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Rates of Deforestation in Los Tuxtlas, a Neotropical Area in Southeast Mexico

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Abstract: *On the basis of ground surveys, aerial photographs (for 1967 and 1976), and satellite imagery (for 1986), maps of rain forest distribution were developed for the northern part of the Sierra de Los Tuxtlas (Veracruz, southeast Mexico).*

Forest coverage maps for 1967, 1976, and 1986 show dramatic deforestation proceeding up from the lowlands, with the remaining natural vegetation now increasingly restricted to the high, steep, and less accessible parts of the Sierra. From the digitizing of the maps it was estimated that (1) during the nearly 20 years of this analysis the vegetation was reduced by 56%, and (2) by early 1986, approximately 84% of the original forest area had been lost.

The derived annual deforestation rates (expressed as the percentage of remaining forest that is cleared per year) were 4.2% for the interval 1967–1976 and 4.3% for 1976–1986. Were these trends and rates to continue, only 8.7% of the original vegetation would persist by the year 2000, and then only in the form of an archipelago of very small forest fragments, of which the largest would be the now-protected areas (e.g., the Los Tuxtlas Biological Station, with only 640 ha), and the most inaccessible tracts.

Immediate action is urgently needed to protect these small but rich remnants and preserve them as foci of potential biological inocula for future ecorestoration of these, the northernmost tropical forests on the continent.

Resumen: *A partir de muestreos a campo, fotografías aereas (para 1967–1976) e imágenes satelitarias (para 1986), se produjeron mapas de distribución de la selva tropical húmeda, de la porción más norteña de la Sierra de los Tuxtlas (Veracruz, sureste de México).*

Mapas de cobertura vegetal para 1967, 1976 y 1986 muestran una dramática deforestación procedente de las tierras bajas, encontrándose la vegetación natural remanente, cada vez más restringida a los sectores más inaccesibles de las Sierras. A partir de la digitalización de los mapas se estimó que: (1) en los casi 20 años que comprende el presente estudio, la vegetación se redujo en un 56%, y (2) hacia los inicios de 1986, aproximadamente el 84% de la selva original se había perdido.

Las tasas anuales de deforestación (expresadas como porcentaje de selva remanente que es cortada por año) fueron estimadas en un 4.2% para el intervalo 1967–1976 y 4.3% para 1976–1986. Si estas tendencias se mantienen, para el año 2000 quedará solamente un 8.7% de la selva original. Aún más, esta selva original se reducirá a pequeños fragmentos, en forma de archipielagos, de los cuales los mayores coincidirán con las areas actualmente bajo protección y aquellas zonas más inaccesibles.

Es necesaria una acción urgente para proteger estos remanentes pequeños, pero de gran riqueza y preservarlos como focos de inóculo biológico potencial para la futura restauración ecológica de estas forestas, que constituyen el límite más boreal de distribución de la selva tropical húmeda en el continente americano.

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Introduction

A common statement in the introductory remarks of many recent scientific and popular articles related to tropical rain forest conservation biology is that though these forests are the most important storehouses of biotic diversity on Earth, they are disappearing (or being disturbed) very rapidly. Although there is little dispute that tropical rain forests are uniquely species-rich (e.g., Erwin 1983, 1988; Gentry 1986; Wilson 1988) or that they are rapidly disappearing, the *rate* at which tropical rain forests are being disturbed on a worldwide scale (Lanly 1983; Myers 1980; Sommer 1976) has been much debated (see, for example, Lugo & Brown 1982; Mares 1986; Simon 1986). This is due mainly to the variability of the reported statistics, and attempts have been made to correct or standardize some of these sources of information (see discussions in Grainger 1984; Mellilo et al. 1985). The overall statistics are so variable in part because estimates of deforestation rates at more local scales are also extremely variable. In Mexico, for example, tropical rain forests are estimated to comprise, currently, an area of 11.1 million ha (or 5.6% of the area of the country) (García & Pérez 1991), the estimated rates of deforestation ranging from 0.46 (Repetto 1988) to (an obviously incorrect extreme of) 1.6 million ha per year (Grainger 1984), with several intermediate values (see, for example, Toledo 1989; Wilcox et al. 1988).

The potential value of such assessments is limited by the unreliability of the disturbance statistics and by discrepancies in terminology and assumptions among workers (see a discussion in Mellilo et al. 1985). Frequently the major problem is that the information used to produce the statistics is not very accurate or recent (see Hadley & Lanly 1983). Quite clearly, accurate estimates of the rates and patterns of tropical deforestation would be extremely valuable for the study and potential solution of problems such as the loss of biodiversity (Reid & Miller 1989; Wilcox et al. 1988; Wilson 1988), soil erosion (Sánchez 1976), climatic changes (Raven 1987), and atmospheric accumulation of CO_2 (Brown & Lugo 1982; Houghton et al. 1983) and other "greenhouse" gases (Matson & Vitousek 1990). Local and regional estimates of tropical deforestation are likely to play an important role in these conditions since: (1) the most accurate estimates can be obtained at a local level, for example, on the scale of a region or small country, and (2) accurate global estimates at the scale of a continent or the world can only be obtained from the summation of reliable local estimates. These local studies can be made more valuable if, in addition to the written descriptions of the extent of deforestation, accurate maps are provided showing the location and dates of forest coverage; these can be used as a baseline for other studies and for the subsequent monitoring of forest change. In this paper we present a time-series of maps of rain forest distribution in the northern part of the Sierra de Los Tuxtlas (state of Veracruz, southeast Mexico), and through them derive the rates of deforestation for the period 1967–1986.

The Sierra de Los Tuxtlas

The Sierra de Los Tuxtlas is the easternmost edge of the volcanic belt that crosses Mexico in a west–east direction. Los Tuxtlas is a complex series of uplifts running in a NW–SE direction. This massif arises on the coastal plain of the Gulf of Mexico and is relatively isolated from other mountain systems. An area of intensive volcanic activity, it is characterized by the presence of numerous small- to medium-sized volcanic structures, the largest of which are the Volcán San Martín Tuxtla (1700 m a.s.l.), and Volcán Santa Marta (1650 m) (Sousa 1968). The area of Los Tuxtlas is naturally divided into two parts, one to the northwest (Volcán San Martín) and one to the southeast (Volcán Santa Marta), separated by a depression in which lies Lake Catemaco, Mexico's fourth-largest lake (Pérez 1984). Although it is difficult to precisely ascertain the original area of tropical rain forest in the Sierra, this was clearly one of the major tracts of tropical vegetation in Mexico (Pennington & Sarukhán 1968).

The predominant potential vegetation of the area is tropical rain forest, with a number of elevational variants (Andrle 1967; Dirzo 1991; Ross 1975; Sousa 1968); the Volcán Santa Marta range (not considered in this study) includes some patches of oak and pine forest (Ross 1975; Sousa 1968). Additional details about the climate and vegetation of the area can be found in Dirzo (1991), Ross (1975), Sousa (1968), and Gómez-Pompa et al. (1976).

Human settlements have been established in the area for about 1500 years, first by the Olmecas followed by the Popolucas and Mexicas. The Spaniards arrived in the area by 1522 (Andrle 1967; Medel y Alvarado 1963; Ross 1975). This long history of continuous human occupation, however, was not associated with a high population density until the beginning of this century, when a railway and highway were constructed connecting the area with the city of Veracruz and other major cities. Increased communication promoted the development of such activities as timber trading, sugar factories, tobacco plantations, and cattle ranching, which have had a marked impact on the forests of the area.

The region is of considerable importance for the following reasons: (1) currently Los Tuxtlas is the northernmost patch of tropical rain forest on this continent (Dirzo & Miranda 1991); (2) the biota of this area, despite its relatively high latitude (18° 27′), is extremely rich and includes a unique mixture of plant and animal

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species of Central and South American (tropical) and northern (temperate) origin, as well as some endemics (Dirzo 1991; Ibarra & Sinaca 1987; Ross 1964, 1975); (3) to the north of this area there is a research center, the Los Tuxtlas Biological Station (owned and operated by the National University of Mexico, UNAM), which is currently the best-studied forest site in Mexico, and one of the best-studied tropical forests of the world (see, for example, Gómez-Pompa et al. 1976; Gómez-Pompa & del Amo 1985).

Materials and Methods

Areas of forest coverage and rates of deforestation rates were calculated only for the northwestern part of the Sierra, since satisfactory remote-sensing materials (aerial photographs and satellite imagery) as well as cartographic information were available only for this area. The surveyed sector, which comprises 850 km^2 (Fig. 1), includes the Volcán San Martín and, to the north and east, the coastal lowlands including the area where the Los Tuxtlas Biological Station is located.

Vegetation maps were prepared on the basis of analysis and interpretation of (1) aerial photographs (scale 1:50 000) for 1967 and 1976, purchased from Aerofoto S.A. (Mexico City) and Dirección Nacional de Geografía (Mexico City), respectively, and (2) satellite (Landsat) imagery derived from a thematic mapper computer-compatible tape (from NASA), from April 1986. The interpretation of these materials was aided by complementary ground surveys of the distribution of the vegetation (see Dirzo 1991; García 1988).

A digitizing program, AU2, obtained from commercial suppliers in Mexico City (GESA S.A.), was used to calculate, from the generated maps, the areas of forest for the three dates. From the calculated areas, rates of deforestation, r, were estimated for the periods 1967–1976 and 1976–1986, as follows:

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

where A_1 = area of forest at the beginning of the period, A_2 = area of forest at the end of the period, and t = number of years for a given period.

In this study, the term "deforestation" refers to the replacement of forest habitat by nonforest habitat, such as pastures, agricultural fields, or human settlements. Disturbances that did not considerably reduce the forest cover (assessed by field inspection) and therefore did not change the general texture or color associated with forest in the remote-sensing imagery were not considered as deforestation. For the analysis, the maps were overlaid to check and adjust the distribution of the vegetation on the three dates. It was found that in some small areas (adding up to less than 3% of the surveyed area), vegetation not shown on a previous date was present in a subsequent one. When the cover of these "regrowth" patches was high enough (>70%) they were included as areas of regenerated vegetation. This criterion contrasts with that of Sader and Joyce (1988), who eliminated all areas of "regrowth" in a similar study.

Results

The forest maps generated for the three dates are shown in Figure 2. Figure 2A shows that considerable forest clearing had occurred before 1967. These clearings are located mainly to the southeast and northwest of the study area and correspond to the presence of major human settlements (Catemaco, San Andrés, and Santiago Tuxtla to the south, and Nueva Victoria to the northwest; cf. Fig. 1). These initial clearings were all associated with relatively low (0–600 m), flat areas. A similar trend appears to continue with time, with most of the pre-1976 deforestation (Fig. 2B) occurring to the north and east-southeast of the area, while deforestation to the south had not yet become extensive. Prior to 1967 the major pulse of deforestation to the east coincided with the opening of a new road connecting Catemaco to Balzapote-Montepío (see Fig. 1), which was completed by 1967. Intensive deforestation continued to the north and east of the area (Fig. 2C), leaving only isolated patches of vegetation. By 1986, the only major tract of remaining vegetation was the area around the Volcán San Martín, roughly from the 900 m elevation contour upwards with a "peninsula" extending east into the lowlands, including the Los Tuxtlas Biological Station. Two general patterns emerge from these maps: (1) deforestation proceeded from the lowlands, pushing the forest margin back to the high, steep, and inaccessible areas of the Sierra; (2) deforestation resulted in the generation of a complex archipelago of mostly small forest fragments. It is our general impression (though we do not have the supporting data) that similar trends took place on the Volcán Santa Marta (the other major area of vegetation in the Sierra) (personal observation; G. Pérez-Higareda, personal communication; G. N. Ross, personal communication) except that the pine and oak forests at mid to high elevations were disturbed here earlier than such forests on Volcán San Martín.

The calculated forest areas and corresponding rates of deforestation are shown in Table 1. If one assumes that the entire surveyed area was originally covered by primary vegetation, by 1967 the area lost was 540 km^2; this corresponds to ca. 64%. Between 1967 and 1976 a further 98.4 km^2 were lost (i.e., 32% of the 1967 area) and the corresponding loss for the interval between 1976 and 1986 added an additional 75.1 km^2 (=36% of the

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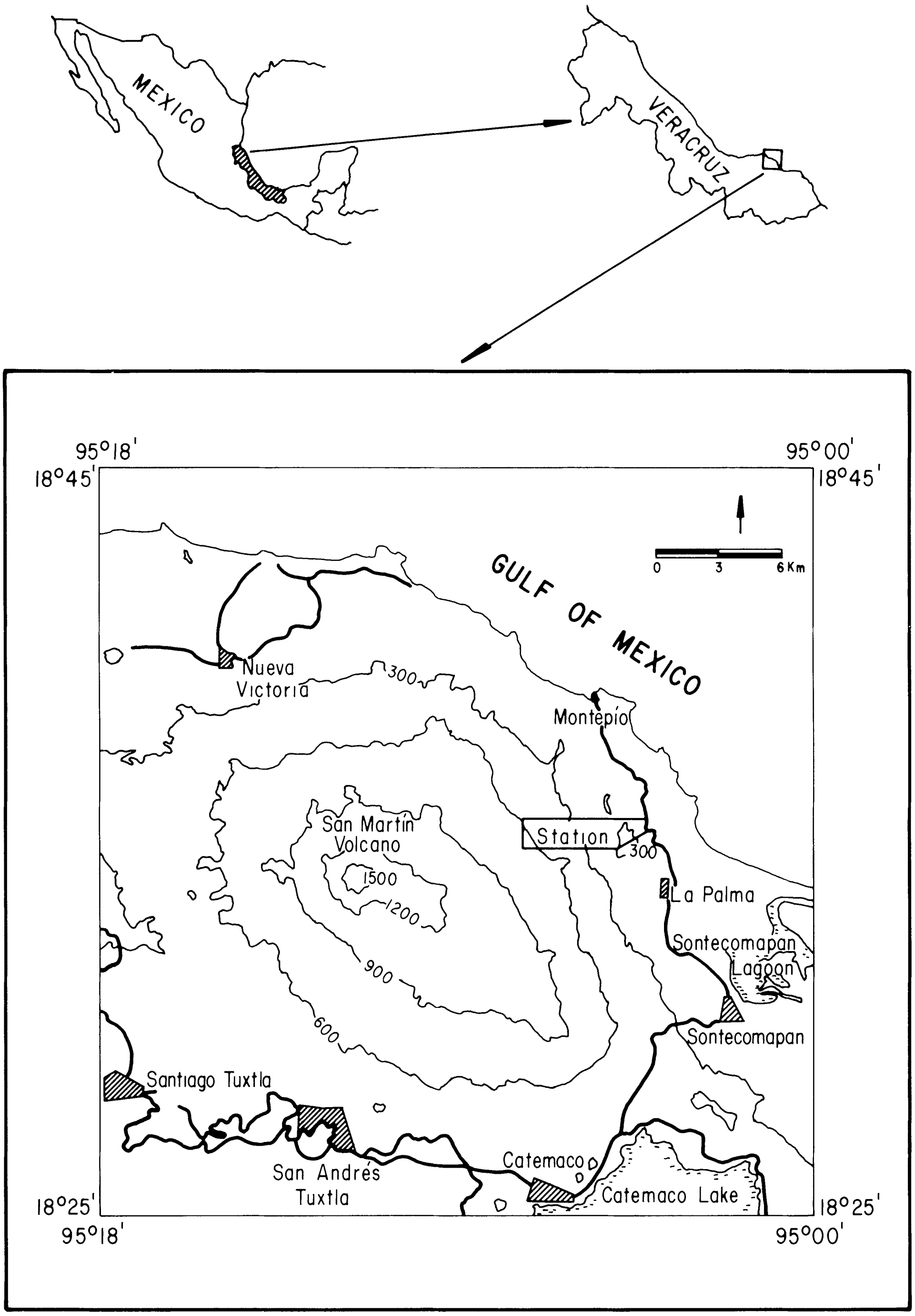

Figure 1. The location of the area of study, in the northern part of the Sierra de Los Tuxtlas, in Veracruz, southeast Mexico. The map depicts the elevation contour lines (300 m intervals), the location of the major population centers (▨) and their connecting roads, as well as the location of the Los Tuxtlas Biological Station.

1976 area). Thus, during the approximately 20 years of our analysis, tropical forest vegetation was reduced by 56%, with an estimated 84% of the *original* vegetation lost by early 1986.

The calculated annual deforestation rates for the periods before and after 1976 indicate (Table 1) that deforestation during the latter period remained practically the same as in the previous decade. Assuming that these deforestation rates continue unchanged, a simple exponential decay model can be used to project the area of forest remaining (AFR) at a given time (t):

$$AFR_{(t)} = A_1(1 - r^t)$$

For example, if the most recent rate of deforestation (i.e., 4.3% per year) is used to extrapolate the trends fourteen years later (i.e., to year 2000), the remaining vegetation would be 73.6 km^2, which is equivalent to only 8.7% of the original vegetation. Very likely, this

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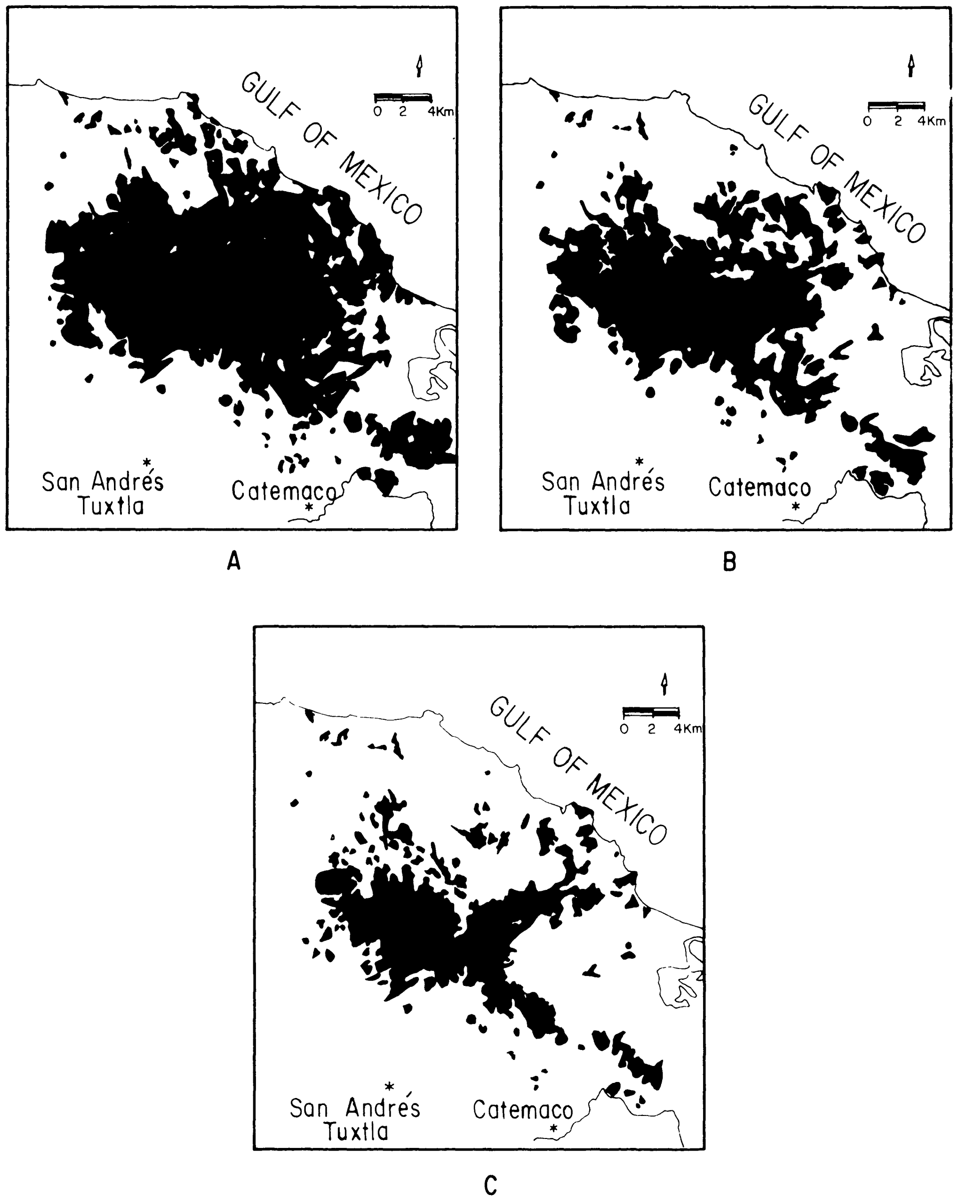

Figure 2. The time-course of forest coverage and distribution in the northern part of the Sierra de Los Tuxtlas (Veracruz, southeast Mexico). The sequence is: A, forest in 1967; B, forest in 1976; C, forest in 1986.

remaining vegetation would be restricted to the most inaccessible parts around the peak of Volcán San Martín, the areas covered by recent lava flows, and the small area (6.4 km^2) corresponding to the Biological Station to the east.

Discussion

The maps and the derived statistics provide dramatic evidence of the intense deforestation in the northern part of the Sierra de Los Tuxtlas. Given (1) the relative homogeneity in history, social structure, human demographic patterns, and land management systems throughout the area, and (2) the similarity of the general ecological conditions of the area studied, in comparison to other parts of the Sierra, we believe our results are, in general terms, applicable to the whole area.

The trends of deforestation in the area reflect a recent history of intense human activity. Between 1960–1986, the populations of the municipalities of San Andrés and Catemaco (to which most of the area belongs) increased by a factor of 2.3 (see García 1988). This population increment was accompanied by a corresponding increase in the number of people dedicated to activities such as timber extraction, cattle ranching, fishing, and hunting. Prominent among these activities is cattle ranching, which seems to be the most ecologically incompatible kind of land use for this particular type of ecosystem (see Toledo 1987), and which has expanded

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Table 1. Calculated forest areas, area loss, and deforestation rates for the northern part of the Sierra de Los Tuxtlas, Veracruz, Mexico.

Year	*Estimated area of forest (km^2)*	*Estimated lost area (km^2)*	*Lost area per year (km^2)*	*Percentage lost*	*Annual rate of deforestation*
Original forest	~849.6				
1967	309.6	540.0		63.6	
1976	211.2	98.4	10.9	31.8	4.2
1986	136.1	75.1	7.5	35.6	4.3

dramatically throughout the Sierra de Los Tuxtlas (see García 1988).

Our calculated annual rates of deforestation considerably exceed the already high rates that have been reported for tropical forests of Mexico in general (e.g., Repetto's [1988] value of 1.0%). These also exceed the values given in Sader and Joyce's study (1988) (using a similar methodology) for Costa Rican tropical wet forests for the periods 1940–1950 (0.8), 1950–1961 (1.3), and 1961–1977 (1.9). However, our estimates are not as high as their calculated Costa Rican annual rate of 8.8% for the period 1977–1983.

A well-known controversy in the literature regarding the rates of tropical forest destruction is the one between Myers (1980) and Lugo and Brown (1982). The latter authors have indicated that there are no hard data on tropical deforestation and suggest that environmentalists such as Myers exaggerate the extent of damage and mislead the public. The present study, based on direct measurements of remote sensing materials, coupled with field surveys of an area we are familiar with, indicates that deforestation in this area is indeed high. However, the deforestation rates we obtained do not seem to be compatible with the more recent claims of Myers (1989) that Mexico is losing 7000 km^2 per year of tropical forest. Quite clearly, studies in which reliable data are obtained for different tropical regions are badly needed.

Given the rates and trends of deforestation detected in this study, it is clear that this important area of the Neotropics is being dramatically altered, probably irreversibly so, unless some action is taken immediately. Our study emphasizes the urgent need to protect the remaining areas of Los Tuxtlas forest (such as those of Volcán Santa Marta—still the largest tract of forest in the Sierra), and to establish a program of forest restoration now, before the new foci of potential ecological inocula of biodiversity disappear. Without these remaining foci, Los Tuxtlas can become an example of what Gómez-Pompa et al. (1972) defined as "tropical rain forests as nonrenewable resources." Of special concern must be the future of the Los Tuxtlas Biological Station. Its location in the lowlands to the east of the Sierra, and the fact that a major road crosses it, increase the risk that it will become a small island of forest surrounded by a sea of intense human impact areas (fields, grasslands, and clearings). A logical course of action for UNAM's Biological Station is to establish a corridor to the west, towards the Volcán San Martín, since the latter is still covered with forest and has been formally declared a protected area from the 1000 m elevation contour to the top (see Dirzo 1991). This would not only increase the area of both protected zones (the Station and the Volcán San Martín), but also insure the continued existence of an elevational gradient (0–1700 m), so necessary for the seasonal migrations of many components of the biota of these forests, and thus preserve a sample of the variety of the natural habitats (see Andrle 1967; Dirzo 1991; Ross 1975; Sousa 1968) typical of this singular Neotropical forest. Immediate action is urgently needed to protect these small but rich remnants of forest and preserve them as foci of potential biological inocula for future ecorestoration of these, the northernmost tropical rain forests on the continent.

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