Land Use Policy 72 (2018) 443–450

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Forest cover change in the Los Tuxtlas Biosphere Reserve and its future: The contribution of the 1998 protected natural area decree

Juan José Von Thaden[a], Javier Laborde[a,*], Sergio Guevara[a], Crystian S. Venegas-Barrera[b]

[a] Instituto de Ecología A.C., Carretera Antigua a Coatepec 351, Col. El Haya, CP 91070, Xalapa, Veracruz, México
[b] División de Estudios de Posgrado e Investigación, Instituto Tecnológico de Ciudad Victoria, Ciudad Victoria, Tamaulipas, México

ARTICLE INFO

Keywords:
LANDSAT
Markov chains
Protected areas
Retrospective and predictive analysis

ABSTRACT

The Los Tuxtlas mountain range harbors one of the last remnants of tropical rain forest on the coastal plain of the Gulf of Mexico. This volcanic range has a high degree of heterogeneity in its geology, climate and ecology, in addition to a very long history of human occupation. The original area covered by tropical forest has been drastically reduced by agricultural activities, and during the last four decades in particular, deforestation has been very intense. In order to protect the remaining forest, in 1998 the Mexican government created the Los Tuxtlas Biosphere Reserve (LTBR). While previous studies estimated deforestation rates and the amount of forest cover remaining in some areas of the LTBR, this is the first study to do so for the entire protected area. A retrospective analysis from 1986 to 2011 was conducted to assess the effect of the 1998 decree of the LTBR on deforestation rates, and to predict future changes in forest cover up to the year 2025 using Markov chains and cellular automata based on current deforestation patterns. The results show that shortly after the 1998 decree, deforestation rates in the LTBR not only decreased but reversed, however this trend did not continue. In recent years deforestation has again increased. Our projection shows that if current trends continue unchanged then by the year 2025 we might have lost close to 14% (ca. 9000 ha) of the forest cover that was present in 2011. The decree of the LTBR was part of the federal policy to protect biodiversity in Mexico and our results show that the strategy of establishing this protected area did work to protect tropical forest, at least temporarily in Los Tuxtlas. Also, our results show that it is not only possible to reverse forest loss within the ample buffer zone of the LTBR, it is also still relatively easy to achieve by promoting passive restoration.

1. Introduction

Protected natural areas (PNAs) are established for the long term conservation of biodiversity and associated ecosystem services in a given area (CONANP, 2006). With the goal of protecting biodiversity and promoting sustainable development, biosphere reserves in Mexico have legal status as a type of PNA (CONANP, 2006). To date, 42 Biosphere Reserves have been officially decreed in Mexico, all of which are under pressure from deforestation, habitat fragmentation, pollution, species invasion, forest fires and illegal hunting (CONANP 2006; Ervin 2003; Figueroa et al., 2011; Figueroa and Sánchez-Cordero 2008; Mendoza et al., 2005). It is necessary to quantitatively assess these pressures and their temporal trends (both recent and previous) in order to fulfil the PNAs' objectives.

In 1998 the federal government published the decree that established the Los Tuxtlas Biosphere Reserve (LTBR) in southern Veracruz. As a result of the decree several actions and environmental projects designed to stop and if possible reverse deforestation within the reserve were initiated. The most noteworthy legal mandates of this decree include: forest cover may not be changed to any other type of land use within the reserve, flora and fauna may not be interfered with or extracted, and new towns and villages may not be established within the reserve (D.O.F., 1998). The reserve includes the largest and last remnants of tropical rain forest on the Gulf of Mexico coast (Guevara et al., 2004). The LTBR covers 155,122 ha (D.O.F., 1998), including three nucleus zones on the top of the highest volcanoes of the mountain range (9805 ha on the San Martin Tuxtla Volcano, 18,032 ha on the Santa Marta Range and 1883 ha on the San Martin Pajapan), all three surrounded by a single buffer zone (125,402 ha) that extends eastward to the Gulf of Mexico coast. In spite of the vast loss of forest cover in the region over the last 5 decades (Dirzo and García 1992; Guevara et al., 2004; Mendoza et al., 2005), the LTBR still harbors a very high diversity of the native fauna and flora. Tropical rainforest on the lowlands and cloud forest on the highest parts of the volcanoes were among the most widespread types of original forest of this region, the largest areas of which occur in the reserve (Castillo-Campos and Laborde, 2004).

* Corresponding author.
E-mail address: javier.laborde@inecol.mx (J. Laborde).

https://doi.org/10.1016/j.landusepol.2017.12.040
Received 11 July 2017; Received in revised form 7 December 2017; Accepted 13 December 2017
0264-8377/

Studies of the distribution of vegetation and plant species in the Los Tuxtlas mountain range have been done in different parts of the range, but typically have been restricted to a given part of the LTBR (Flores, 1971; Dirzo and García 1992; Ramírez 1999; see also Soriano et al., 1997), though some have encompassed the whole protected area (Andrle 1967; Guevara et al., 2004; Velazco Tapia 2007; PSSM-CONANP, 2011). These studies differ widely in the types of vegetation and land use cover reported and their respective areas, in part due to differences in the delimitation of the study site, but also as a result of the methods used to classify and estimate vegetation and land use cover types. Few of these studies indicate whether ground truthing was done, and when done, the methodology is rarely described in enough detail to replicate. None of these studies provides a quantitative assessment of the accuracy and degree of confidence in their vegetation and land use classification. This complicates the implementation and monitoring of sustainable management and conservation plans in the reserve. Until now we have not had any consistent or reliable maps of the forest cover in the whole area of the LTBR in which the methodology used to produce them and a quantitative assessment of their classification confidence are clearly stated.

Given the current threats facing all of the protected areas in Mexico and those threatening the LTBR in particular, it is crucial to develop a monitoring protocol that combines different spatial and temporal scales, in order to detect past and current trends in cover change that can be used as basis for estimating future trends and to identify those areas most at risk. In this study, we have made detailed maps of the forest cover for the entire LTBR over three decades in order to determine past changes and the current extent of forest cover, and to use the trends detected to predict changes in forest cover. Our main goal is to provide current, reliable, quantitative information for researchers, the authorities, and the inhabitants of the region of Los Tuxtlas and also for the decision-makers responsible for managing the LTBR. Information on the intensity, rate and trends of change in forest cover, as well as the magnitude and location of the affected areas is indispensable for making sound decisions on the sustainable use of resources and improving people's welfare, in addition to preserving biodiversity and the environmental services provided by the LTBR and the Los Tuxtlas region in general.

2. Methods

2.1. Study area

The Los Tuxtlas Biosphere Reserve is located on the coastal plain of the Gulf of Mexico, in southeastern Veracruz, between 18°30′–18°40′ N latitude and 95°03′–95°10′ W longitude and covers a total area of 155,122 ha (Fig. 1). The reserve includes large parts of the municipalities of San Andres Tuxtla, Catemaco, Soteapan, Mecayapan, Tatahuicapan and Pajapan, as well as small portions of the municipalities of Santiago Tuxtla and Angel R. Cabada. The LTBR spans a very steep elevation gradient (0–1683 m a.s.l.) with a tropical wet climate in the lowlands and temperate very wet climate in the highlands. Mean temperatures are 18–22 °C with a maximum of 36 °C (Soto, 2004). Mean annual precipitation is 4700 mm/year with a relatively dry season from March to May (CONANP, 2006). The highly heterogeneous landscape of the reserve and its location on the southern coast of the Gulf of Mexico has promoted a high diversity of flora and fauna (3356 and 1702 species, respectively; Guevara et al., 2004).

2.2. Forest cover maps

The maps of forest cover were based on the hard classification of LANDSAT satellite images, obtained from the USGS Science for a Changing World project (http://glovis.usgs.gov/) for the years 1986, 1993, 1998, 2003 and 2011. All images were obtained with geometric corrections and we performed an atmospheric correction for all of them. The images were classified with a Maximum Likelihood algorithm run in Idrisi SELVA (Clark Labs, 2012) using 6 of the 7 bands (numbers 1–5, and 7).

Traditionally, training fields or pixels sets are defined by on-screen digitalization of polygons representing a given type of land cover that, ideally, has been verified in the field (i.e. ground truthed). However, this methodology usually produces classification errors by assigning different spectral characteristics or signatures to a given polygon. This explains why different GIS users often produce different classifications of the same image. To minimize this bias, our study included a segmentation routine, which generates polygons of pixels with similar spectral signatures that are contiguous (Liu et al., 2008, Blaschke 2010). In other words, in addition to the spectral attributes of the pixels, their spatial relationships are taken into account when the image is being classified. Our study defined only two land cover categories: forest and non-forest cover. Segments with a continuous tree cover were classified as forest cover and areas devoid of trees or with discontinuous tree pixels (i.e. isolated trees) were classified as non-forest cover, including manmade pastures, crop fields, human settlements, roads and water bodies (i.e. rivers and small lakes).

2.3. Analysis of forest cover change

The magnitude and tendencies of forest cover change were assessed by cartographic overlap and by estimating differences in forest cover between dates, to generate maps of change and their respective transition matrices for the following periods: 1986–1993, 1993–1998, 1998–2003 and 2003–2011. Deforestation rates (r) were estimated using the equation proposed by the FAO (1996):

$$r = 1 - (1 - \frac{A_{1-A_2}}{A_1})^{1/t}$$

Where A1 = forest area at t1 (initial area), A2 = forest area at t2 (final area), t = time difference between t2 and t1 in years

To estimate the degree of accuracy in our satellite classification maps we compared the classification values obtained from our most recent image (i.e. 2011) with the actual cover type recorded in the field. First, to assess the number of validation points needed for a high degree of accuracy (> 85% concordance), we pre-sampled 50 randomly selected sites within our study area, visiting them between February and March of 2014. This allowed us to estimate the proportion of concordances (p) and number of discrepancies (q) between the value indicated in the classified image of 2011 and the real cover type verified on the ground in 2014, by applying the following formula (Chuvieco, 1991):

$$n = \frac{z^2pq}{E^2}$$

Where n = number of sampling points, z = abscissa of the normal distribution curve for a given probability value, p = proportion of concordances, q = proportion of discrepancies (q = 1 − p), E = allowed error level (± 5%).

Based on this pre-sampling of 50 points (which indicated an accuracy of 0.88) it was determined that 162 validation points were needed to attain a high level of accuracy in our classification. The 162 randomly selected points spread throughout the study area were used to estimate the Cohen-Kappa index of concordance, where values approaching 100 are very accurate. For earlier images (i.e. those older than 2011) we used the same 162 points to estimate their accuracy following the procedure of Campbell et al. (2015). Data were arranged in a confusion matrix, with observed land cover classes (verified forest and non-forest cover) from the ground as columns and satellite classes (classified as forest or non-forest) as rows. The Kappa (k) index formula is (Cohen, 1960):