Can drone RGB images detect leaf age changes in upper canopy Amazon forest?

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1. Introduction

Most leafy crowns in evergreen Central Amazon rainforest undergo changes in color as a function of post-flush leaf age (Lopes et al., 2016). These color changes are of interest for deriving monthly leaf demography of the upper canopy, as leaf age drives the seasonality of Gross Primary Productivity in evergreen Amazon forest (Wu et al., 2016). Typically, leaf flush events are detected using tower-mounted phenocams taking many photos per day, from which only those with optimal sky conditions are selected to produce fine-resolution timelines of spectral indices for each crown (Lopes et al., 2016).
Unmanned Aerial Vehicle (UAV) images have some advantages compared to tower-mounted phenocams. They provide a georeferenced nadir view with fixed scale, high spatial resolution, and broader spatial coverage. They can also be obtained quickly at remote sites lacking a tower. But few field visits mean accepting the different illumination conditions available during a visit. Here we ask if ortho-mosaicked commercial drone images can detect seasonal changes in leaf color, by classifying drone images into three classes: light green leaf, dark green leaf, and bare branch.

2. Methods

Over one year we obtained eight orthomosaics of a 425 m x 350 m for a Central Amazon old-growth forest on a well-drained oxisol plateau near the ATTO tower (59.0005° W and 2.1433° S). We used the Phantom 4 Pro V1 and V2 UAVs with their standard wide-angle cameras. We used Agisoft Metashape v. 1.5.2 for image pre-processing and ortho-mosaicking. The resolution was ~3 cm, fine enough for pixels to be pure leaf or pure branch. Georeferenced control points were taken from separate airborne lidar coverage. Using the R package randomForest v. 4.7-1.1 we classified the entire orthomosaic into two leaf color classes and one bare branch class. We report the mean and variance for the fractional cover of the three materials for 450 upper canopy crowns with area $\geq 50\ m^2$. We make the simplifying assumption that dark green leaves are mature to old (> 2 mo age) and light green leaves are young (< 2 mo).
The challenge is to minimize artifacts caused by illumination intensity and illumination quality, that occur both within and across orthomosaics. Illumination intensity is by far the greatest source of variance in the RGB values of pixels in our mosaics, as shown by the fact that PCA1 accounts for 98% of total variance in a diffusely lit image. To this end, we (1) masked all pixels having deep shade (where digital numbers R+G+B < 200); (2) used as classifier predictors only those spectral indices with low sensitivity to illumination intensity; (3) obtained all images at the fixed shutter speed of 0.01 sec, because some digital cameras produce different relative shapes of their R, G and B histograms at different shutter speeds; (4) underexposed all images by one f-stop to reduce saturated pixels; (5) set the camera to a fixed white balance to prohibit unknown changes to R, G and B gains and offsets as the UAV view footprint moves in and out of cloud shadows (Richardson et al., 2009); (6) adjusted all orthomosaic histograms to a master mosaic obtained under diffuse illumination (we used the Cumulative Distribution Function histogram matching method from WhiteboxTools, which does not produce saturated pixels); and (7) trained the classifier for each material under four combinations of illumination conditions: low and high diffuse, low and high direct (we used the diffusely lit master mosaic and a separate CDF-adjusted mosaic captured under direct sunlight).
Finally, we compared the fractional cover of crowns by light green leaves to the monthly fraction of crowns reaching their annual peak flush, obtained from daily, diffusely illuminated, oblique-viewing RGB phenocam images, as reported by Lopes et al., (2016, their Fig 3).

3. Results and Discussion

1. Overall classification accuracy using five-fold rotation of training and validation sets from the same image was 93%. Overall accuracy of the classifier applied to a separate (but CDF-adjusted) validation image that was captured with a newer model of the UAV and camera was 95%.
2. We detected a clear seasonal change in the crown-scale fractional cover of pixels classified as young light green leaves (**Fig. 1a**). After appropriate scaling, the eight UAV-derived values closely matched eight same-date values from a LOWESS curve applied to 12 monthly flushing crown frequencies from a phenocam (Pearson Correlation = 0.80). Both methods show low values in the rainy season and high values in the drier months, indicating that leaf turnover is concentrated in the dry months.
3. The fractions of bare wood in crowns was also higher in the drier months (**Fig. 1b**), but values were lower than those expected from Lopes et al (2016, Fig 3). We tentatively attribute this to crowns being wider than they are deep. The phenocam looks horizontally through the crowns while the drone views crowns from above and sees through the sparser branches to the underlying green vegetation of mid-canopy trees.
4. Inter-crown variance for the fraction of young leaves, mature leaves and bare branches in 450 crowns, show similar seasonal trends, with fractional composition of crowns being spatially homogeneous in the wet months and heterogeneous in the dry months (**Fig. 1c**). This is an expected corollary of the higher number of leaf shedding and flushing events in the dry months creating a patchwork of crowns at the different phenostages (bare, recently flushed, mature/old).
5. Landscape-scale patterns are expected to be largely attenuated by all images having been histogram matched to a master image, so future work includes inferring flush and leaf-off seasonality from each crown´s timeline.

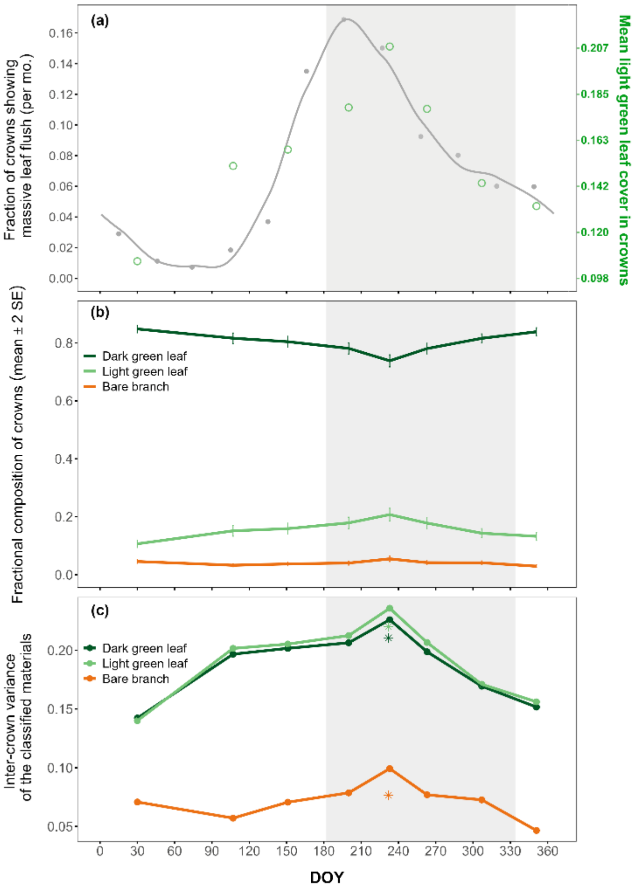

Figure 1**. Panel a:** Validation of UAV-derived light green (young) leaf cover fraction; open green circles are means from each UAV campaign for 450 upper canopy crowns. Grey points and grey LOWESS smoother represent the expected seasonal pattern, modified from Lopes et al. (2016). The eight fractional covers are strongly correlated to LOWESS prediction (r = 0.80). Grey shading represents the five driest months. **Panel b:** Fractional cover composition of upper canopy crowns by dark green leaves, light green leaves, and bare branches at eight UAV campaign dates (mean ± 2 standard errors, n = 450 crowns). **Panel c:** Inter-crown variance for each of three crown components, all peaking in August. Asterisks show variance from a CDF-corrected orthomosaic obtained in August under direct light, close in time to the diffuse-lit master image.

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