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Identifying deforestation attractors and patterns of fragmentation for seasonally dry tropical forest in central Veracruz, Mexico

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ABSTRACT

Seasonally dry tropical forests (SDTF) are exposed to numerous threats stemming from human activity and are considered a high conservation priority globally. Nevertheless, planning the conservation, management, and restoration of forests requires a detailed regional understanding of current forest distribution, and patterns and attractors of deforestation. We explored SDTF cover in the state of Veracruz, Mexico, where little is known about this type of forest since it was erroneously considered to have been eliminated and thus has not be included in recent conservation planning in Mexico. A time-series of land use and land cover (LULC) maps, based on Landsat imagery from 1973 (MSS), 1990 (TM), and 2000 (ETM+), was used to analyze historical patterns of deforestation and fragmentation of SDTF in a priority watershed in central Veracruz. Stepwise logistic regression was used to identify the main attractors of forest loss. Maps based on higher resolution SPOT imagery (2007–2008) were used to determine the current extent of SDTF. Results from our LULC analysis revealed landscapes that were consistently dominated (>50%) by some combination of intensified land use including cattle pastures, rain-fed and irrigated agricultural lands, with closed SDTF cover fluctuating from 11.3 to 9.26% during the study period (1973–2007). Annualized rates of forest loss between Landsat images (1973 vs. 2000; −2.02%) and between Landsat and SPOT images (1973 vs. 2007; −0.59), were moderate to low, with historical records suggesting that most deforestation occurred more than a century ago before the Mexican revolution. Nevertheless, rates of forest loss varied considerable between different time periods, with slight reforestation initially (1.55%; 1973–1990), followed by a marked decline (−8.08%; 1990–2000), and finally a noticeable increases in forest cover (4.92%; 2000–2007) that corresponds with changes in public policy and trends in population migration. The number of forest patches tripled between 1973 and 2000 and the mean forest patch area decreased almost 80% over the same time period. Logistic regression analysis (1973–2000) indicated that the main attractors of closed forest transformation were proximity to gentle slopes, cattle pastures, and the hydraulic infrastructure needed for crop irrigation. Although SDTF is highly fragmented and perturbed, important remnants of this diverse native forest still persists in the region. Our findings are discussed in the context of future conservation and restoration efforts.

Introduction

Seasonally dry tropical forests (SDTF) originally represented 40–42% of global tropical vegetation cover (Murphy and Lugo, 1986; Miles et al., 2006). However, approximately 50% of these forests have been converted to other land uses (Hoekstra et al., 2005; Miles et al., 2006) making them the most threatened tropical forest worldwide (Janzen, 1988; Miles et al., 2006). This ecosystem has historically had high human population densities given climatic and edaphic characteristics that are attractive for human settlement and agriculture (Portillo-Quintero and Sánchez-Azofeifa, 2010). SDTF are typically exploited for fuelwood and then cleared, burned, and grazed for cattle, in a cycle that has repeated itself frequently in the last century (Quesada et al., 2009; Griscom and Ashton, 2011). As a result, remaining SDTF fragments face constant degradation, isolation, and reduction, with climate change emerging as another factor threatening their persistence (De la Barreda-Bautista et al., 2011).

The main feature of SDTF is its seasonality, with a 4–6 months dry season (rainfall <100 mm), which has favored dominance by tree species that shed their leaves during the dry season to conserve water. Beyond their distinctive seasonality and phenology, SDTF are

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characterized by high beta diversity and a notable concentration of endemic species (Linares-Palomino et al., 2011).

Mexico contains the largest extension of SDTF (181,461 km^2) in the Americas (38% of the total; Portillo-Quintero and Sánchez-Azofeifa, 2010). However, the current extent of Mexican SDTF represents only 27–29% of its potential distribution (Trejo and Dirzo, 2000; Portillo-Quintero and Sánchez-Azofeifa, 2010) and more than half (62%) of remaining SDTF cover in the country is degraded (Challenger and Dirzo, 2009). SDTF in Mexico is exposed to a variety of threats including high frequency of fires, fragmentation, and conversion to agriculture or cattle pastures (Miles et al., 2006). Nevertheless, these forests comprise a relatively low proportion of regional protected areas (8.9%; Koleff et al., 2009).

In Mexico, 84% of dry tropical forests are found on slopes in the western portion of the country (Portillo-Quintero and Sánchez-Azofeifa, 2010) and most scientific efforts to study and conserve SDTF have been focused in Pacific ecoregions (Ceballos and Garcia, 1995; Trejo and Dirzo, 2000; Velázquez et al., 2003; Gordon et al., 2004; Maass et al., 2005; Romero-Duque et al., 2007; Kalacska et al., 2008; Montoya, 2009; Quesada et al., 2009; Rosas et al., 2011). Relatively little attention has been paid to tropical dry forests in the lowlands regions of the Gulf of Mexico (Gove et al., 2005; Williams-Linera and Lorea, 2009; Williams-Linera and Alvarez-Aquino, 2010; Cantarello et al., 2011; Williams-Linera et al., 2011), despite the marked isolation, species richness, and endemism of woody plants in these forests. Williams-Linera and Lorea (2009) found high beta diversity of woody species resulting from high regional landscape heterogeneity. They recorded 98 canopy tree species, of which four species are endemic to Mexico, four have disjunct distributions between western and eastern Mexico, and two are endangered species.

Although the rapid destruction and degradation of dry forests in the Gulf of Mexico region was mentioned in a previous study (Trejo and Dirzo, 2000), specific local patterns of forest loss have yet to be documented for this region. Tracts of STDF in this region appear to have been largely overlooked in previous national forest assessments and subsequent regional planning exercises due to structural biases in sampling protocols that locate fewer sampling points in fragmented landscapes (R. Flores, personal communication).

Effective conservation and restoration strategies require the documentation of changes in land-use and the potential effects of such trends on STDF regeneration (Quesada et al., 2009). To our knowledge, this is the first study that has explored the historical patterns of land use land cover (LULC) change in landscapes in the Gulf of Mexico region originally dominated by SDTF. This study seeks to enhance understanding of patterns of forest fragmentation and transformation, and to identify the underlying attractors (*sensu* Bürgi et al., 2004) of these changes in Central Veracruz over a 34-year period (1973–2007), thus establishing a baseline for prioritizing restoration and conservation activities in the region. This study was part of a long-term multidisciplinary research project (Restoration of Forest Landscapes for Biodiversity Conservation and Rural Development in the drylands of Latin America or ReForLan) focused on identifying and promoting approaches for sustainable management, conservation, and restoration of STDF landscapes in Latin America (Rey Benayas et al., 2011; Newton et al., 2012).

Materials and methods

Study area

The study area in central Veracruz, Mexico, covers a total area of 160,000 ha and is located along the coastal plain (Fig. 1). The boundaries of the study area were defined using the altitudinal limits of SDTF in the region (0–800 m; Rzedowski, 2006) and the inclusion of the major sub-watersheds (5 in all; CONABIO, 1998) found within, and comprising the latitudinal limits of, the study area. These subwatersheds are part of the Antigua River watershed considered a national priority for restoration given the extensive alteration of its vegetation structure and hydrological functions (Cotler et al., 2010). Climate in this area is warm sub-humid with a mean annual temperature of 22 °C (average range 14–36 °C), and rainfall of 1134 mm (800–1200 mm). Most rainfall occurs in the summer (95%), followed by an extended (4–5 month) dry season from October to May (García, 1990; Williams-Linera and Lorea, 2009). Topography in the northwestern portion of the study area is very heterogeneous and marked with steep canyons. The coastal zone is formed by eolian sediments, except in the center where it is dominated by sandstone and conglomerate covered by shallow soils. Soil types are very diverse but Haplic Phaeozems, Leptosols and Pellic Vertisols prevail (INIFAP-CONABIO, 1995). The study area spans 12 municipalities, including 490 rural (<1000 inhabitants) and 15 urban localities. Land is mainly in private hands covering 74% of the study area, which is the reverse of national trends where property is mainly communal ('*ejidos*').

Image acquisition and pre-processing

To document historical trends in LULC change, LANDSAT images from April to May 1973 (MSS, 57 m pixels), 1990 (TM, 28.5 m),

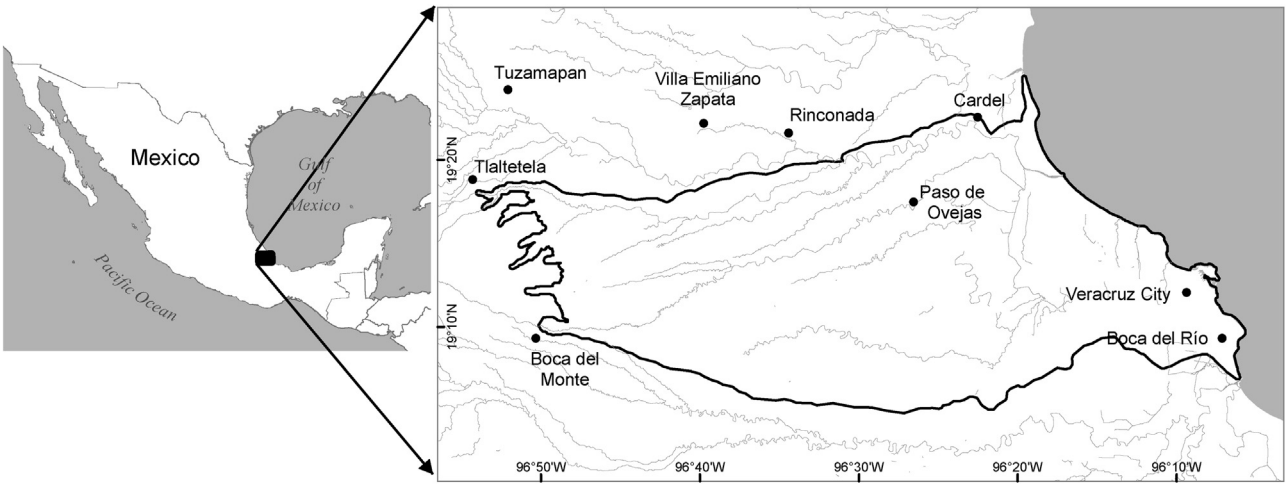

Fig. 1. Limits of the study area in central Veracruz state, Mexico. Lines correspond to permanent rivers and dots to major localities.