Lidar-based assessment of forest edge effects across a degraded landscape in the Brazilian Amazon

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Highlights: We quantified edge effects in forest fragments using lidar-based tree height over a degraded landscape in the Brazilian Amazon and found that the distance that characterizes an edge is more variable than previous studies have detected. This edge variability is key to understanding effects on ecosystem services such as changes in carbon stocks.

Key words: *edge effect, forest degradation, airborne lidar, Amazon.*

Introduction

Forest fragmentation divides forest areas into smaller discontinuous fragments, increasing the forest edge area that experiences different environmental conditions from interior areas [1]. According to one study, logging and deforestation generate ~32,000 and 38,000 km of new forest edge each year in the Brazilian Amazon [2]. Nearly 20% of the world's forests are within 100m of agriculture, urban, or other non-forest land uses [3].

Forest edges suffer changes in microclimate, with reduced moisture and increased variability of temperature compared to the forest interiors. In addition, winds cause greater structural damage near the forest ends and affect other ecological processes such as pollination, seed dispersal, nutrient cycling and carbon storage.

The extent of forest edges in the Brazilian Amazon grows each year, caused by deforestation and forest degradation from human activity. However, the extent of edge forests, and the changes in carbon stock resulting from alterations in microclimate and disturbance near forest edges are difficult to quantify. Previous studies have used multispectral remote sensing and geographic information systems (GIS) analysis to quantify fragmentation and the effect of edges [2]. We used lidar (light detection and ranging) measured canopy heights as a proxy variable to quantify forest edge effects across a degraded forest landscape of the Amazon in the Paragominas Municipality in Para State, Brazil. To our knowledge no previous study has used variability in forest height from lidar data to quantify changes in forest structure near edges in tropical forests. Lidar provides data with sub-meter vertical and horizontal accuracy, greatly improving forest structure quantification compared to traditional field studies.

Material and methods

The study area is located in the municipality of Paragominas (3°S, 50°W), in the eastern Brazilian Amazon. Paragominas was a center for timber production in the Brazilian Amazon in the 1980s and 1990s and large areas were deforested for cattle pasture. Today, the landscape is characterized by a range of agricultural uses (ranching, soy, plantation forestry, and natural forest management), with remnant logged, burned, secondary, and unmanaged forests interspersed across the municipality. High density (average of 17.9 points/m^2) lidar data was acquired over 30 transects (200 x 5000m), systematically distributed across a 34 by 180 km area inscribed within the borders of the municipality using an airborne scanning laser system (Optech Orion M-200) in August/September 2013 and June/July 2014.

In our study, forest edge was considered as the interface between a forest and a non-forested land. This definition of edge was applied on the lidar derived Canopy Height Model (CHM), a high resolution (1 meter) raster representation of the tree canopy height. We identified 57 forest/non-forest edges within the 30 transects. Based on the TerraClass land cover maps [4], we classified the forests as either old-growth, forests that were never cleared but may have been burned and/or logged and secondary, forests that regenerated after total clearance for pasture or agriculture. The interface land-uses included annual agriculture, pasture, pasture with regeneration and roads.

We defined a series of 10m wide buffers from each forest edge based on the CHM. The maximum distance from each edge was either half the fragment width or a maximum of 710m as only 26% of the fragments were wider than this width, generating up to 71 strips. A variable number of 5x5m samples (up to 18, depending on buffer geometry) were randomly allocated within each strip, and the 95th percentile of height within each sample was calculated using Fusion software [6] to represent canopy height. The 5x5m sample window size was chosen as a compromise to fit within the 10m strips and to smooth canopy variability.

In order to test the existence of an edge effect, the set of samples of canopy height in each buffer segment was compared with samples of canopy height in the forest interior. The forest interior was defined for each lidar transect using first an area of old-growth forest classified by TerraClass land cover maps [4], free of perturbation by fire [5] and/or logging. In case no area complied with these characteristics, we selected a zone of secondary forest according to TerraClass maps [4] without fires [5] or logging. We generated 1000 bootstrap realizations based on the samples in each edge width and the interior to test the difference of the means and conservatively considered samples statistically distinguishable only if they were separated with 99% confidence.

Results and discussion

Figure 1 illustrates the extent of edge effects for the 57 edges in the Paragominas study area. The length of each bar shows the maximum distance into the forest where an edge effect (height differences) could be statistically separated with 99% confidence from the interior forest.

Nearly half of the analyzed edges had statistically significant differences in height compared to interior forests throughout the entire forest sample length (confidence interval of 99%). Secondary forests were more likely than old-growth forests to be classified entirely as edge. Forests fragments with a maximum measured transect of less than 200m in old-growth forest and 100m in secondary forest were all classified as edge. The average length of forest analyzed was 355m ± 256m (mean ± standard deviation) and the average edge effect observed was 162m ± 170m (mean ± standard deviation).

Three edges, all occurring in areas classified as old-growth forest, presented no discernible edge effect, meaning that the forest edge did not show difference in height when compared to the interior. Edge effects have a major impact on large trees, which often die off within 300m of the forest edge [7]; we found that approximately 44% of the studied edges were significantly different up to a distance of 320m from the edge.

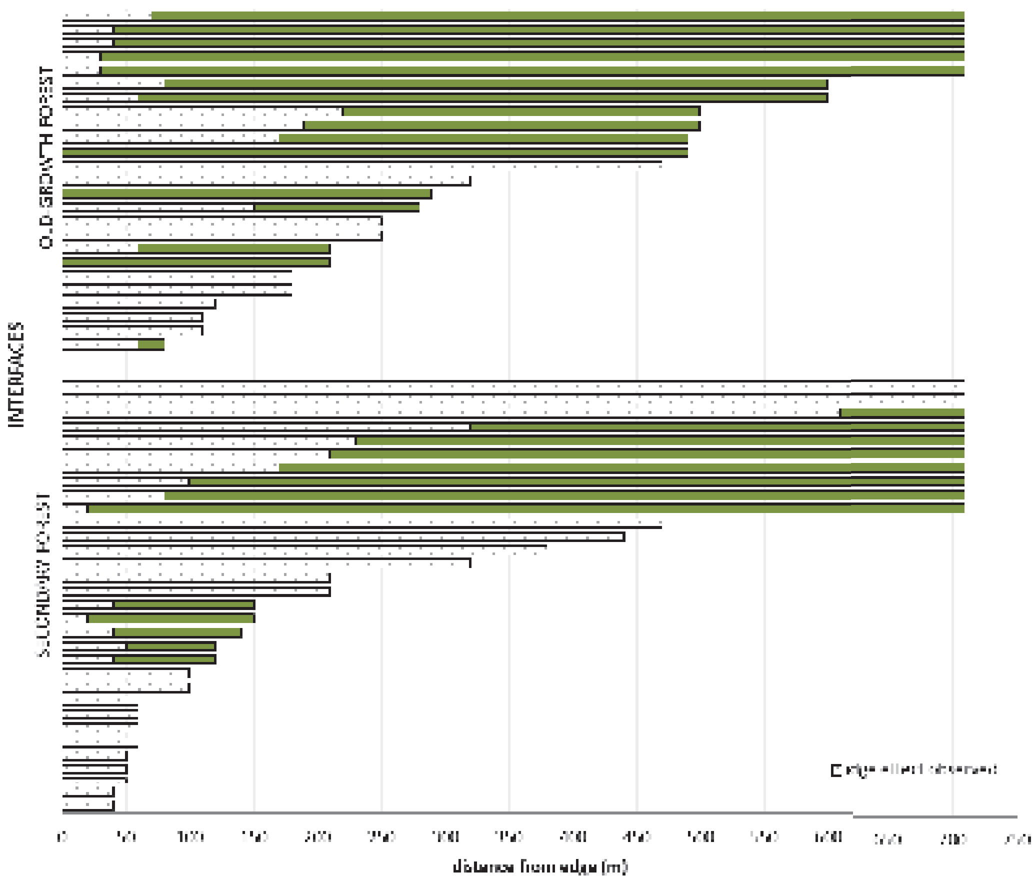

Figure 1: Edge effects observed in a degraded landscape. The white portion of the bar indicates the distance from the forest edge where edge effects were observed (statistically significant differences in forest heights, relative to the interior site at 99% confidence). On the top of the figure are the edges with primary forest/other land-use interface (25 edges) and on the bottom are the edges of secondary forest/other land use (32 edges).

Conclusion

Using tree height to measure edge effects we found that edge effects in a complex degraded forest landscape were highly variable. In general, secondary forests had a greater edge distance than old-growth forests but this difference was not statistically significant. Comparisons to previous studies that examined edge effects in controlled experimental settings [1] suggest that in real landscapes edges have greater variability. Under a mixture of land uses, edges are exposed to a broad range of degradation processes overlapping in space and time. Controlled experiments, while useful for process understanding, may not be suitable for extrapolation across broad areas. Vegetation height is well correlated with biomass; therefore, our results present an avenue for quantifying the importance of edge effects on Amazon region forest carbon stocks.

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References

[1] Laurance, W.F., 2000. Do edge effects occur over large spatial scales? Trends in Ecology and Evolution 15, 134–135.

[2] Broadbent, E. N., Asner, G. P., Keller, M., Knapp, D. E., Oliveira, P. J., & Silva, J. N. (2008). Forest fragmentation and edge effects from deforestation and selective logging in the Brazilian Amazon. Biological conservation, 141(7), 1745-1757.

[3] Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., ... & Townshend, J. R. (2015). Habitat fragmentation and its lasting impact on Earth's ecosystems. Science Advances, 1(2), e1500052.

[4] Almeida, C.A., Pinheiro, T.F., Barbosa, A.M., Abreu, M.R.B.S., Lobo, F.L., Silva, M., Gomes, A.R., Sadeck, L.W.R., Medeiros, L.T.B., Neves, M.F., Silva, L.C.T. and Tamasauskas, P.F.L.F., "Metodologia para mapeamento de vegetação secundária na Amazônia Legal". Instituto Nacional de Pesquisas Espaciais, 32 (2009).

[5] Morton, D.C.; DeFries, R.; Nagol, J.; Souza Jr, C.; Kasischke, E.; Hurtt, G.; Dubayah, R. Mapping canopy damage from understory fires in Amazon forests using annual time series of Landsat and MODIS data. Remote Sensing of Environment, n. 115, p. 1706-1720, 2011.

[6] McGaughey, R. J. FUSION/LDV: Software for LIDAR Data Analysis and Visualization. Seattle, WA: USFS, 2014.175 p.

[7] Laurance, W.F., Delamonica, P., Laurance, S.G., Vasconcelos, H.L., Lovejoy, T.E., 2000. Rainforest fragmentation kills big trees. Nature, 404.