Deforestation and dry season rainfall in northern Mesoamerica: Implications for forest sustainability

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Abstract

The forest types in northern Mesoamerica generally are those that require dry season rainfall for their survival. However it is not clear whether the current rainfall amounts are sufficient to maintain existing forests and regenerate the pristine forests in the deforested patches. The climatological rainfall records at 266 stations in Guatemala and adjacent areas show statistically significant (t-values) higher dry season rainfall over forested areas than deforested areas of the major Holdridge life zones. Climatological cloud cover also is often statistically significantly higher over forested regions (ANOVAS were significant). The rainfall predicted from the correlation (R=0.68; standard error = 0.8) of these two records for March shows rainfall deficiencies >25mm in several Holdridge life zones compared to the climatological rainfall observed by the rain gauges over the forested regions.

With the onset of the wet season however, from April through June the observed rain gauge rainfall differences between forested and deforested regions becomes statistically insignificant and the estimated rainfall deficiencies are slowly removed based on the Holdridge life zones.

This suggests the climatic consequences of deforestation for forest regrowth on connecting corridors may vary by life zone. In particular, reduced dry season precipitation in deforested areas of northern Mesoamerica originally occupied by wet forests might become a two-fold problem for the many connecting corridors of the MBC that lie within these life zones. The data suggest that deforestation is locally intensifying the dry season, so that forest regeneration in some parts of the MBC, particularly in the central Peten of Guatemala, may not result in second-growth forest that is characteristic of that life zone but rather in forest regeneration more typical of drier conditions. The extent to which this would influence the conservation utility of any given corridor depends upon the ecological requirements of the organisms concerned.

1. INTRODUCTION

At least half of all species are found in humid tropical forests, but these forests are disappearing rapidly. Only about half of the pre-industrial forest area remains, and this is badly fragmented. A

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disproportionately high proportion of the earth's biota is found in the Mesoamerican biodiversity hotspot. The scale and speed of habitat loss and fragmentation in one of the earth's biologically richest regions has led conservationists to propose the Mesoamerican Biological Corridor (MBC), an integrated regional initiative intended to conserve biological and ecosystem diversity in a manner that also provides sustainable economic development. This project proposes to connect isolated parks, preserves and forest fragments with new protected areas to create a network of biological corridors within the five southern states of Mexico and the Central American countries of Guatemala, Belize, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. The intent is to provide an environment that provides better prospects for the long-term survival of species, while at the same time addressing the region's socioeconomic needs.

The establishment of effective MBC corridors depends upon forest recovery, but deforestation like that in Central America has local climatic consequences that might influence forest regeneration. A serious concern is the drying of deforested regions. *Lawton et al* [2001] and *Nair et al* [2003] showed that cleared regions in lowland Costa Rica were warmer, had lower dew point temperatures, had altered sensible and latent heat fluxes, had fewer clouds and had altered cloud properties as compared to nearby forested regions. *DeFries et al*. [2002] suggest that in general land use changes may influence regional climate, which then enhance and sustain these changes. Thus, the current alterations of the natural landscape in Central America, coupled with continuing high rates of deforestation, may have climatic consequences that affect both the stability of the existing protected forests and the rate of regeneration on now deforested components of the MBC. The primary objective of this investigation is to determine regions within the proposed MBC that are significantly drier than the climatological conditions that have maintained forests in these regions.

2. DATA

The topography at 1km spatial resolution is derived from the global USGS database.

Holdridge (1967) Life Zones are based on three climate parameters: 1) mean annual biotemperature; 2) annual precipitation; and 3) potential evapotranspiration (PET) ratio. Each of the Life Zones is named so as to suggest a vegetation formation. The nine primary Holdridge Life Zones in the Guatemala study area are: (1) Subtropical Lower Montane Moist forest; (2) Subtropical Moist forest; (3) Tropical Moist forest; (4) Subtropical Lower Montane Wet forest; (5) Subtropical Montane Wet forest; (6) Subtropical Wet forest; (7) Tropical Wet forest (8) Subtropical Dry forests; and (9) Tropical Dry forests.

Within each Holdridge Life Zone, there may be a variety of forest types and anthropogenically-derived vegetations. We use the 14 classes of the University of Maryland (UMD) Global Ecosystem Database at 1km spatial resolution [*Hansen et al*., 2000] to provide additional ecosystem information.

Moderate Resolution Imaging Spectroradiometer (MODIS) vegetation and land surface temperature (LST) products are used to determine the average values over the different ecosystems types within each Holdridge Life Zone

Daily Geostationary Environmental Observational Satellite – East (GOES-E) observations over are used to determine the relationship between rainfall and cloud frequency of occurrence over Mesoamerica. The GOES visible channel data is centered at 0.65 μm (0.52 – 0.72 μm) and has a spatial resolution at nadir of 1 km in the north-south direction and 563 m in the east-west direction. This study of cloud frequency of occurrence is restricted to the dry season month of March (in four consecutive years 2000 to 2003). The month of March is chosen as the peak of the dry season, a time when ecosystems are under maximum water stress. Results from the dry season months of February and April provide similar results.

Rainfall measurements have been collected by the Guatemalan National Institute of Seismology, Volcanology, Meteorology and Hydrology (INSIVUMEH) for the time period of 1961 to 1997, and the data have been converted into monthly climatological records.

3. METHODOLOGY

The primary focus of this investigation is to determine whether deforested areas receive less dry season rainfall than do forested areas within the same Holdridge life zones within northern Central America. To address this issue, we determine dry season cloud frequency of occurrences from GOES satellite imagery and then correlate that cloud cover frequency with March raingauge data from 266 stations in Guatemala from 1961 to 1997 in order to generate regression estimates of current local rainfall within Guatemala and adjacent areas. Differences between estimated current rainfall and historical values define regions under increased dry season water stress.

The fundamental assumption is that the various Holdridge life zones have a certain cloud cover and precipitation range associated with them, creating local climatic conditions that sustain that life zone. We further assume that if the estimated rainfall associated with forested regions also exists over deforested regions in the same life zone, then the climatic conditions are appropriate for the deforested regions to recover into forests like those originally present. On the other hand, if the estimated rainfall is substantially lower than average for the life zone, present forest fragments may be more susceptible to drought and fires [*Cochrane*, 2003] and may further degrade, and forest recovery on cleared areas may be slow and eventually result in forests different in species composition or structure from those originally present.

4. RESULTS

Observed March rainfall differs among life zones, ranging from about 23mm/15mm for the forested/deforested regions of the relatively dry subtropical lower montane moist forests to 105mm for the forested regions of the subtropical rain forests. More importantly, in each of these life zones, the forested regions have larger March rainfall than do the corresponding deforested areas.

T-statistics tests were conducted to determine whether the rainfall amounts over forested regions were significantly different (higher) than over the deforested regions. For the two largest Holdridge life zones, Subtropical moist forests and Subtropical wet forests, the t-values were significant ($p = 0.001$, and $p = 0.02$ respectively) for March. In April the t-values were significant only over the Subtropical moist forests, whereas in May and June they were not significant. Indeed, with the onset of the wet season, from April through June the observed rain gauge rainfall differences between the forested and deforested regions become statistically insignificant and the estimated rainfall deficiencies are slowly removed for all Holdridge life zones.

Figure 1 shows the relationship at daytime hourly intervals between cloud frequency of occurrence and climatological rainfall measured at 266 stations in Guatemala (approximately 13°N to 19°N and 94°W to 86°W) for the month of March. The linear correlations found between cloud frequency and rainfall depend upon the time of the day. Indeed, morning cloud cover is uncorrelated with precipitation, but correlations in the afternoon are relatively high with a maximum of 0.48 at 1415 LST.

To improve the fit, the cloud frequency at 1415 LT was averaged over four years (2000 to 2003) for the month of March, and these averaged values were used to estimate March rainfall in a cubic model:

$$Y = 2.2875E\text{-}5(X^3) - 0.0036(X^2) + 0.1971(X) + 0.2897$$

where, Y is the logarithm of rainfall and X is the climatological March cloud frequency at 1415 LT (Figure 3). The correlation is 0.68 with $p < 0.01$.

Using the cloud cover-rainfall regression, rainfall was estimated for the month of March, at the height of the dry season, when there is maximum water stress on the vegetation. Figure 2a shows the estimated March rainfall, excluding the proposed corridors and protected areas (which are shown in white), and Figure 2b shows the corresponding values within the proposed protected regions. Although most parts of northern Mesoamerica have estimated values of March rainfall between 20mm and 60mm, some are estimated to receive substantially less and others substantially more.

A map of estimated March rainfall deficits from average raingauge values was created, as shown in Figure2c and 2d. Figure 2c shows the estimated March rainfall deficits in Northern Central America, excluding the proposed corridors and protected areas. Figure 2d shows the corresponding estimated rainfall deficits within the proposed MBC. Areas shown in green in Figures 2c and 2d are those regions that have estimated March rainfall comparable to climatological values from forested areas within the same Holdridge Life Zone. In these areas there should be no dry season climatic obstacles to the preservation of existing forests or to forest recovery. In contrast, the narrow Pacific coastal regions have estimated rainfall deficits of between 15mm to greater than 25 mm. In the Maya Lowland region estimated March rainfall deficits are commonly >25 mm. This deficit is approximately one-third of the March rainfall over forested parts of those life zones. This suggests that deforestation can substantially intensify the dry season, and thus increase susceptibility to fires, slow forest regrowth, and shift forest composition toward that characteristic of drier sites. In such cases, corridors linking the large protected areas may not serve well those species which have difficulty adjusting to altered ecosystems.

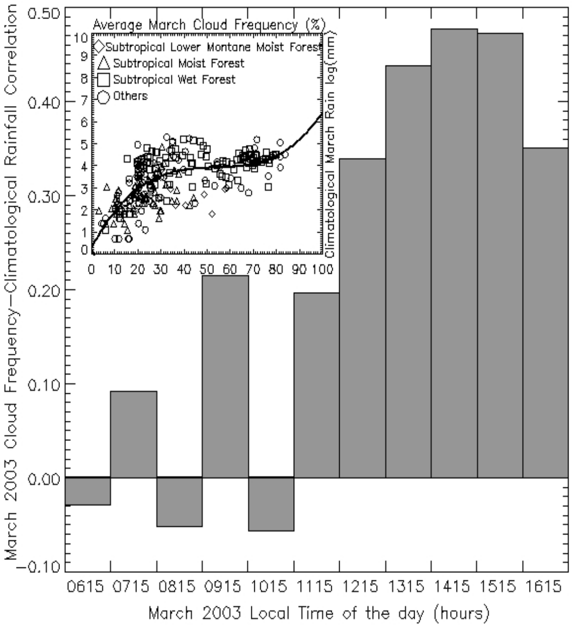

Figure 1. Correlations found between cloud frequency and rainfall at hourly intervals from 0615 LT (1215 UTC) to 1615 LT (2215 UTC) for March 2003. Inset shows the scatter plot between the Average March Cloud frequency (2000-2003) at 1415 LT (2015 UTC) – when maximum correlations are found – and logarithmic (natural log) transformed climatological rainfall. The Correlation (R) is 0.68, $R^2 = 0.46$, Standard Error of prediction (SE) is 0.80, $p < 0.01$, and the cubic predictor curve is: $Y = 2.2875E\text{-}5(X^3) - 0.0036(X^2) + 0.1971(X) + 0.2897$. The cubic model is used to estimate rainfall.

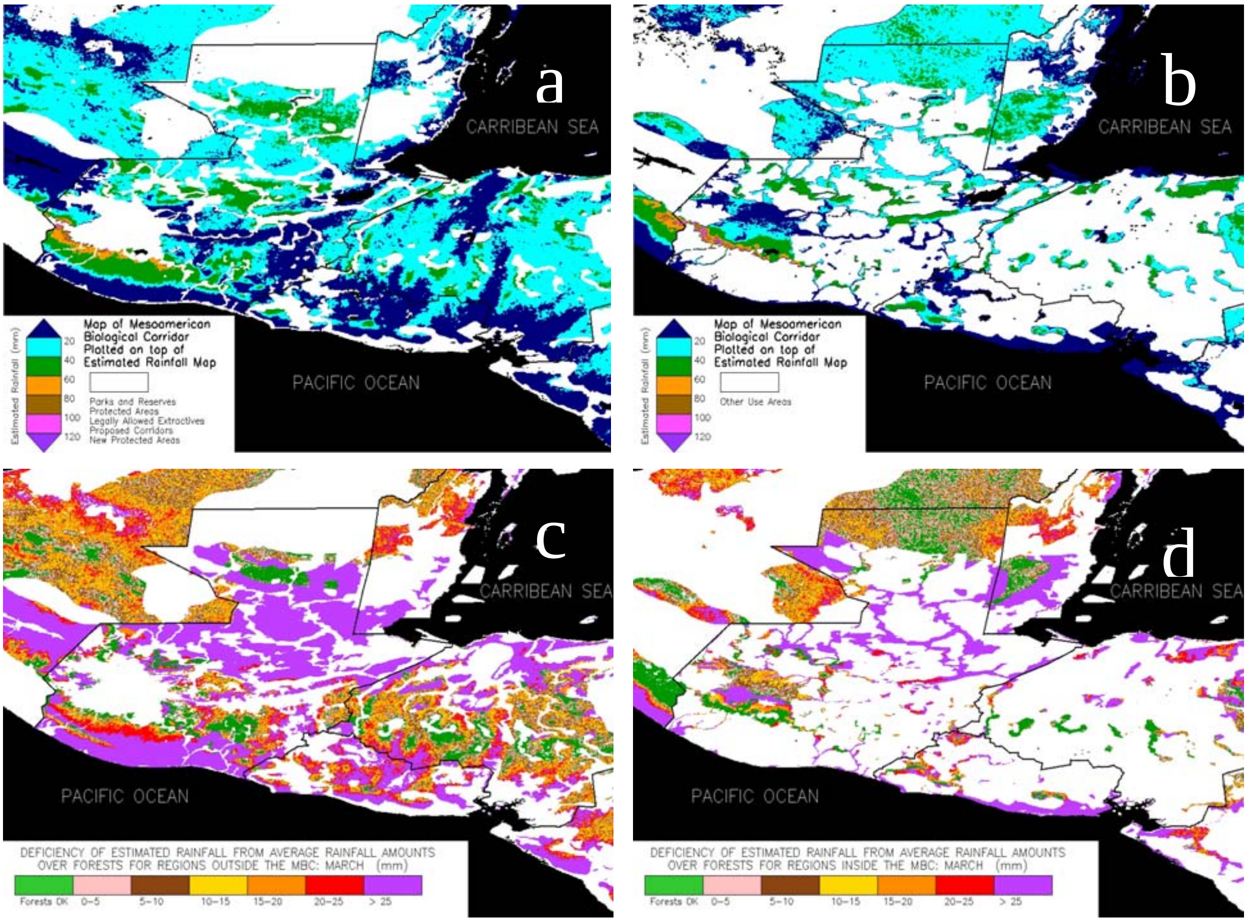

Figure 2 (a). Estimated rainfall from average cloud frequency and cubic equation (Figure 1) for areas surrounding the MBC. The MBC is colored in white. (b). Same as (a) but showing rainfall only for the MBC areas with the other use areas in white. (c) Rainfall deficiency map for the other use areas derived by subtracting the estimated rainfall from the rain gauge derived average rainfall for each Holdridge Life Zone. Some small Holdridge Life Zones did not have rain gauge values and these were left out of the current analysis. Otherwise this map is almost identical in areal coverage compared to Figure 2a. (d) Same as Figure 2b but for the protected and other use areas of the MBC. Again some small Holdridge Life Zones areas could not be included in the analysis.

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