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Milpa imprint on the tropical dry forest landscape in Yucatan, Mexico: Remote sensing & field measurement of edge vegetation

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Abstract

The Yucatan Peninsula hosts part of Central America's largest remaining tract of tropical dry forest and has been identified as a region of critical landscape change. This study complements the extensive research on land cover conversion in the region by investigating a subtle but important aspect of forest modification. We examine changes in the spatial characteristics of *milpa* cultivation plots in the swidden landscape of Peto municipality in Yucatan state from 1988 to 2003 using remote sensing. We also test the hypothesis that *milpa* clearings create a discernible edge effect in terms of forest structure. Results indicate that spatial patterns of *milpas* have changed over time. The amount of *milpa*/forest linear interface increased over the study period. Both satellite-based vegetation indices and field-based canopy cover measurements indicated that forest buffering *milpa* clearings had significantly lower biomass than background forest, despite that the background forest is itself a mosaic of successional forest stages. In contrast, there was no difference in stand basal area for *milpa* edge forest and background forest. Multivariate models demonstrated that the *milpa* edge indicator was the most important variable in explaining differences of vegetation indices for *milpa* edges and background forest compared with other factors that create edges in the landscape. Models were relatively effective in explaining mean values of vegetation indices; but they performed poorly in terms of explaining measures of forest vegetation heterogeneity. Comparing model results from each date suggests that the importance of *milpa* edges decreases over time, possibly as a function of the accumulated land use history as *milpas* rotate through the forest matrix. Evidence supports the notion that the effects of *milpa* land use extend beyond the clearing itself and into adjacent forest.
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1. Introduction

Human land use shapes ecosystem structure and function at multiple scales of time and space (Turner et al., 1995). One of the most significant global challenges in the next century relates to management of the transformation of the earth's surface occurring through changes in land use and land cover (Mustard et al., 2004). Much land change science research for tropical regions focuses on deforestation using discrete land cover classifications to study wholesale conversion, like deforestation (DeFries et al., 2000). Land cover modifications, such as forest degradation without wholesale clearing, also merit attention. Such modifications may have drastic effects on ecosystem processes and services like species composition and richness (Ferguson et al., 2003), trophic pathways (Bunn et al., 1999), carbon sequestration (Lawrence and Foster, 2004), and land-surface energy balance (Southworth, 2004).

The tropical dry forest life zone supports much of the world's agriculture, having more productive soils than those of humid tropical forests (Murphy and Lugo, 1986). The dry forest life zone covers 42% of all land area in tropical latitudes. Despite this geographic predominance, fewer

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studies have been conducted on this forest type relative to moist and wet tropical forests (Ramankutty et al., 2006; Perez-Salicrup et al., 2004). The Yucatan peninsula of southeastern Mexico hosts part of the largest remaining expanse of seasonally-dry tropical forest in Mesoamerica and has been identified as a "hot spot" for tropical deforestation, in part related to government-sponsored agrarian settlement programs (Chowdhury and Turner, 2006).

Agriculture is the major driver of land cover change in tropical regions (Lambin et al., 2001). Swidden agriculture, in particular, comprises a major land use and an important resource-management system in many parts of the tropics (Coomes et al., 2000). An extensive ethnographic literature classifies and describes these cultivation systems throughout the world (Unruh, 1990; Banerjee, 1995; Teran and Rasmussen, 1995). *Milpa* is the traditional form of recurrent swidden in Mesoamerica. It is based on rotation of maize fields and fallows, during which secondary forests are established to replenish organic matter and nutrients. *Milpa* cultivation in the Yucatan Peninsula generally occurs in conjunction with communal "*ejido*" tenure. This coupled land-use and land-tenure system has sustained cultivation on poor soils by regulating the number and timing of *milpa* fields; the amount of *ejidal* forest land (through deliberate set-asides); and the effects of population growth on land resources through generally non-divisible inheritance rights (Plaza, 2000).

In 1992, however, an amendment to Article 27 of the Mexican constitution provided a multi-step process through which *ejido* members may elect to privatize their long inalienable *ejidal* land. This amendment occurred as part of a national agenda to create an institutional framework favoring private investment, the development of a land market and productivity gains in agriculture (Johnson, 2001). Many *ejidal* communities have rejected these attempts to promote privatization, sometimes fearing taxation of privatized parcels. Some communities have elected to privatize parcels on which houses were located but not agricultural land, and others have delineated family parcels within the community-owned *ejidos* (Chowdhury and Turner, 2006). Other efforts aimed at "modernizing" Mexican agriculture include extension programs like PROCAMPO, PRONASOL, and other economic incentives that promote sedentary, intensive cultivation (Chowdhury and Turner, 2006).

Of all forested land in Mexico, 85% occurs in *ejidos*, making the country unique among both developed and developing nations (White and Martin, 2002). In Yucatan state, most *ejidos* are dominated by *milpa* land use. At broad spatial scales in the Yucatan, the precipitation gradient is the most important variable driving vegetation patterns (Lawrence et al., 2004). At local scales, like within an individual *ejido*, however, the structure and function of Yucatecan forests—from litter production to biomass and soil properties—are more strongly influenced by forest age and history of cultivation than by environmental gradients (Turner et al., 2004). The process of clearing land for swidden cultivation and the subsequent regeneration of forest during fallow periods creates a landscape mosaic of active *milpas*, forest patches in various stages of succession, and edge forest at the linear border between the two. Structural differences between mature forests and forests regenerating after *milpa* use have been well documented by many researchers. Differences in aboveground live biomass, soil fertility, species richness (Lawrence et al., 2004) and species composition of flora and fauna (Vester et al., 2007) have all been documented between mature forest and regenerating forest in the Yucatan.

Many biophysical, structural and floristic changes occur as a result of *milpa*/forest adjacency and due to the use of fire in creating the *milpa* clearing (Eaton and Lawrence, 2006). These changes may reinforce, or be reinforced by, land use feedbacks. One such feedback is that after clearing vegetation to make a field, forest at the interface immediately experiences an increase in both photosynthetically active radiation (PAR) and wind penetration at the ground level; altered albedo; and changes in surface energy and water balances. Subsequent land use in the edge forest may include collection or harvesting of fuel wood and cultivation of fruit trees (Ochoa-Gaona, 2001). Both these biophysical and land-use effects reinforce longer-term changes in soil properties, floristic composition, and plant and animal dispersal (Fig. 1).

Remote sensing and geographic information science have become standard tools for addressing these complex human–environment interactions at the landscape-level. Remotely sensed vegetation indices have also proven useful for coarse-scale biodiversity assessment, complementing field-based surveys (Nagendra, 2001). With such great emphasis on deforestation in the land change science arena, only recently have researchers begun to address more subtle issues of regrowth/succession and other qualitative forest changes and feedbacks (Chowdhury et al., 2004; Moran, 2004; Rudel et al., 2005). Most such studies still rely on the use of discrete land-cover classifications; yet a more effective approach is to use the full suite of continuous data available from satellite imagery (Southworth et al., 2004). Normalized differenced vegetation index (NDVI) has long been used as a proxy for biomass (Jensen, 1996) and to study structural forest attributes like canopy architecture (Eamus, 2001). Similarly, thermal band data have been useful in discriminating successional stages of forest (Southworth, 2004) given that surface energy balance is linked to the character of land cover and thus past land use.

With continuous data, both land-cover conversions *and* within-class modifications are detectable. Not only can conversion from 'agriculture' to 'successional forest' be seen after field abandonment, but also within-class changes. The latter includes processes such as changes in forest density, forest degradation or the ability to identify a greater number of successional stages as a forest matures