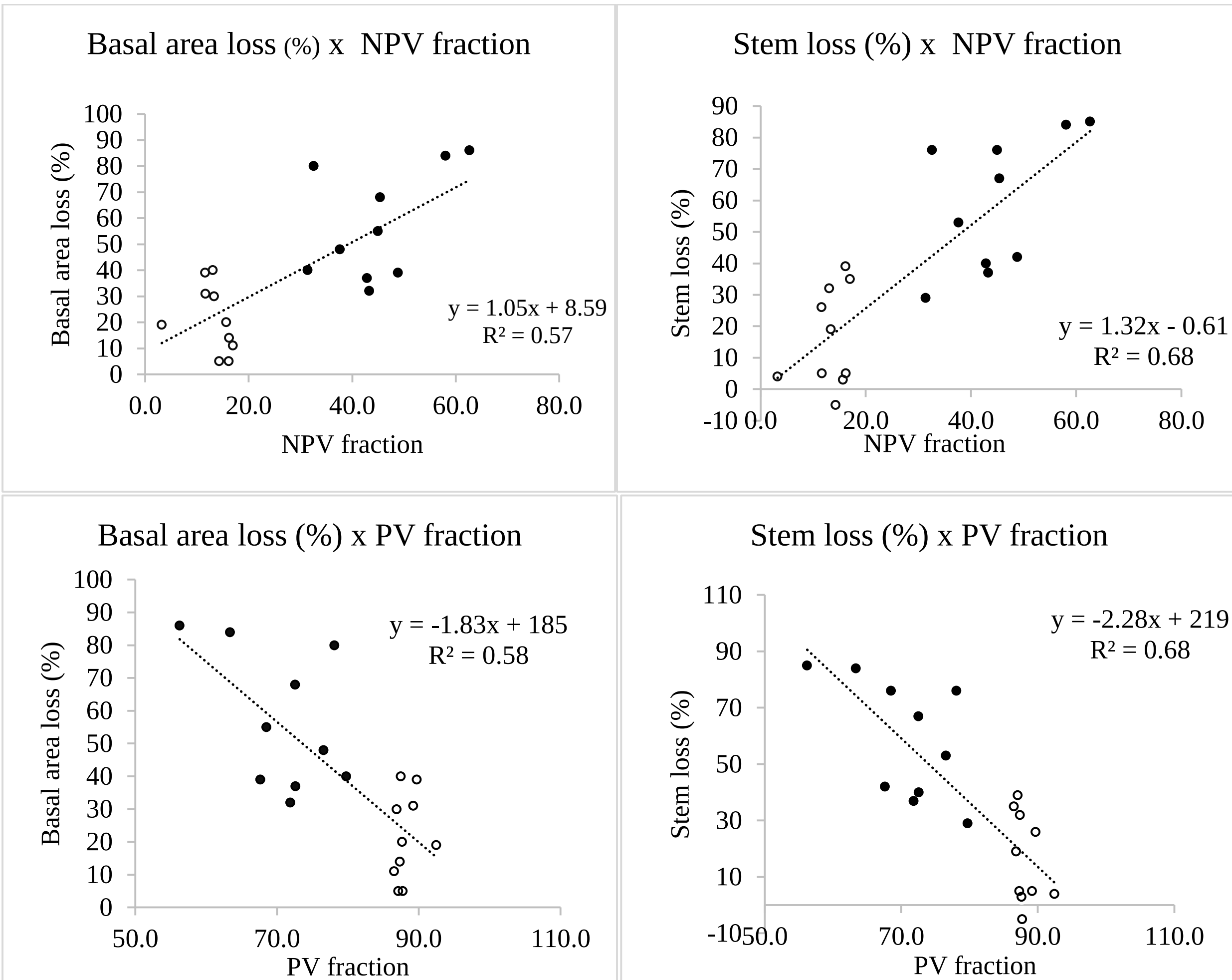

Figure 2. Linear relationships between forest structure damage and the two spectral end members NPV and PV for the 20 burned forest plots. Closed circles are upland and open circles are floodplain (*igapó*) forests.

4. Conclusions

Sub-pixel fractions of NPV and PV obtained from a Landsat image acquired one year after a surface fire were good linear predictors of two metrics of forest fire damage – percent loss of basal area and percent loss of stem density.

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