**Title.** Land-use history shapes tree aboveground biomass patterns in tropical montane cloud forest landscapes

**Authors**

**Affiliations**

**Keywords**

**Abstract**

**Introduction**

How does small-scale farming shapes regional patterns of AGB in tropical montane cloud forest across environmental gradients?

Acronyms: TMCF, FI

**Methods**

*Study Area*

We delimited a study area following a TMCF regionalization conducted by Toledo-Aceves *et al.* in 2011 based on geomorphology, forest cover, watershed margins, rivers, and cultural differences (such as presence of indigenous groups). We focused on the Northern Mountains of Oaxaca (NMO), a region that harbors some of the most biodiverse forests in that country including the largest and most continuous TMCF, and where forest conservation is considered a critical priority (Toledo-Aceves et al., 2011). In NMO, TMCF are found on hillslopes and humid ravines with frequent fog and drizzle. The mountains impose an environmental gradient that goes from warmer to cooler temperatures as elevation increases. Soils in these forests usually develop from the weathering of metamorphic rocks and volcanic outcrops, they tend to be deep, and rich in clay and organic matter (Torres, 2004). We defined the distribution of TMCF within NMO using the official map of vegetation and land-use series V published by the National Institute of Statistic and Geography (INEGI) in 2013 (CITA) (Figure 1).

*Data Collection and Processing*

We integrated information on forest structure and composition, environment, topography, and land-use, gathered from different sources into a single dataset. The main data source for this work is the publicly available Mexican National Forest Inventory database, which contains information on forest structure and composition, as well as forest disturbance. From this database we estimated forest structural attributes, AGB, and land-use variables. To complement this data, we obtained information on mean annual precipitation and temperature from WorldClim (CITA). Lastly, we retrieved topographical information from NASA’s Shuttle Radar Topography Mission digital elevation data (~30 m resolution) using Google Earth Engine (Farr et al., 2007). A detailed description of the foregoing variables can be found below (see also Table 1 for a summary of the variables).

*Forest Inventory Sites.* FI data collection was carried out between 2009 and 2014 following a hierarchical nested sampling method with 1-ha circular sites as main sampling unit. Within each site, four circular plots of 400 m2 were established. One in the center of the site, and the other three in a north, southeast, and southwest direction, respectively, at 45.14 m from the central plot. All trees, lianas, shrubs, palm trees and ferns within the plots with a diameter at breast height (DBH) larger than 7.5 cm were sampled. Height, DBH, basal area (BA), and taxonomic identification of all sampled individuals was recorded. Information about the geographic location, vegetation type, and land ownership of each site was also documented. All sites were established 25 km apart from each other in a grid-like fashion.

*Forest Structural Attributes and Aboveground Biomass Estimation.* Based on FI raw data, we derived three structural attributes at plot level that were then averaged by site: (1) stem density, *i.e.*, the number of trees per hectare; (2) basal area, defined as the sum of the cross-sectional surface area of trees per hectare; and (3) Lorey’s height, which is a measure of forest stand height weighted by its basal area.

To estimate AGB, we first calculated each individual’s AGB using 47 different allometric equations (Table 2). Whenever allometric equations were available in the scientific literature at species or genus level we would use them. Otherwise, we used the following generic allometric equation developed by Chave *et al.* (2014) for tropical trees based on tree wood density, height and DBH:

AGB = 0.0673 \* (WD \* H \* D^2)^0.976

We corrected taxonomic names collating a list of species with the Taxonomic Name Resolution Service and searched for the wood density value of each species or its closest relative in global wood density databases. Functions to correct taxonomic names and search for wood density values are available in the R package BIOMASS (Réjou‐Méchain, 2017).

We calculated AGB per plot adding up the biomass of each individual tree and AGB per site averaging plot’s AGB. There is always some uncertainty inherent to upscaling biomass estimates from trees to forest stands that arises from the propagation of errors in field data collection, allometric equations, wood density estimates, and forest variation. To account for this uncertainty, we estimated plot AGB standard deviation following error propagation using the function AGBmonteCarlo assuming 95% of the samples have a low diameter error and the remaining 5% a high diameter error (close to 5 cm), and a height error of 10%, as suggested in Chave et al. (2004). We assumed standard error independence to estimate site’s AGB error, and used the following equation:

AGBsite = (Eplot1^2+Eplot2^2+Eplot3^2+Eplot4^2)^1/2

*Tree Diversity.* We calculated species richness, *i.e.*, the total number of species, Shannon (H) and Simpson (D) diversity indices with the following equations, respectively:

H = -sum p\_i log(b) p\_i

1-D, where D = sum p\_i^2

EXPLANATION.

Environmental and Topographic Variables

Land-use Variables

Data Selection and Quality Control

Statistical Analysis

**Results**

Tree AGB and Diversity in TMCF

Patterns of Tree AGB and Diversity Across Land-use and Environmental Gradients

**Discussion**

Spatial heterogeneity caused by small-scale forest disturbance determines AGB patterns at landscape and regional scales.

The effect of environmental variables on tree AGB and diversity is evident once land-use is taken into consideration.

**Conclusions**

**Tables**

Table 1. Variables used in this study

Table 2. Allometric equations

Table 3. Structural attributes, tree AGB and diversity

Table 4. Multiple regression model-AGB

Table 5. Multiple regression model- diversity

Table 6. GAM

**Figures**

Figure 1. Map

Figure 2. Structural attributes and tree size contribution to AGB and stem density.

Figure 3. Relationship between forest structure and diversity

Figure 4. Relationship between AGB and landscape composition (mosaic), and diversity and landscape composition (mosaic)

Figure 5. GAM result or surface plot

**Supporting Information**

Non-hierarchical cluster analysis – plots categories in three ‘successional stages’

PCA of environmental variables