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REGIONAL DEFORESTATION IN A TROPICAL MONTANE CLOUD FOREST IN ALTA-VERAPAZ, GUATEMALA

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Abstract. From 1986 to 2000 we quantified and qualified the deforestation at a regional scale in the northern mountain ranges in the Sierra Yalijux (819.5 km^2 in total) in central Guatemala using Landsat TM and ETM+ satellite imagery. However, the area is of special interest from a conservation biology perspective as comparatively large tracts of primary oak-pine cloud forests remain above 1800 m. The area is steadily diminishing through slash-and-burn agriculture and replacement by milpa (corn and bean agricultures). Agricultural activities reduced natural oak and pine forest in the study region between 1986 and 2000 at a mean rate of 0.2% annually, representing 25 km^2 of the area during that period. The country-wide mean deforestation rate in Guatemala from 1990 to 2000 was 1.7%. Therefore the regional deforestation rate is negligible, and may be traced back to methodological features or conservation efforts. The consequence of our finding is that typical nation-wide assumptions of deforestation are not always useful for conservation concerns, and should be treated with caution. Regional differences in deforestation should be considered also. *Accepted 25 February 2006*.

Key words: *biodiversity*, *conservation*, *deforestation*, *Guatemala*, *land-use change*, *Neotropis*, *tropical mountain cloud forest*.

INTRODUCTION

Deforestation is one of the largest threats to tropical forest biodiversity (e.g., Pievello 1999, Douglas 2001, Paulsen 2003), and steadily continues in some countries at a high and often increasing rate (FAO 2003). Deforestation has been measured several times on broad scales (continents or country-wide), but typically lacks fine-scale differentiation regarding the degree of deforestation (FAO 2003, Polk *et al*. 2005, Leimgruber *et al*. submitted). For instance, the mean annual deforestation rate is 1.7% for Guatemala (FAO 2003), but within the country the rate varies between regions, e.g., the northern region in El Petén experienced higher deforestation during the last decade than the central highlands, while the southern Pacific slopes were deforested during the first half of the 20th century and are now almost forest free (Unger 1988, Markussen 2004). Since these data sets are rough and measured on a broad scale, untouched areas in the central parts of Guatemala are hardly or not at all represented by these analyses. Therefore we established a regional deforestation map for the northernmost mountain range in Guatemala (Sierra Yalijux) to discover whether the regional deforestation is higher or lower compared with country-wide deforestation trends. These regional deforestation and land-cover analyses are important to justify further studies in, for instance, diversity assessments or implementation of new sanctuaries/reserves. They could also serve as the basis for economic and social studies involved in biodiversity conservation (Máñez-Costa & Renner 2005, Markussen & Renner 2005).

STUDY AREA AND STUDY PLOT

The study region – from now on Sierra Yalijux – is located close to the communities of Chelemhá and Caquipec (Fig. 1). Both communities are located in the Departamento Alta Verapaz, Guatemala, 12.5 km north of Tucurú and the Río Polochic, and 35 km south-south-west of Cobán. We added the northern and southern parts neighboring the Sierra Yalijux to the area of interest since most deforestation has taken place at the forest margins during the last two decades (Fig. 3), while the study plot resembles the centered rectangular in Fig. 3.

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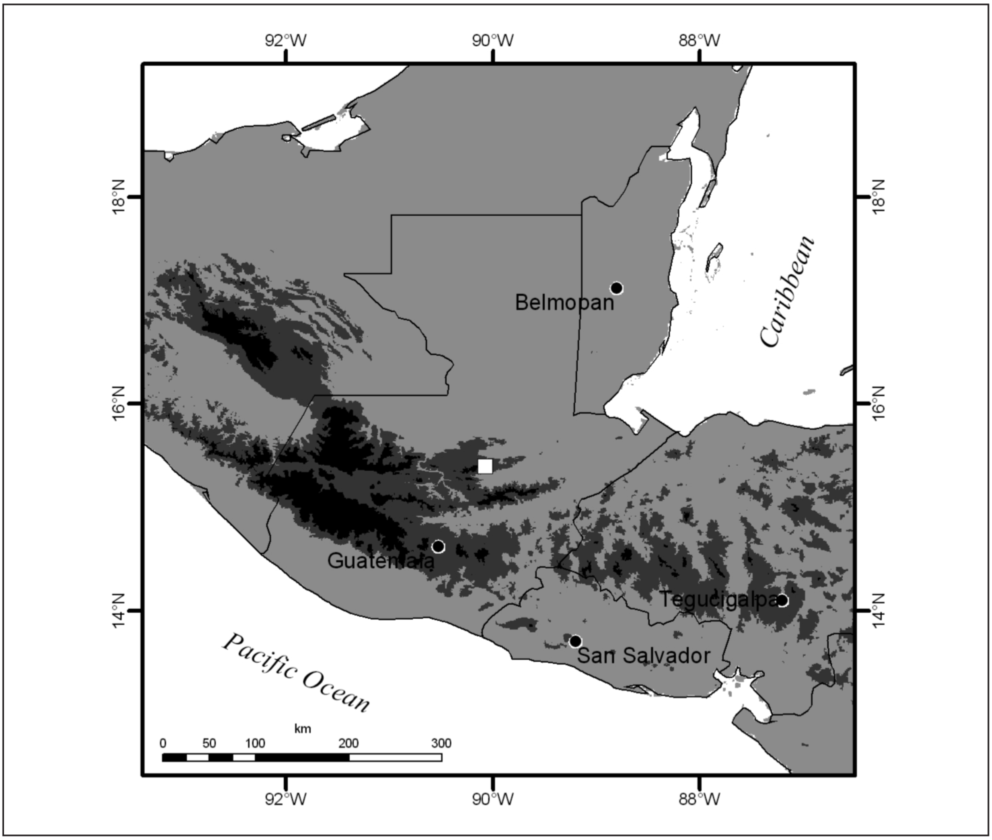

FIG. 1. Location of the study region in Guatemala (rectangle represents location of Fig. 3). Dark gray > 1000 m, black > 2000 m.

The Sierra Yalijux is assumed to consist of three fragments of 5500-ha montane cloud forest (Schulz & Unger 2000, Markussen 2004), but a precise delineation of the Sierra Yalijux is missing so far. We apply here a forest-cover-based concept, i.e., the Sierra Yalijux is entirely covered by primary forest. The primary forest in the Sierra is mainly mixed oak (*Quercus* sp.) and pine forest, with *Pinus maximinoii* as the dominant species < 1800 m and *Quercus* dominant > 1800 m (Veblen 1976, Moziño 1996). Oaks are especially abundant on limestone, and pines mainly abundant on the southern slopes where precipitation is lower (Unger pers. comm.). The secondary vegetation type is all kinds of secondary growth, including agricultural areas with corn (*Zea mays*), beans (*Phaseolus vulgaris*), pine-reforestation (*Pinus maximinoii*), and shrub vegetation as a consequence of fallow periods. Secondary growth is here usually a patchwork of several small to very small areas (≤ 0.2 ha rarely reaching 1 ha). After corn and bean cultivation, shrubs can grow up to 10 m in height during a fallow period of seven years. Generally, there is only a fallow period of 0–3 years in the community of Chelemhá. The shrubby habitat is composed of many different tree species, including oaks, but in contrast to primary forest, pines are rare and the shrubs form only a single vegetation layer. Also important and highly abundant are members of the family Lauraceae serving as food for Resplendent Quetzals *Pharomachrus mocinno*. The overstory exceeds 35 m and mean dbh (diameter at breast height) is 75.6 ± 13.4 cm; mean understory dbh is 5.3 ± 1.6 cm. The understory typically reaches 7 m and overstory (canopy) starts at around 20 m (compare Renner 2005).

TABLE 1. Reference data for land-cover change detection.

Parameter	Contents
Images	Landsat-TM from 13 March 1986 (WRS-2: Path 020, Row 049), 30-m resolution
	Landsat-ETM+ 23 January 2000 (WRS-2: Path 020, Row 049), 30-m resolution
Programs	ERDAS Imagine 8.7
	ArcGIS 9.1 (ArcINFO) with Spatial Analyst
Procedures	Supervised classification for Area of Interest with 29 initial classes (+ class "no data")
	Neighborhood statistics (Type: majority, 3 * 3 pixels, rectangular)

METHODS

Forest cover was analyzed using two satellite images. We used Landsat-TM and Landsat-ETM+ (Tab. 1). Analyses were performed with ERDAS 8.7 and ArcGIS 9.1. Both images were processed jointly (layer stack) and changes in land cover were mapped by the change in emission ("change detection"), especially in the near infrared bands (bands 4, 5, and 7). Forests are distinguishable from other land-cover types in near infrared bands (4/5). The following land-cover classes were applied: cloud forest (mainly *Quercus* sp.); pine forest (*Pinus* sp.), and old secondary forest; open areas including settlements, milpa, and bush and shrubs as consequences of milpa; water bodies with adjacent boulder areas; deforestation for all forest occurring between 1986 and 2000. The latter class includes also a few pixels (< 10) with 'no data'. We applied a supervised classification with initially 30 classes and finally chose the 5 classes mentioned above. Neighborhood Statistics were performed on the recoded map (type: Majority, rectangular 3 by 3 pixels, output resolution 30 m) to smooth the results and reduce noise. In addition, we summarized and analyzed all deforestation factors occurring in Guatemala, and also at the regional scale. For further aspects of the study area, see Renner & Markussen (manuscript submitted) and for discussion on methodology see Voigt (2004). We also reviewed the literature on deforest-

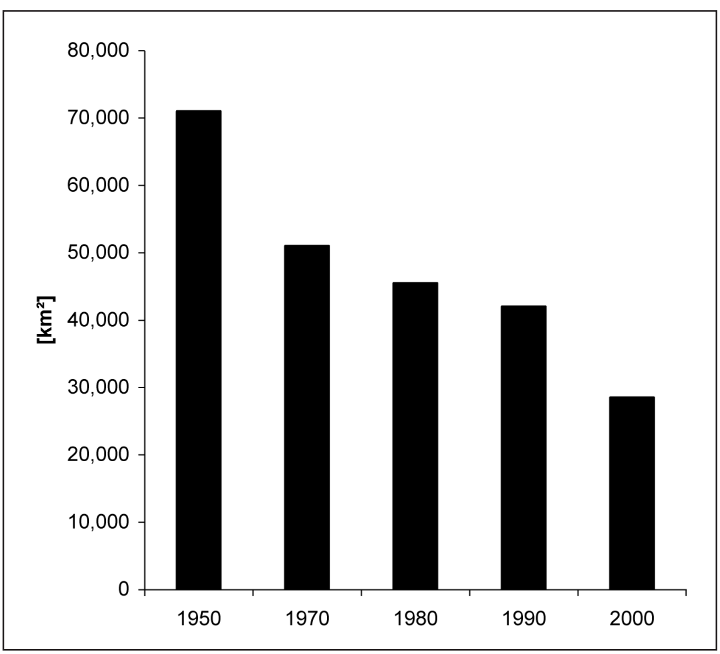

FIG. 2. Forest cover in Guatemala 1950 to 2000 (adapted and altered from Markussen 2004).

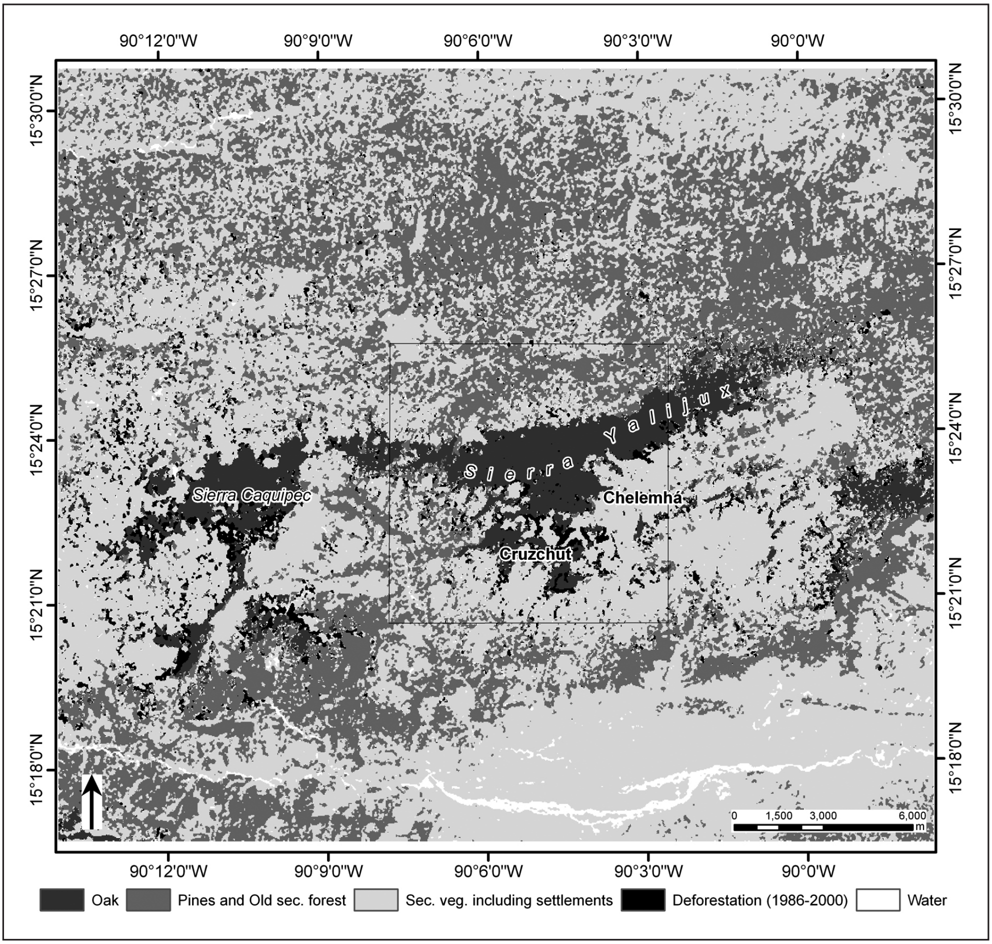

FIG. 3. Forest-cover change in the Sierra Yalijux between 1986 and 2000 (supervised classification). Mature forest consists mainly of *Quercus* sp. and pine forest mainly of *Pinus* sp. *Rectangle* refers to the study plot while the whole image outlines the study region (study plot: 86.84 km^2 out of 819.54 km^2 total of the study region; Tab. 2).

ation in Guatemala nation wide to compare our regional results with these found in other locations in the country.

RESULTS

Deforestation in Guatemala. Deforestation rates have increased in Central America during the last three centuries (Myers & Tucker 1987). Houghton *et al.* (1991a, b) analyzed land-use changes in Latin America from 1850 to 1985 by using historical sources. The slash-and-burn area expanded almost constantly until 1940, and 28 % of the area has been converted to human used areas since 1940. Approximately half (44 %) of this 28 % was converted to pasture, 25 % to arable farming, and 10 % to slash-and-burn subsistence cultivation. Several other processes degraded the remaining 21 %.

Forest cover in Guatemala decreased significantly from 65 % of total area in 1950 to 26 % in 2000 (Fig. 2). Annual forest cover lost in Guatemala is between 50 000 and 60 000 ha (Baumeister 2001, FAO 2003), approximately 1.7 % of the total area annually. This represents a very high international deforestation rate, in line with Haiti (5.7 %), Saint Lucia

(4.9 %), Nicaragua (3.0 %), Belize (2.3 %), and Nepal (1.8 %). The trend of forest cover decline in Guatemala is significant, applying both linear and exponential models ($p < 0.05$, linear trend: $y = -9400.6 x + 75801$, $r^2 = 0.92$, exponential trend: $y = 83\,589 e^{-0.202} x$, $r^2 = 0.9351$; Fig. 2). Both models explain very well the deforestation trend in Guatemala ($r^2 > 0.9$).

Deforestation in the Sierra Yalijux. Forest cover decreased slightly within the Sierra Yalijux region between 1986 and 2000 (Fig. 3). However, the mean deforestation rate during this period, 0.22 % annually, is far below the general deforestation of the entire forested area in Guatemala (1.7 % annually). All secondary habitats such as milpa, bush and grassland, farming, and all settlements in the study region comprised approximately to 56 % (Tab. 2), and increased by exactly the area that was deforested between 1986 and 2000. Mature forest and old secondary regrowth (approximately 15 years and older) comprises 40 % of the study plot (rectangular in Fig. 3). Deforested areas in the study region (Sierra Yalijux) equal 3.08 % of the land-cover between 1986 and 2000. Applying the study plot, and hence a smaller area, as an example for different deforestation rates in different areas, the deforestation rate is twice as high at 6.0 % (Tab. 2). This simple consideration reveals that scale matters significantly in analyzing deforestation and land-cover changes.

DISCUSSION

The consequences of deforestation have been reported previously (e.g., Markussen & Renner 2005), and they include a lower abundance of forest species and higher habitat fragmentation as well as habitat destruction in central Guatemala. Moreover, climate may change at a local as well as at broader scales, and soils may be altered (Markussen 2004).

The mean deforestation rate of 0.22 % annually between 1986 and 2000 in the Sierra Yalijux is comparatively low. In the whole of Guatemala the rate is eight to nine times higher. The low deforestation rate in highlands like the Sierra Yalijux contrasts with the above-average deforestation in the northern Guatemalan lowlands of El Petén. Reasons for deforestation vary regionally and have been analyzed before. However results are partly contradictory and not congruent. Cuadernos Chac (1996) conclude from their investigation that policy implementation currently encourages new deforestation in Guatemala. For instance, the Guatemalan authorities finance deforestation indirectly by providing payments for new agricultural areas (14 820 Guatemalan Quetzals per km^2 in 1992/1993, ca. 1475 Euro in November 2004, but only 764 Quetzals, ca. 75 Euro, for forested areas or reforestation). Expanding farmland in El Petén was particularly responsible for the diminished forest area (Kaimowitz 1996, World Bank 1995).

Another factor in deforestation is human migration caused by property rights. Property rights force landless people to migrate to areas of less dense population, which are generally still covered with vast areas of primary forest. For instance, the population in El Petén increased by 11% in the early 1990s (Cuadernos Chac 1996). Various reasons for deforestation are frequently suggested but a general disagreement over these reasons exists, with the two most important causes being ‘agricultural migration’ (78.5 %

TABLE 2. Classification of land-use in Chelemhá (km^2) based on changes from 1986 to 2000.

Class	Study region	% study region[1]	Study plot[2]	% study plot[1]
Mature forest (mainly *Quercus* sp.)	55.5	6.7	13.1	24.6
Pines (mainly *Pinus* sp.) including old secondary regrowth (15 years and older)	271.9	33.2	12.6	23.8
Secondary area including settlements, bush and shrub as well as milpa and coffee plantations	458.8	55.9	24.9	47.1
Deforestation since 1986 (14 years, annual mean: -0.22%)	25.2	3.1	3.2	6.0
Water bodies and related features	8.1	1.0	> 0.1	> 0.1
Total:	819.5	100.0	53.8	100.0

[1] In 2000.
[2] Study plot refers to central rectangle in Fig. 3.

of all conversions) and ‘extensive farming’ (10.0%) (CONAMA 1999, DIGEBOS in lit.). World Bank (1995), ENB (1999), FAO (1999), Chemonics International *et al.* (2000), Katz (2000), and INAFOR (no date) analyze in detail the land property rights and consequences for deforestation but draw no clear conclusion in the end. The topic remains complex and unanswered. However, all authors agree that deforestation exists and Baumeister (2001) summarized land-use in Guatemala and its changes; the greatest area was converted from forest to agricultural land.

Even when considering the study region and the entire Sierra Yalijux, deforestation occurs very locally in Guatemala (Fig. 3); deforestation “hotspots” are distributed in time and space over the country, as can be well seen in the study region and study plot. For instance, the Pacific slopes of the country had been deforested by the beginning of the 20th century and the ancient Maya culture is believed to have used the entire Yucatán Peninsula before the arrival of the Spanish conquistadores in the 13th and 14th centuries (Watson and Townsend Peterson 1999, Watson 2003). Even in the study region and study plot, deforestation is patchily located. Especially in the south of the community of Chelemhá, near Cruzchut (see Fig. 3), large tracts of mature oak forest were cleared within 15 years, while at the highest altitude or in the center of the mature oak forest hardly any trees have been slashed. The lack of accessibility as well as “development” programs for avoiding deforestation have had a positive effect. For instance, the local acting NGO ‘UPROBON’ engaged and implemented the Reserva Privada de Chelemhá, a category for private sanctuaries to prevent further deforestation in the region. Since the implementation of the sanctuary in 2000 (official status was granted in 2003), deforestation has been reduced to zero and the first reforestation projects have succeeded in the reserve area. In addition, Schulz & Unger (2000) analyze the factors reducing regional deforestation in the study region and conclude that conservation efforts since 1989 are strongly influencing locals to preserve the forest as a resource for their own use.

Most studies analyzing deforestation in Guatemala focus on the northern lowlands, with vast areas of almost untouched primary forest in El Petén (Hayes *et al.* 2002, Sader *et al.* 2001, Sader *et al.* 1997) and Reserva Biosfera Sierra de las Minas. Estimates have also been made for the Sierra Yalijux by Schulz and Unger (2000) to determine the cloud forest area in Guatemala. They concluded that just 5500 ha of the original cloud forest area remain in the Sierra Yalijux. However, the methods employed to determine the original cloud forest area may be biased (everything >1800 m in the northern Cordillera of the country), which would also apply to estimates of deforestation.

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