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WHICH VARIABLES IN FOREST SURVEY DATA CAN BETTER DISTINGUISH CONSERVED AND DEGRADED TROPICAL DRY FOREST?

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ABSTRACT:

This paper presents the results of a statistical study of forest inventory data for tropical dry forest in Ayuquila River Basin, Jalisco state, Mexico. The field inventory was carried out between May-June of 2019 which is at the end of dry season and the beginning of raining season. The field inventory data were collected in 43 plots of 500 m^2 each which were designed in a way to include tropical dry forests in two conditions: degraded and conserved. In each plot, the collected data include DBH, tree height, number of trees per plot, and the density of tree stems. A study was carried out to find out if there are statistically significant differences variables relating to forest structure between degraded and conserved status. The Mann-Whitney test shows that there is significant differences in canopy cover, biomass, tree height, and basal area. This information is important since it helps to understand whether and how forest degradation can be detected using remote sensing data.

1. INTRODUCTION

Forest biomes provide important ecosystem services, habitat for many species (Gentry 1992), and economic benefits through supply of subsistence products, commercial forestry and tourism (Buettel et al., 2017). Forest disturbance or degradation affects forest structure, function, ecosystem processes, and the carbon balance (Herold et al., 2011). Unlike deforestation, forest degradation is usually a gradual process which involves long-term and severe environmental changes while the forest remains in principle a forest. It includes small removals of biomass below the forest canopy where cattle might browse freely or where there is cyclical use of forest, like shifting cultivation. It may alternatively be associated with changes due to cyclical silviculture or selective felling practices (Thompson et al., 2013). Ultimately, forest degradation affects forest functioning and diminishes the provision of ecosystem goods and services (Chazdon 2008; Modica et al., 2015).

Although tropical forest loss (deforestation) is said to contribute 5-15% carbon emissions to the atmosphere (Bullock et al., 2018), the amount contributed by forest degradation is unclear (Baccini et al., 2017). The large uncertainty in emission estimation from degradation is a consequence of many factors, including differences in the definition of forests and forest degradation (Bullock et al., 2018). There are more than 50 definitions for forests and forest degradation (Putz et al., 2010), and lack of agreement on ecological, anthropogenic and conceptual aspects of forest degradation hinder its clear definition (Ghazoul et al., 2015). But even if definitional issues are resolved, the monitoring of degradation by remote sensing raises considerable challenges. It certainly requires higher spatial and temporal resolutions than does for monitoring deforestation. High image acquisition frequency is mandatory for operational degradation monitoring systems (Verhegghen et al., 2015), and higher spatial resolution of images is also important since forest degradation often happens at small scales (Morales-Barquero et al., 2014; Joseph et al., 2011). Moreover, while emissions from deforestation are usually calculated using an area estimate from remote sensing multiplied by an emission factor representing the average amount of carbon per hectare in each forest type, in the case of degradation, there is need not only for estimates of the area degraded, but also of the quantity of carbon lost in any given forest in a given year, which can vary enormously.

One method that has often been used to quantify forest degradation using remote sensing is by defining degradation as the gross change from primary forest to secondary forest, applying emission factors for “typical” secondary forest. This method is however flawed, because the classification of primary and secondary forest using remote sensing involves high uncertainties, and as mentioned already, the amount of carbon lost in the conversion from primary forest to secondary forest are not in any way fixed or uniform. In order to obtain more accurate estimates of rates of degradation in the context of international policies such as Reduced Emissions from Deforestation and forest Degradation (REDD+), a mixed method, involving both remote sensing and detailed ground level forest surveys, will be necessary.

After disturbance, forests change their structural and composition characteristics. A first step in developing mixed methods is therefore to establish to what extent degraded forest can be distinguished from conserved forest using ground level data. The purpose of the work presented here is to determine which structural and composition indices present statistically significant differences between degraded and conserved tropical dry forests. Only when this is clear, can the capacity of remotely sensed data to pick up these variables be tested. This paper is a first step towards developing a methodology linking ground characteristics with remote sensing, since it will tell us which characteristics are the most relevant at ground level firstly to distinguish between conserved and degraded forest, and secondly to estimate the changing biomass levels within degraded forest.

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2. DATA, METHODS, RESULTS

2.1 The study area and data

The Ayuquila River Basin is in western Jalisco, Mexico. Mean annual temperature is about 19°C and mean annual rainfall ranges from 700 to1000 mm (Jardel et al., 2012). Tropical dry forest is the largest forest category covering about 24% of the total area. During the past 20 to 30 years, tropical dry forest and scrubland in its central part have been cleared for permanent agriculture (Morales-Barquero et al. 2014). Forest degradation continues in much of the remaining forest area. The main drivers include shifting cultivation, cattle grazing, fence pole extraction, and forest fires.

2.2 Forest measurement data

The field survey was carried out between May and June of 2019 which is at the end of dry season and the beginning of rainy season. The field data were collected in 43 plots of 500 m^2 each. Plots were selected to include tropical dry forests in two conditions: degraded and conserved. The plots were selected in collaboration with local forest officers who are very familiar with the sites and could clearly identify which areas were degraded and which were in a more pristine state and could be considered "conserved". Expert advice from *Junta Intermunicipal del Río Ayuquila (JIRA)* was also taken regarding to accessibility and safety when selecting the plots to carry out the forest inventory.

In each plot, collected data included diameter at breast height (DBH), tree height, number of branches, canopy cover, and number of trees per plot, from which the density of trees/ha was calculated. All trees with DBH greater than 2.5 cm were measured in a radius of 3 m from the centre. Then all individuals with DBH higher than 5 cm were measured up to a radius of 9.6 m. Of the total 43 plots, 24 plots were of conserved forest and 19 degraded forest. Canopy cover was measured using a spherical densometer. The structural parameters measured are summarized in table 1. In addition, the presence of anthropogenic activities such as cattle / cattle faeces, logged tree trunks, leaves and seedlings was noted, as this supported identification of plots as being "degraded". The geographic conditions were also recorded including types of soil, and the slope of the plots.

2.3 Biomass and basal area

Biomass data was calculated using the allometric equation developed by Martínez-Yrizar et al. (1992).

$$log_{10} Y = A + log_{10} \ BA$$

This equation is adjusted to Tropical Dry Forests, where Y is the biomass in kg/m^2, *A* is the regression constant and BA is the Basal Area (cm^2).

Basal area was calculated from the following formula using the diameter at breast height (DBH):

$$BA = \pi \left(\frac{DBH}{2}\right)^2$$

Table 1. Summary of forest structural parameters between conserved and degraded forests.

Variables	Conserved / Degraded			
	Max	Min	Mean	Std, dev
Canopy cover (%)	100/100	83 / 16	96.2 / 68.5	0.71 / 6.56
Basal area (cm^2)	367.9/288.9	88.7/54.7	174.5/119.4	14.13 / 13.32
Height (m)	7.7 / 7.2	3.7 / 2.5	5.8 / 4.8	0.22 / 0.31
Biomass (Mg/ha)	53.3 / 38.5	6.9 / 1.0	22.6 / 12.3	2.53 / 2.49
No. of branches (> 2.5cm)	102 / 128	24 / 27	65.7 / 74.7	4.46 / 6.75
Number of trees	62 / 71	11 / 11	36.9 / 34.4	2.45 / 4.5

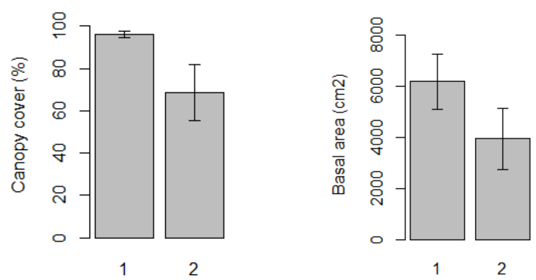
2.4 Can the structural variables differentiate these two states of forest?

We evaluated if forest structure variables differ between the two levels of forest conditions (i.e. conserved and degraded). Due to that the six forest structure variables did not follow a normal distribution, we evaluated whether tropical dry forest condition was different from each other using a Mann-Whitney test. The results showed statistically significant differences between the means of four of the six tested variables: canopy cover, basal area, height, and biomass (table 2).

Table 2. Results of Mann-Whitney test for forest variables. The variables that present significant differences between conserved and degraded forests (Wilcox test, α<0.05) are in bold and italic font.

	Mann-Whitney test
Measurements	P-Value
Canopy cover (%)	***8.641e-06***
Basal area (cm^2)	***0.002***
Height (m)	***0.009***
Biomass (Mg/ha)	***0.005***
No. of branches (> 2.5cm)	0.386
Number of trees	0.335

Figure 1 shows the comparison between the two forest conditions. As can be seen, the conserved forests show a greater cover, larger basal area, as well as height and biomass.



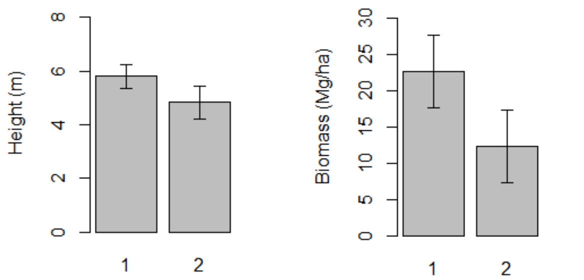


Figure 1. Comparison between structural characteristics of the two forest types from field survey, 1: Conserved forest; 2: Degraded forest

2.5 Correlation between variables of forest attributes

2.5.1. Correlation at individual tree level

Correlations were carried out between height and basal area of individual trees, for conserved and degraded forest (Figure 1). The correlation coefficient R^2 is higher in conserved forest (0.54/0.27).

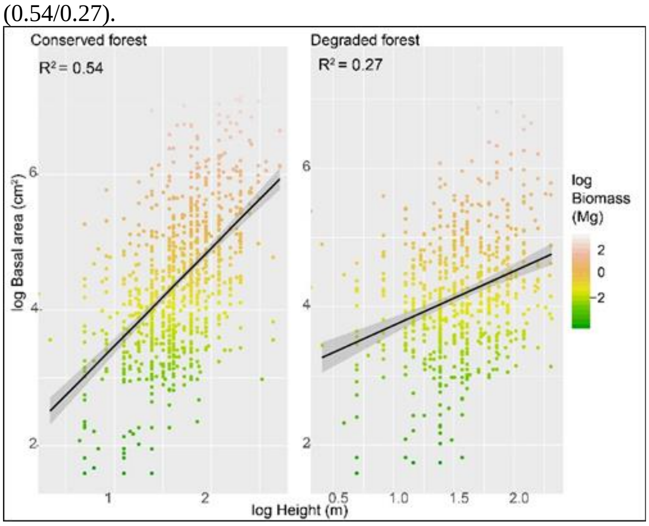


Figure 2. Correlation between logarithms transformed tree heights and their basal area at the individual trees level, in conserved forest and degraded forest.

2.5.2 Correlation at plot level

Inter-correlations at plot level were calculated for the four variables of canopy cover, basal area, tree height, and biomass. The Kendall tau correlation was applied, and the results are shown in figure 3, 4, and 5. First all the plots mixed were tested (Figure 3), and we did not find good correlations between the variables. Then we did the same analysis separately for the two groups of forests: conserved (Figure 4) and degraded (Figure 5). The strongest correlation was found for degraded forest; the variables which demonstrate strong correlations are between the number of trees and biomass and between the number of trees and the number of branches with Kendell's tau of 0.63 and 0.61, respectively.

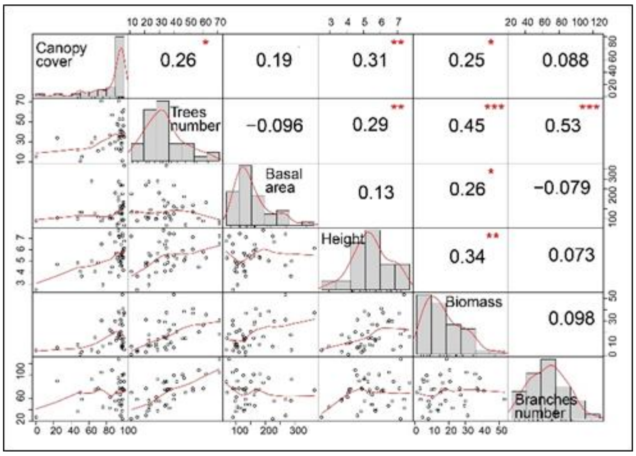


Figure 3. Correlation by Kendell's tau between canopy cover, basal area, tree height, and biomass at plot level for all plots (n= 43). p< 0.05 *, p<0.01 **, p<0.001 ****** The histograms show the distribution of the variables and que scatterplots the correlation between the variables.

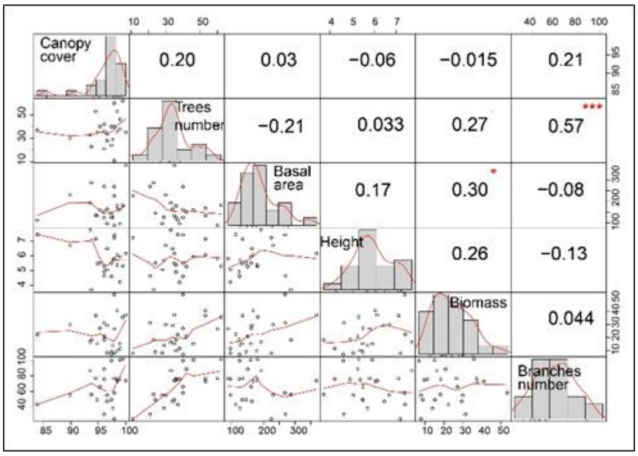


Figure 4. Kendell's tau correlation only for conserved forest plots (n=24). p< 0.05 *, p<0.01 **, p<0.001 ***

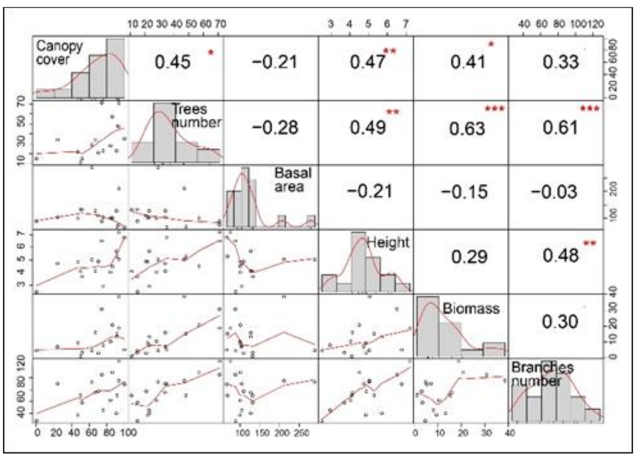


Figure 5. Correlation by Kendell's tau for degraded forest plots (n= 19). p< 0.05 *, p<0.01 **, p<0.001 ***

2.5.3 How slope affect the structural variable distribution

Geographical factors may influence forest structure variables: here we review the effect of slope. The distribution of slope values in conserved and degraded forest is presented in Figure 6. It shows that slope does not explain variations in forest structure variables when the plot data is considered as one dataset (degraded and conserved forest) together. However, when analysed separately, slope can partially explain variations in height (slope -0.03, $0.01<p<0.05$) and the number of trees (slope -0.19, $0.01<p<0.05$) for conserved forest.

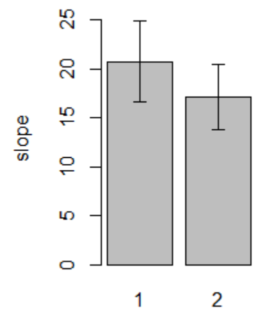


Figure 6. the distribution of slope values in conserved (1) and degraded (2) forests.

3. DISCUSSION

The Mann-Witney test showed that several forest attributes that are regularly recorded in forest surveys can be used to distinguish degraded and conserved forests at ground level. These include mean canopy cover, mean tree height, basal area, and total biomass. The analysis also shows that the number of trees per plot and number of branches do not significantly differ between these two states of tropical dry forest. But we note that although mean canopy cover discriminates reasonably well between conserved and degraded forest, this variable has a wide standard deviation in degraded forest, such that some degraded plots had 100% canopy cover, although the average was much lower. Indeed, the variance of all variables is proportionally much higher in the degraded plots compared to the variance of these same variables in the conserved plots, indicating greater variability in the degraded forest. Nevertheless, of the six indicators, tree height has the highest correlation with biomass, and in the context of programmes such as REDD+, it is loss and gain of biomass that is the primary variable of concern.

These findings raise challenges for the application of remote sensing to the quantification of degradation. To estimate the area affected by degradation, canopy cover is the variable that could most easily be measured using (high spatial resolution) remote sensing, but overall it has only a 35% correlation with biomass (which is the proxy measure of degradation in the context of climate change). It may not be possible to "see" much of the area which is in fact degraded, i.e. those degraded areas that have higher than average levels of canopy cover.

At the same time, the most promising indicator of biomass level, the change in biomass levels, and carbon emissions from degraded forest areas is tree height, which is difficult to measure with satellite images. Although it is possible to measure tree height using LIDAR data or images of drones over small areas, the high cost and limited areas hinders its application over extended areas.

In order to improve the capabilities to study degradation, there are certain sources of error associated with field measures and data transformation that need to be minimized. For example, the uncertainty associated with tree height measures, species wood density and allometric equations influence the biomass values calculated for each plot (Barbosa et al., 2014; Réjou-Méchain et al., 2019). Thus, the ability to correctly monitor biomass changes will strongly depend on the precision of the method used to calculate biomass.

In part these difficulties may be attributed to the fact that we asked the local expertise to make a simple distinction between "conserved" and "degraded" forests. It is possible that a more nuanced classification of degraded forest in levels of highly degraded, moderately degraded, and lightly degraded would have resulted in higher correlations with the most promising variables.

4. CONCLUSIONS

This paper has presented findings of a statistical study of conserved and degraded forests based on a recent forest survey in tropical dry forest. The forest attributes that are significantly different between conserved and degraded forests include canopy cover, basal area, tree height, and forest biomass. Canopy cover presents large variance in degraded forests which implies that this variable cannot be used as a reliable measure of area degraded in remote sensing images. There is significant difference in mean biomass values between conserved and degraded forests when measured on the ground. However, the variable that best predicts this (tree height) cannot be assessed with standard remote sensing technology.

It is important first to calibrate canopy cover against degradation using a sliding scale of intensity of degradation as observed at ground level. This would likely enable a more reliable estimate of area of degradation using remote sensing. It remains uncertain that variations in biomass could be quantified in this way.

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