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Carbon Emissions and Sequestration in Forests: Case Studies from Seven Developing Countries, Vol. 4: Mexico

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VOLUME 4: MEXICO

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Series Editors: Willy Makundi and Jayant Sathaye

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Berkeley, CA, USA

CARBON EMISSIONS AND SEQUESTRATION IN FORESTS: CASE STUDIES FROM SEVEN DEVELOPING COUNTRIES

VOLUME 4: CARBON EMISSIONS FROM DEFORESTATION IN MEXICO: CURRENT SITUATION AND LONG-TERM SCENARIOS

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TABLE OF CONTENTS

PREFACE

In January 1990, scientists and policymakers from around the world convened for a meeting of the Intergovernmental Panel on Climate Change (IPCC) in São Paulo, Brazil, to continue the ongoing discussions on emissions of greenhouse gases and global climate change. As part of the effort to further understand the sources of carbon dioxide (CO_2) and other major greenhouse gases, LBL and the University of Sao Paulo, with support from the U.S. Environmental Protection Agency, organized a workshop on tropical forestry and global climate change which was attended by the IPCC conference participants. Discussions at the workshop led to the establishment of the Tropical Forestry and Global Climate Change Research Network (F-7). The countries taking part in the F-7 Network -- Brazil, China, India, Indonesia, Malaysia, Mexico, Nigeria and Thailand -- possess among the largest tracts of the Earth's tropical forests and together experience the bulk of tropical deforestation.

The following research objectives were identified as the F-7 Network's priorities:

1. To improve and expand the body of knowledge about the extent of tropical deforestation through the use of available tools, including remote-sensing imagery, detailed biomass measurements and existing models.

2. To explore the dynamics of forest land use within the context of individual country's social and economic structures.

3. To identify alternative response options aimed at stemming deforestation and promoting sustainable land-use practices while maintaining each country's economic well-being. Meeting this objective includes carrying out an assessment of the economic costs of implementing various mitigative policies.

One of the strategies of this project was to rely on the work of indigenous researchers and institutions from each of the participating countries. This approach allowed for the integration of more precise, on-site information, some of which had not been previously published, into the more general and universally available base of knowledge. The Lawrence Berkeley Laboratory (LBL), which employed a similar approach to carry out a study on carbon emissions from energy use in developing countries (LDCs) (see Sathaye and Ketoff 1991), coordinated the work of the researchers and provided scientific and institutional support for the F-7 participants. The U.S. Environmental Protection Agency (EPA) financed the Network's work.

The information contained in this report represents the results of the first phase of the F-7 project, which had the explicit aim of providing quantitative data on forestry-related carbon emissions in the F-7 countries. This report contains the results of the first phase of the research effort. The next stage of the process will involve an assessment of response options in the forestry sector and the economics of undertaking these measures.

The following scientists and institutions participated in the research:

Country	Expert	Institution
Brazil	Philip Fearnside	Departmento de Ecologia Instituto Nacional de Pesquisas de Amazonia Manaus-Amazonia
China	Xu Deying	Research Institute of Forestry Chinese Academy of Forestry Beijing
India	N.H. Ravindranath B.S. Somashekhar Madhav Gadgil	Centre for Ecological Sciences Indian Institute of Science Bangalore
Indonesia	Edy Brotoisworo	Institute of Ecology Padjadjaran University Bandung
Malaysia	Roslan Ismail Ismariah Ahmad Faizah Fakhruddin	Forest Research Institute Kepong Kuala Lumpur
Mexico	Rodolfo Dirzo Minjarez Omar Masera Cerutti María de Jesús Ordóñez	Centro de Ecología Universidad Nacional Autonoma de México Mexico City
Thailand	Somthawin Patanavanich Ladawan Atipanumpai	Thailand Development Research Institute Faculty of Forestry, Kasetsart University Bangkok
USA	Willy Makundi Jayant Sathaye	Energy and Environment Division Lawrence Berkeley Laboratory

The opinions expressed in this work are those of the authors and do not necessarily reflect those of the affiliated institutions or of the respective governments.

An international workshop to discuss the methods, results and policy issues associated with this project was held at the Lawrence Berkeley Laboratory in May 1991. We would like to thank the workshop participants and extend a special acknowledgement to Ken Andrasko of the U.S. EPA for his contribution. A full list of the workshop participants is provided in the appendix. The authors would also like to thank Nina Goldman for editing this work.

ABSTRACT

Estimates of carbon emissions from deforestation in Mexico are derived for the year 1985 and for two contrasting scenarios in 2025. Carbon emissions are calculated through an in-depth review of the existing information on forest cover deforestation rates and area affected by forest fires as well as on forests' carbon-related biological characteristics. The analysis covers both tropical -evergreen and deciduous- and temperate -coniferous and broadleaf- closed forests. Emissions from the forest sector are also compared to those from energy and industry. Different policy options for promoting the sustainable management of forest resources in the country are discussed.

The analysis indicates that approximately 804,000 hectares per year of closed forests suffered from major perturbations in the mid 1980's in Mexico, leading to an annual deforestation rate of 668,000 hectares. Seventy five percent of total deforestation is concentrated in tropical forests. The resulting annual carbon balance is estimated in 53.4 million tons per year, and the net committed emissions in 45.5 million tons or 41% and 38%, respectively, of the country's total for 1985-87. The annual carbon balance from the forest sector in 2025 is expected to decline to 16.5 million tons in the low emissions scenario and to 22.9 million tons in the high emissions scenario. Because of the large uncertainties in some of the primary sources of information, the stated figures should be taken as preliminary estimates.

1. INTRODUCTION

Deforestation and logging of primary forests constitute a major source of global net carbon emissions to the atmosphere (IPCC, 1990; Houghton, 1990). Estimates for the late 1980's suggest that from 0.6 to 3.6 gigatonnes of carbon (GtC), or about 11% to 39% of total CO_2 emissions from human origin, come from the forest sector (IPCC, 1990; Hao et al. 1990; Houghton, 1990). Most forest-related emissions are concentrated in developing countries.

The wide range of existing estimates on global carbon emissions from the forest sector reflects the difficulties in getting accurate information regarding deforestation rates, forest-conversion activities and the relevant forests carbon-related parameters. Also, there is not always a complete consistency in the definitions of deforestation, forest types and which forests are included in the deforestation figures.

Country estimates present the same or even larger problems. In the case of Mexico, the two currently available estimates for carbon emissions from deforestation (WRI 1990; Myers 1989) differ by a factor of two (32 and 64 million tons of carbon, respectively). Part of the variation stems from divergences in the estimates of deforestation rates and of the types of forests included in the calculations of carbon emissions. Also, most attention has been paid to assessing deforestation rates in Mexico's tropical evergreen forests (i.e. Myers, 1989), neglecting about 80 percent of Mexico's closed forest coverage which is composed of tropical deciduous and temperate forests.

Detailed country studies on carbon emissions from the forest sector are therefore urgently needed in order to provide improved estimates which can serve to better assess global carbon additions from deforestation. From a policy perspective, a more accurate determination of carbon emissions at the country level is an important first step in the efforts towards reaching a global convention on climate change. The examination of future long-term emission scenarios will also help in assessing the amount of potential carbon savings, as well as the possibilities and constraints for achieving those savings.

Forests provide key services to Mexico and to its local residents as sources of diverse wood and non-wood products for local consumption and trade, biodiversity, climate regulation, recreational sites, etc. "Carbon storage" is only one and, at least for local people, not the most important function of forest resources. The analysis of potential carbon savings, thus, should take into account the multiplicity of possible uses for forest resources, making carbon-saving strategies the by-product (as opposed to the starting point) of more general strategies aimed at the sustainable management of forest resources.

In this study we estimated carbon emissions from deforestation through an in-depth review of the existing information on forest cover and deforestation rates as well as on forests' carbon-related biological characteristics. The methodology used is based mainly on the CO-PATH model (Makundi *et al.* 1991), although several additions and modifications were incorporated into the model. We relied on local information -- both from official sources and from case-studies -- as extensively as possible, using estimates from other regions only when local data were not available. The study covers all closed forest types in the country, that is: tropical evergreen, tropical deciduous, temperate coniferous, and temperate broadleaf.

This study is based on estimates of vegetation cover and deforestation rates corresponding to the mid-1980s. Because of the large uncertainties about and inconsistencies among some of the primary sources of information, the stated figures should be taken as preliminary estimates. It is our hope that this report will prompt further research in the area and stimulate the monitoring of deforestation rates and their associated carbon emissions.

We begin the report with a brief overview of Mexico's aggregate demographic, economic and other relevant indicators; we also trace the evolution of the demand for and production of forest products in Mexico during the last decade and describe Mexico's overall land-use patterns. In the second section we discuss the major ecological characteristics of Mexico's forests and present a simplified classification of Mexican forests. In the third section, we estimate deforestation rates within closed forests. We review the current estimates and discuss the leading factors of deforestation by type of forest. The fourth section is devoted to a detailed analysis of current carbon emissions from deforestation. Emissions are calculated by type of forest and conversion activity; an intensity index (tonnes of carbon per hectare) is calculated for each case. In the fifth section we discuss two contrasting scenarios for carbon emissions from deforestation in the year 2025. A subsequent section compares carbon emissions from deforestation with those from energy use and cement production. Thus, current and long-term overall carbon emissions in Mexico are estimated. We then assess different policy options for promoting the sustainable management of forest resources in the country. The report ends with a set of concluding remarks on research needs for future studies of carbon emissions from deforestation.

2. A GENERAL OVERVIEW OF MEXICO

2.1. Economic situation

Mexico spans almost 2 million km^2 and has a population of 81.1 million (1990). Population growth has slowed down from an average of 3.3 percent/year (yr) during 1970-80 to 2.1 percent/yr from 1980-90. The rural population, which presently accounts for approximately 30 percent of the total population, has remained at a practically constant size since 1980, largely because of an intensive migration to cities. The gross domestic product (GDP) per capita averages US$ 2,500, with large differences across social groups. About 35 percent of total economic activity is concentrated in the industrial sector (INEGI 1990; Banco de Mexico 1991) (Table 1).

The Mexican economy has undergone major changes during the last decade, due to an acute economic crisis. Oil exports, which comprised a 67 percent share of total export earnings in 1980, accounted for only 37 percent in 1990. The share of manufacturing exports in total earnings increased from 20 percent to 50 percent during the same period (Banco de Mexico 1991). Extensive privatization programs have undermined the role of the state in the economy.

Foreign investment and free-trade policies have been actively promoted. The different "structural adjustment" programs have made it possible to control inflation and have permitted the country to re-pay the interest on its large foreign debt (approximately US$ 80 billion). These policies, however, have exacted important social costs: living conditions have deteriorated during the decade, salaries have contracted to levels lower than those of 1976 and environmental degradation has accelerated both in cities and within the countryside.

The on-going negotiations of a free-trade agreement with the United States as well as debt-renegotiations indicate that Mexico's economic performance will be better in the 1990s.

Table 1. Summary statistics for Mexico

Indicator	
Demographic (1990)	
Population (million)	81.1
AAGR 1980-90 (%)[a]	2.1%
Rural	24.0
AAGR 1980-90 (%)	0.6%
Economic (1987)	
GDP (US$ billion)	189
Industry	35%
Manufacturing	29%
Energy	6%
Transport	6%
Services	50%
Agriculture[b]	9%
GDP AAGR (%)	
1980-87	$< 0.1\%$
1970-87	4.2%
Land Area (million ha)	196.7
Closed Forests	26.3%
Open Forests	15.5%
Agriculture	13.9%
Pasture	40.6%
Other	3.7%

Source: INEGI (1990) and Banco de Mexico (1991).
Own estimates of land-use patterns (see Appendix I).

Notes: a. AAGR = annual average growth rate
b. Includes forestry and fishing

2.2. Land-use patterns

No reliable statistics exist on the current distribution of the country area by land-use category. Estimates of vegetation cover for closed forests alone range from 44.2 to 61.8 million hectares (ha) (Table 2). These discrepancies are the result of inconsistencies in the definition of vegetation types by different sources (see Appendix I) and of obsolete statistics on land-use patterns. In fact, the currently available vegetation maps and land-use charts have been derived from satellite images corresponding to the early 1980s.[1]

Table 2. Forest cover: range of estimates (10^3 ha)

Forest Type	Low Estimate	High Estimate	This Study
Tropical (A)	25468[a,b]	29697[c,d]	25823
Temperate (B)	18709[a,e]	32121[c,d]	25754
Total Closed (A + B)	44177	61818	51577

Source: a. Castillo *et al.* (1989)
b. Toledo *et al.* (1989)
c. SPP (1980)
d. SARH (1986)
e. Flores-Villela and Gerez (1988)

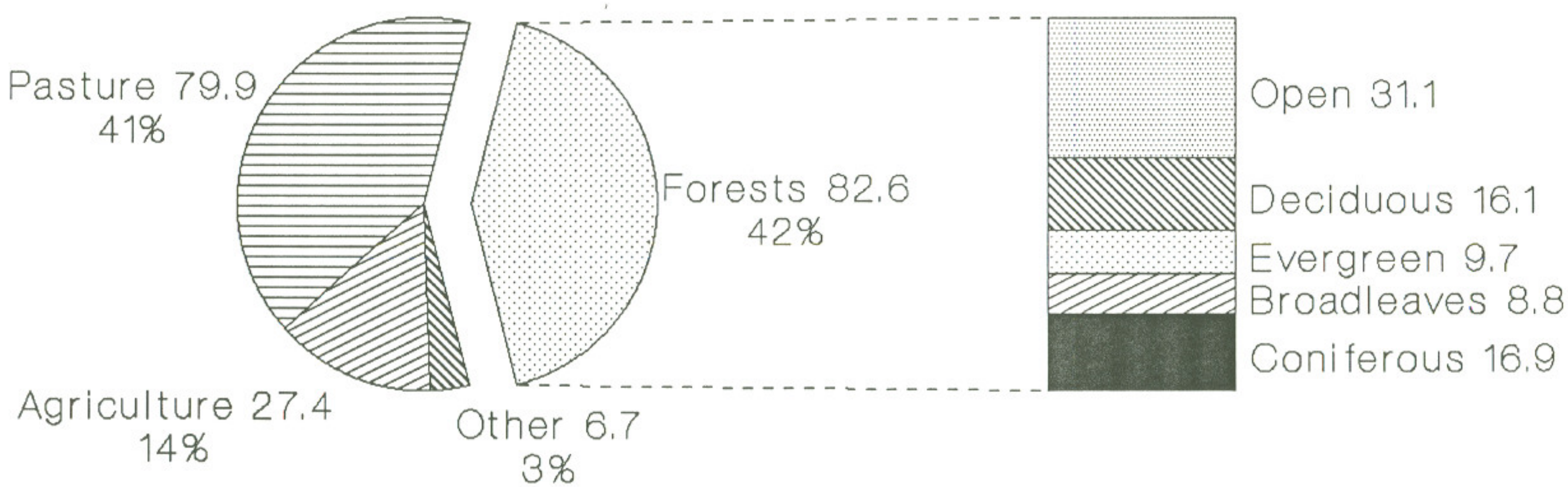
Note: Refer to Appendix I for a complete description of existing vegetation cover estimates in the country.

This study drew data from the best existing primary sources and refined and rearranged it. Based on this data, we estimate that, as of the mid-1980s, about 26.3 percent of Mexico's 196.7 million hectares were covered by closed forests (cf. Table 1). Land devoted to livestock production, which increased dramatically since the sixties, already occupied over 40 percent of the total area of the country (79.9 million ha, Figure 1). In contrast, only 13.9 percent was used for agriculture (27.4 million ha).

Against this background of land utilization, the protected areas in the country amount to 5.7 million hectares. Of this total, about 5 million hectares are in relatively well-preserved areas. Thirty-four percent of all protected areas are located in tropical evergreen forests, 2 percent in tropical deciduous forests, 7 percent in temperate forests and the remainder in open forests (Table 3). Additionally, there is a minor area (0.7 million hectares), which is partly to largely

[1] This situation is likely to improve soon, due to the forthcoming studies by the National Institute of Statistics (INEGI) and the Ministry of Agriculture (SARH) in collaboration with the U.S. Department of Agriculture.

FIGURE 1
LAND-USE PATTERNS IN MEXICO
MID 1980'S



TOTAL 196.7 MILLION HA

altered, assigned as national parks, and a small (though not quantified) area of natural vegetation in good condition which is not formally protected.

Table 3. Protected areas within closed forests

Forest Type	Area (ha)
Tropical[a]	1,791,904
Evergreen	1,684,928
Deciduous	106,976
Temperate[a]	357,989
Open forests[a]	2,887,659
National Parks[b]	688,953
Tropical	93,743
Temperate	314,075
Open forests	281,135
Total	5,726,505

Source: From SEDUE (1989) and Ordóñez (1990).
Notes: a. largely unaltered, includes biosphere reserves, special biosphere reserves, protected areas, forest protected zones, natural monuments and fauna refugees.
b. partly to largely altered.

3. MEXICO'S FORESTS

3.1. Ecological features

Mexico lies at the point where the holartic and neotropical geographic regions converge. Mexico's location, together with its high climatic diversity, complex topography and geological history, has resulted in a very rich and unique constellation of ecological situations all within the national boundaries. It is estimated that approximately 10 percent of the world's biodiversity is concentrated in Mexico (Flores and Gerez 1988), a fact that has placed Mexico among the 12 mega-diverse countries in the world (Dirzo and Raven 1991; MacNeely *et al.* 1990). Mexico's forests show a very high proportion of endemisms. Likewise, many economically important crops, such as maize, beans, cocoa and others, have originated in Mexico. Mexico's forests also represent a bank of germplasm for improving many agronomically important species (e.g., perennial maize) or for identifying new species with potential economic value as sources of drugs, biocides, timber, etc. (Dirzo and Raven 1991).

National vegetation classification systems range from the system of Miranda and Hernandez-X (1963), which incorporates 32 major forest types, to the simplified system of Rzedowski (1978), which includes only 10 major forest types.[2] We used Rzedowski's simplified classification and re-organized it into five main forest types: tropical evergreen, tropical deciduous, temperate coniferous, temperate broadleaf and open forests. Table 4 shows how our classification system compares with those of Rzedowski and Holdridge in order to facilitate cross-country comparisons. Figure 1 shows the relative shares of each forest type in Mexico's total area. Figure 2 displays their estimated geographic distribution within the country.

Table 4. Simplified classification of Mexican forests

This study	National Classification (Rzedowski 1978)	Holdridge Equivalence (1967)
Tropical evergreen	Evergreen and semi-evergreen tropical forests	Subtropical wet pre-montane forests; subtropical moist pre-montane moist forests
Tropical deciduous	Tropical deciduous; thorny tropical forests	Subtropical dry pre-montane forests
Temperate broadleaf	Oak-coniferous forests; cloud forests	Subtropical pre-montane and low-montane forests; subtropical mountain wet forests
Temperate coniferous	Oak-coniferous forests	Subtropical montane dry forests
Open Forests	Grassland; scrublands	Subtropical desert; subtropical scrub desert; subtropical montane thorny

In the present study we restrict the analysis to the country's closed forests. While open forests occupy a large fraction of the forested area, there is no reliable information on their deforestation rates. Also, given their lower carbon content per hectare, the contribution of open forests to the country's carbon dioxide emissions from deforestation are minor compared to that of closed forests.

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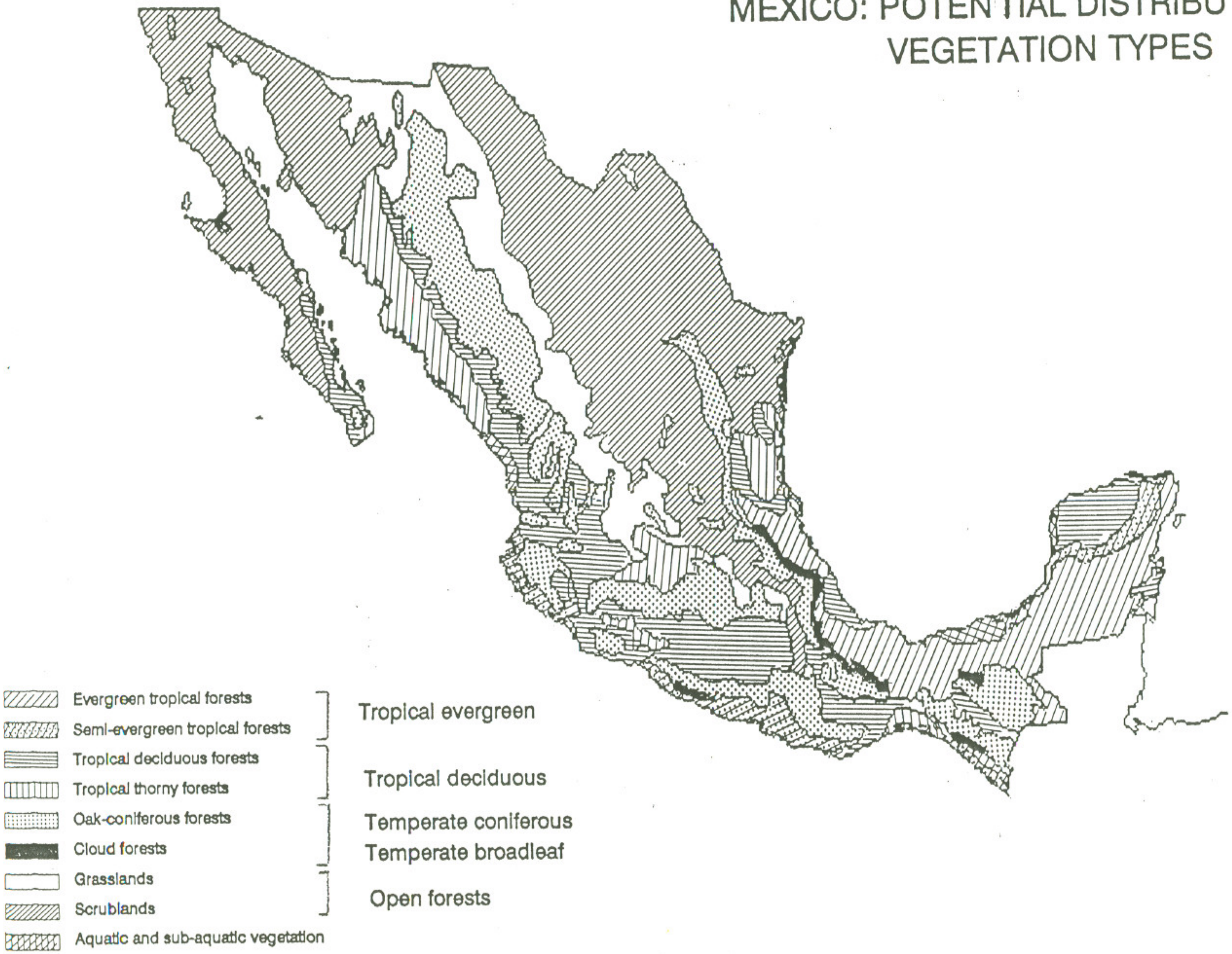
[2] The enormous altitudinal and climatological variability of Mexico makes Holdridge's life-zones classification difficult to apply (Holdridge 1987). Mexico traditionally has used its own local (national) systems in the past.

FIGURE 2
MEXICO: POTENTIAL DISTRIBUTION OF VEGETATION TYPES



Source: Rzedowski, 1978

The main ecological features of each forest type are summarized in Table 5. Temperate forests, usually neglected in studies of deforestation, cover 31 percent of the total forested area. They concentrate the highest diversity of *Pinus* and *Quercus* in the world (e.g., they have more than 50 species of pines and 140 species of oak) (Rzedowski 1991).

Coniferous forests are dominated by *Pinus*, but also include *Abies*, *Cupressus* and mixed *Pinus-Quercus* forests. Coniferous forests are located all along the different mountain formations, at altitudes ranging from the lowlands to the timberline.

Quercus is the dominant genus in broadleaf forests. These forests lie in the areas surrounding coniferous forests and are dominant at lower altitudes and/or in drier conditions. Aside from their importance in terms of biodiversity, these forests are crucial in the hydrological cycle and as sources of timber and fuelwood.

Tropical evergreen forests are concentrated in the southern and south-eastern areas of the country. In the present study they include both truly evergreen (16.9 percent total area) and semi-evergreen tropical communities. The most important feature of these forests is their enormous contribution to biological diversity. These forests include the largest number of woody species per unit area, which in turns determines the existence of a considerable diversity of other organisms (e.g., birds, mammals, insects). They also are important as potential new sources of economically useful resources.

Tropical deciduous forests are mostly located along the Pacific Coast, with patches in the Yucatan peninsula and the Balsas watershed (Table 5). They cover a wide range of ecological conditions in hot climates. These forests constitute the most extensive area of tropical vegetation in the country. A considerable portion of the open-forest areas of Mexico are the result of the alteration and, sometimes, the eradication of tropical deciduous forests. In contrast to evergreen forests, tropical deciduous forests have received much less attention from the scientific community and management planners. Protected areas including deciduous forests are grossly under-represented (see Table 3), despite the fact that deforestation in absolute terms is the highest for tropical vegetation (see below).

Table 5. Ecological features of Mexican closed forests

Forest type	Estimated area (million ha)	Geographical distribution	Climatological range	Dominant species
Tropical evergreen	9.7	Lowlands of the gulf coast of Mexico; south of Yucatan peninsula; northern part of Veracruz state	Hot humid climates free of frosts; relatively aseasonal	*Brosimum alicastrum* *Ceiba Pentandra* *Terminalia Amazonia* *Manilcara zapota* *Nectandra spp.* *Several Leguminosae*
Tropical deciduous	16.1	Low lands of the Pacific coast of Mexico; northern Yucatan peninsula; Balsas watershed; southern tip of Baja peninsula	Hot and dry climates, free of frosts; marked seasonal variation in rainfall	*Bursera spp.* *Enterollobium cyclocarpum* *Several Leguminosae*
Temperate coniferous	16.9	Mountainous ranges of Mexico: Sierra Madre Oriental and Occidental; neo-volcanic belt; Sierra Madre del Sur	Temperate, ranging from semi-dry to moist; marked cold and dry season (both during the winter)	*Pinus spp.* *Abbies religiosa* *Juniperus spp.* *Cupressus spp.* *Quercus spp.*
Temperate broadleaf	8.8	Lower parts of the ranges occupied by temperate coniferous forests	Temperate, ranging from dry to moist; marked dry season, free of frosts	*Quercus spp.* *Alnus spp.* *Arbutus spp.*

3.2. The forest sector

Despite the country's relatively large forested area, the Mexican forest sector has not played an important role within the country's overall economic strategy. During the last two decades in particular, the forest industry has undergone a deep economic crisis.

The contribution of the forest sector to the national GDP has fluctuated between 1.8 percent to 2 percent between 1983-87 (SARH 1989a). Commercial wood production -- which includes timber, cellulose and commercial firewood -- stagnated at around 9 million cubic meters (m^3)/yr during the last nine years (Table 6). Domestic production is not sufficient to cover the country's internal demand of wood products and large quantities of cellulosic products have to be imported. By 1989, net imports from forest products reached US$ 392 million (CNIF 1991).

Table 6. Production and demand of forest products in Mexico

A. Wood Products

	(million m^3/yr)	
Product	1981	1989
Timber	6.5	6.4
Cellulose	2.5	2.4
Fuelwood	25.6	23.5
Commercial	0.6	0.4
Rural[a]	25.0	23.1
Total Production	34.0	32.3
Exports	0.1	1.3
Imports	4.4	2.4
Total Demand	38.3	33.4

B. Non-Wood Products

	(10^3 tonne/yr)	
Product	1981	1989
Resin	44.4	36.9
Fibers	3.6	3.0
Yam	2.8	1.1
Other	10.6	33.1
Total	61.4	74.1

Source: From SARH (1981-1989); fuelwood use figures from Masera, 1990; wood exports and imports from CNIF (1991).

Note: a. Estimates from fuelwood use within the country range from 13.6 million m^3/yr to 32 million m^3/yr (Guzmán *et al.* 1985).

We estimate that the total production of wood products in 1989 was 32.3 million m^3, about 70 percent (23.5 million m^3) of which was used for firewood (Table 6). Fuelwood is used mainly for cooking in rural areas (approximately 19 million people still cook with fuelwood in the country), but it is also common in small rural industries (bakeries, ceramic workshops, etc). The role of fuelwood in total consumption is obscured by official statistics, which only report "commercial" fuelwood use (or 3 percent of total fuelwood use). Wood for timber and timber products (6.4 million m^3) together with cellulose (2.4 million m^3) provide the balance. Domestic demand for wood products cannot be satisfied with local production, leading to net imports of 1.1 million m^3 (Table 6). Imports of pulp and paper are particularly large and have fluctuated between 1.6 million m^3/yr and 2.0 million $m^{3/}$/yr during the last decade (CNIF 1991). The industry of non-wood products has also been affected by the country's overall economic crisis and by a lower international demand, with the dominant products (resin, fibers and yam) showing a decline in production during the last decade (Table 6).

Commercial forest exploitation is concentrated on temperate forests (93 percent of total harvesting) and, within them, on coniferous forests (Table 7). Adding the area harvested by rural villages for local consumption to that harvested for commercial purposes, it can be concluded that, with the exception of a few inaccessible areas, most forests in the country are or have been under some sort of harvesting. Thus, few old growth forests remain, even within tropical areas (Jardel 1989).

Table 7. Resource availability in Mexican forests by type of forest and tree genus

Forest Type	Resource Availability late 1970s	Commercial Harvesting 1989	
	(10^6 m^3)[a]	(10^6 m^3)[b]	(%)
Temperate	1,989	8.38	94.0%
Coniferous[c]	1,491	7.77	
Pinus		7.46	87.5%
Abbies		0.24	84.8%
Other		0.07	2.7%
Broadleaf	498	0.61	< 0.1%
Quercus		0.44	6.5%
Other		0.17	5.0%
			1.5%
Tropical Evergreen	1,136	0.50	6.0%
Precious		0.07	< 0.1%
Common		0.43	6.0%
Total	3,125	8.88	100%

Source: From SARH (1981-1989).
Notes: a. Refers to stemwood with commercial value from commercial tree species.
b. Corresponds to authorized timber harvesting by SARH.
c. Figures for resource availability include coniferous-broadleaf associations.

Only selective cutting is permitted within areas under management. The dominant method of timber harvesting (Método Mexicano de Ordenamiento de Bosques) has been criticized as inefficient and as leading to changes in the composition of forest species (Jardel 1989). The same method is applied to temperate and tropical forests. Beginning in the 1970s a more intensive method of timber harvesting (Método de Desarrollo Silvícola) was promoted, but it is only applied to 3.5 percent of the total managed area.

The institutional framework of forest exploitation is very complex and largely responsible for the problems of the forest industry. About 70 percent of the forested area lies in communal and "ejido" lands, while only 23 percent is owned by private proprietors.[3] The timber industry is, however, controlled by a few relatively large private enterprises. Traditionally, forest production has been structured as a supply source for industry and not as a development option for local communities. The disparity between those who own and those who benefit from the forests is at the root of the crisis within the sector and has led to severe environmental degradation within managed forests.

The government regulates forest harvesting by two mechanisms: harvesting permits (concessions) and bans (Jardel 1989). Up to the mid-1980s, permits were issued only to large companies for a fixed amount of time to manage village forests. The companies were also in charge of the technical management of forest resources. Villagers usually supplied labor for the timber harvesting and were paid a very low quota or "forest right" for the timber extracted. In 1986 a new forestry law was passed allowing villages to take responsibility for the technological and administrative management of forests. In practice, however, large companies still retain control over most of the forest resources. Bans on commercial exploitation have been applied at different points in time, but with negative results (Jardel 1989). The cutting of wood for alleged forest "sanitation" purposes or the extraction of allegedly "dead wood" generated from forest fires has led to resource depletion in areas with timber bans or limited production allowances. These two problems are common in the exploitation of temperate forests (Omar Masera, pers.dos) and the second problem is also frequent in tropical areas (R. Dirzo, pers.dos).

4. THE DEFORESTATION PROCESS

Mexico has lost a large fraction of its original forest coverage. It is estimated that tropical evergreen forests, for example, currently are restricted to 10 percent of their original area (Rzedowski 1978). The deforestation process has been particularly dramatic since the sixties. Both in the late sixties and during the seventies, "development projects" -- many of them funded by multilateral lending agencies -- and important subsidies for cattle ranching provided the basis

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[3] A new law has recently been approved in Mexico privatizing ejido lands. The law will have enormous repercussions for the management of natural resources (particularly forests). There is currently an intense debate going on within Mexico about the virtues and drawbacks of this legislation. However, it is clear that if the privatization process leads the nation's land to be further concentrated into fewer hands it will exacerbate the problems surrounding the sustainable management of natural resources.

for extensive clearing of forested areas. Deforestation continued during the 1980s, fostered by the country's economic crisis and a deepening of rural poverty.

There are no reliable statistics on deforestation rates in the country. Current estimates range from 400,000 ha/yr to 1.5 million ha/yr (Table 8). Part of the discrepancy derives from the definitions of forest types used by each particular source. Some authors only include tropical forests, which have captured the most international attention; others account for both open and closed forests (i.e., Toledo 1989). The debate became even more confusing when deforestation figures calculated for all forest types (FAO 1988) were assigned to tropical closed forests (Myers 1989). Moreover, tropical deforestation has been largely estimated on the basis of some measurements carried out in evergreen forests only (i.e., ignoring deforestation patterns in tropical deciduous vegetation).

Table 8. Range of estimates of deforestation rates in Mexico (10^3 ha/yr)

Source	Temperate	Tropical	Total
PND 1983[a]	n.a.	n.a.	400
Toledo 1989[a]	n.a.	n.a.	1500
Repetto 1988	n.a.	460	460
Myers 1989	n.a.	700	700
FAO 1988; WRI 1990	125	470	595
SARH 1990[b]	127	202	329
Castillo *et al.* 1989[c]	273	473	746
This study[d]	167	501	668

Notes: a. Figures include deforestation in open forests. Estimates from PND quoted in Jardel (1989).
b. Adjusted to exclude open forests. The original figure was 370,000 ha lost per year.
c. Figures correspond to annual averages for projected deforestation during the period 1988-1994. The deforestation rate by forest type is as follows: Coniferous: 154,000 ha/yr; Broadleaf 119,000 ha/yr; Tropical Evergreen 174,000 ha/yr; Deciduous 299,000 ha/yr.
d. See text for details on the calculation procedure.

In this study, deforestation rates were estimated through an extensive review of official statistics and of very detailed case studies. Relatively accurate information was available only for tropical evergreen forests; for the remaining forest types, and especially for deciduous and broadleaf forests, only partial information was obtained.

State-wise available data on forest perturbation rates (SARH 1990) and five-year averages of forest fires by forest type (SARH 1989b) provided the basis for estimating deforestation rates.[4] Refinements were done to fit official data within our simplified classification system. For tropical forests, further adjustments were done using data from case studies and recent estimates from satellite images. No explicit account was taken for deforestation from energy projects (construction of dams and oil exploration/extraction activities) and road construction. However, part of the deforestation caused by these activities is already implicit in the estimates derived from satellite images of tropical forests.

Forest degradation is occurring in most areas where harvesting is taking place. Thus, there are net contributions to carbon emissions from managed forests. It is, however, extremely difficult to obtain estimates of the area currently being harvested and of both the extent and pace of the forest degradation process. For these reasons, carbon emissions from existing areas being harvested (both for commercial and fuelwood extraction purposes) were not fully incorporated into our estimates. In the absence of more precise information, we assign a conservative fraction of the total deforested area to harvesting, and from this figure carbon emissions are calculated.

According to our results, approximately 670,000 ha were lost each year during the mid-1980s, leading to an overall deforestation rate of 1.29 percent/yr (Table 8). Total forest losses are split into 167,000 ha of temperate and 501,000 ha of tropical forests. Deforestation rates are substantially higher for tropical forests (1.90 percent for deciduous forests and 2.00 percent for evergreen forests) than for temperate ones (0.64 percent/yr for coniferous forests and 0.64 percent/yr for broadleaf forests, Table 9). It should be noted that the figures represent conservative estimates, as they are well below those found for some case studies covering the different forest types (Table 10).

The main activities causing deforestation vary according to forest type. Deforestation is, however, ultimately rooted in the overall rural development strategy followed by the government during the last four decades. In this strategy, the rural sector -- particularly peasant agriculture -- was to pay for the country's industrialization. Cheap-food policies and low prices for peasant products with respect to industrial goods promoted the exploitation of forests. An increasing land concentration forced peasants to move to marginal lands. During the seventies, colonization programs were established in the tropical forests to avoid a politically difficult land-reform. Extensive subsidies were provided to cattle ranchers, making ranching much more profitable than other productive activities. Long, unsolved disputes on land tenure and a complex and tedious process of land titling have added to the forces favoring deforestation. During the 1980s, the overall economic crisis of the country worsened the rural crisis. Peasants have been among the social sectors most adversely hit by structural adjustment policies undertaken by the government.

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[4] Most of the area affected by forest fires undergoes natural regeneration. Only the fraction of the area burnt **not allowed (or not able) to regenerate** is included in our estimates for deforestation. The following fractions of the areas affected by forest fires are assumed to do not regenerate: temperate conifer (30%); temperate broadleaf (40%); tropical evergreen (20%); and tropical deciduous (30%).

The few incentives for natural resource conservation that still remain have been largely eroded (Janvry and Garcia 1988). Following increasing land concentration, the recent reform to the land tenure system in the country might also prompt rapid deforestation in particular regions.

Table 9. Deforestation and reforestation rates by forest type (10^3 ha/yr)

Activity	Temperate coniferous	Temperate broadleaf	Tropical evergreen	Tropical deciduous	Total
Deforestation	108	59	195	306	668
Reforestation	13	3	6	0.8	19
Deforestation rate (%/yr)	0.64%	0.67%	2.00%	1.90%	1.29%

The expansion of cattle ranching has been by far the leading factor encouraging deforestation in the tropical forests (Toledo 1990; Synnott 1988; Tudela 1990; Dirzo and Garcia 1991) and it has also affected temperate forests (see Table 11). The precise impact of this activity in deforestation is difficult to assess because most estimates do not disaggregate forests by type. Also, part of the expansion in livestock production has occurred in lands already cleared for agriculture.

It is estimated that from 1981 to 1983 the area under livestock production increased by over 1.5 million ha/yr, surpassing the 1.1 million ha/yr increase between 1970 and 1980 (Toledo 1990). In the state of Tabasco alone (Tudela 1990), the area devoted to livestock production increased from 30 percent to 70 percent of total state area in 20 years, mainly through the clearing of rain forests (Figure 3). Within temperate forests, ovine and, particularly, caprine livestock production have increased significantly in certain areas.

A typical sequence in the deforestation process of tropical forests begins with timber extraction. This activity provides the first roads to the forest, from which spontaneous or directed colonization by poor settlers is facilitated. The harvested forest is usually dedicated first for a few years to annual agriculture, from which it subsequently moves into permanent pasture. The many comparative advantages of livestock production with respect to traditional crops (specifically maize) and the absence of markets for other rain forest products induce the ultimate conversion of forests to pasture (Janvry and García 1988).

Table 10. Deforestation rates and leading causes of deforestation in selected regions

Region	Ecological features	Deforestation rates (%/yr)	Leading factors of deforestation
Los Tuxtlas, Veracruz[a]	Tropical evergreen	750 ha/yr (4.3%/yr) 1976-86	cattle ranching
Selva Lacandona[b] (Usumacinta River)	Tropical evergreen	14,700 ha/yr (4.5%/yr) 1980-88	cattle ranching (200% increase), opening to agriculture (67%)
South-east Mexico[c]	Tropical evergreen	~40,000 ha/yr (7.7%/yr) 1974-86	cattle ranching (42% of deforested area), eroded (6.7%), shifting agriculture (3.7%); 45% on secondary vegetation.
Palenque, Chiapas[d]	Tropical evergreen	9,500 ha/yr (12.4%/yr) 1973-1981	cattle ranching, (no rainforest remains at present in this area)
Chamela, Jalisco[e]	Tropical deciduous	26,700 ha/yr (3.8%/yr) 1982	cattle ranching, shifting agriculture.
Purepecha Highlands, Michoacan[f]	Temperate coniferous	1,800 ha/yr (1.5-2%/yr)	clandestine logging, unsettled land tenure conflicts among villages, crisis peasant economy

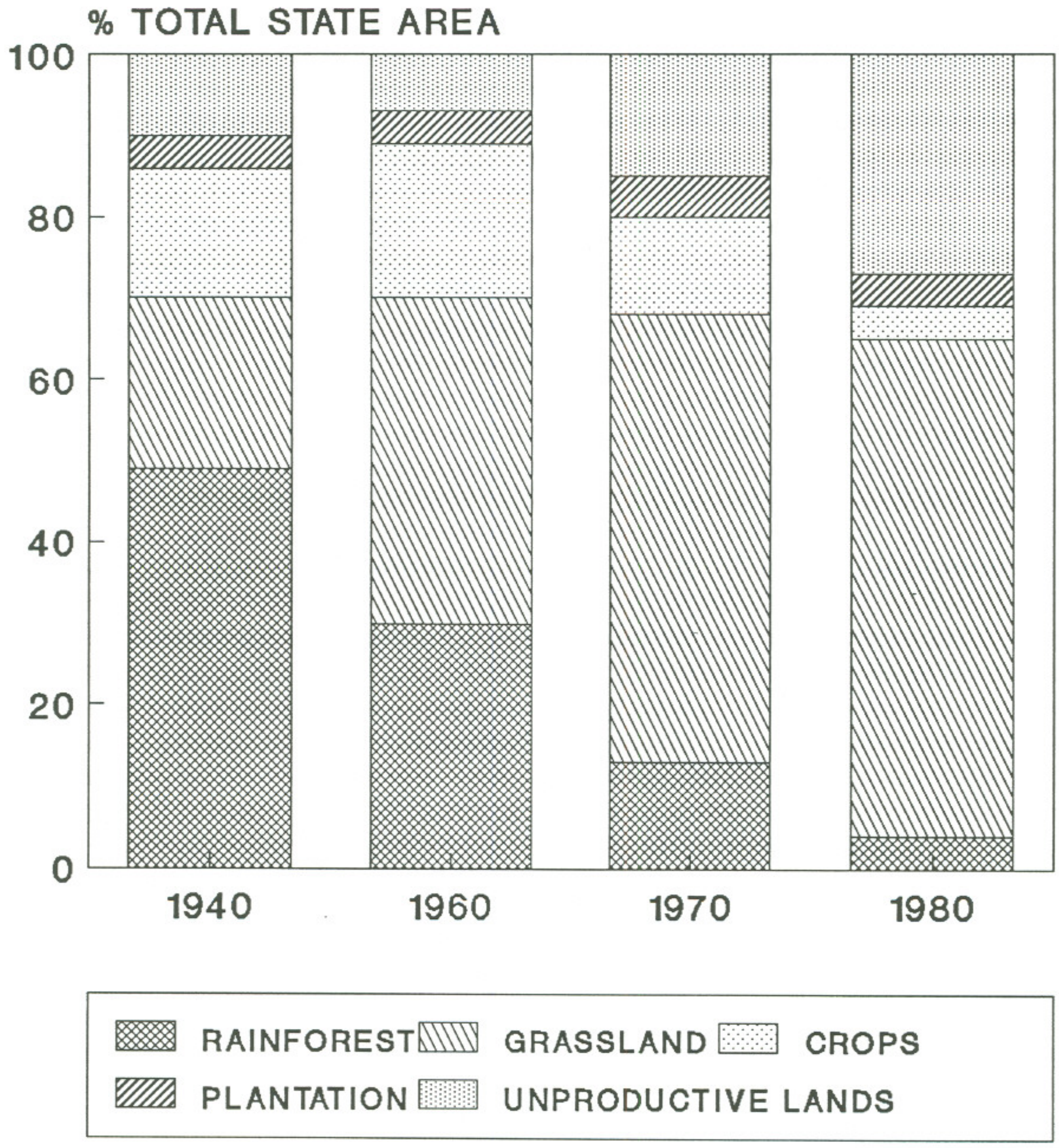
Source:
a. Dirzo and García (1991)
b. Cortez-Ortiz (1990) (using satellite images)
c. Cuarón (1991) (using satellite images)
d. SARH (1984)
e. De Ita *et al.* (1991)
f. Caro (1987) and Caro (1990).

Table 11. Main sources of deforestation by forest type

Forest type	Main sources of deforestation
Temperate coniferous	forest fires (largely anthropogenic), livestock (bovine, caprine and ovine), clandestine logging, agriculture expansion.
Temperate broadleaf	forest fires, livestock (bovine, caprine and ovine); agriculture expansion; clandestine logging.
Tropical evergreen	extensive cattle ranching; agriculture expansion; oil extraction, mining and road construction, forest fires, timber extraction.
Tropical deciduous	extensive cattle ranching; agriculture expansion; timber extraction; forest fires.

Notes: Some of the structural factors favoring deforestation include: (a) subsidies to cattle ranching; (b) underpricing of agricultural products relative to industrial products; (c) anti-peasant biases -- insecure land tenure; concentration of good land in large farms--; and (d) break-down of local collective institutions for natural resource conservation.

FIGURE 3
EVERGREEN FOREST CONVERSION IN TABASCO, MEXICO



Total state area: 2.5 million ha.
From Tudela (1990)

Forest clearing for shifting agriculture also adds to the deforestation process, particularly when the fallow period is shortened. The impact of oil extraction (which not possible to quantify in this study) has also been very large in specific areas (e.g., the state of Tabasco) (Tudela 1990).

Anthropogenic fires have increased substantially during the previous decade, becoming the leading factor of deforestation in temperate forests. Fires are produced to burn the forest understory to increase pasture production and to claim timber as "dead wood" in areas without harvesting permits. Clandestine forest clear-cutting and opening for agriculture are other major causes of deforestation within these forests (Table 11).

The rapid pace of deforestation has prompted an increase in government-led reforestation programs during the last decade. Official figures indicate that approximately 50,000 ha have been reforested annually between 1985 and 1990, for a total of 432,000 ha reforested since 1960 (SARH 1991a). In a report about Mexico, FAO (1990) estimates that the average seedling survival rate in reforestation programs is 34 percent. Thus, the actual area reforested reached at most one-third of the planted area. In our calculations, we used figures for the year 1990 which, taken into account survival rates, give an estimated net 19,000 ha reforested yearly, and a net 146,000 ha of cumulative area under reforestation. Most reforestation is concentrated on areas previously inhabited by coniferous forests (Table 9). In the past, reforestation was largely carried out with non-indigenous species (e.g., *eucalypti, casuarins, Pinus radiata*). However, the most recent reforestation programs have incorporated a more intensive use of native species, mostly pines (SARH 1991b).

5. CARBON EMISSIONS FROM DEFORESTATION AND FOREST FIRES

5.1. The Current Situation

Carbon emissions from deforestation and forest fires were estimated using the CO-PATH model (Makundi *et al*. 1991). The BASIS module of COPATH was modified to accommodate all forest types in the same spreadsheet, as well as to incorporate summary carbon statistics for the country. The structure of carbon uptake was also modified to include the contribution of the area reforested. Three additional spreadsheets, VEGET, DEFORES and C02CONST, were created and linked to the BASIS module to facilitate the estimation procedure (see Figure 4 for a diagrammatic description of the procedure to estimate carbon emissions). VEGET contains state-wise estimates of vegetation cover and land-use patterns for the country. DEFORES incorporates the information on deforestation rates by forest type and conversion activity. CO2CONST estimates the different biological parameters (biomass, density, carbon content, combustion and uptake parameters) used in BASIS.

For each forest type, estimates on forested area, deforestation rates, and the area affected by forest fires, were complemented with information on forest conversion activities, biological data and official estimates on reforestation rates. The whole area affected by forest fires, as opposed to only that area which will not regenerate, is included in our calculations. This is because **for the purposes of determining current carbon emissions any activity leading to an immediate**

or future change in the original forest carbon content must be accounted for. Thus, even if most of the area affected by forest fires will eventually regain the original forest cover and will thus result in no net future contribution to carbon emissions, it will certainly add to carbon emissions in the year forest fires occur. As with the rest of forest conversion activities, the "carbon uptake" from the vegetation regenerating after the fires is separately taken into account within the CO-PATH model, and subtracted to emissions. The future net additions to carbon emissions from forest fires will thus ultimately depend on the fraction of the area affected by fires that is not allowed to regenerate.

An accurate partition of the deforested area into the different conversion activities is still more difficult than the estimation of deforestation rates. Available estimates on deforestation rates give only the amount of land deforested but do not indicate the conversion activity. As explained in the previous section, usually there is a sequence in the deforestation process: for example, the forest is first cleared for agriculture from which it turns into permanent pasture. Also in many cases, pasture cannot be sustained and erosion takes place. In temperate forests, areas cleared often simply are abandoned: in these cases, the extent to which they are able to regenerate or become completely eroded is also difficult to estimate. Thus, it is difficult to determine the long-term composition of the deforested area (e.g., how much of the forest cleared will end up as pasture, will be devoted to annual or permanent agriculture, will undergo natural regeneration or will be eroded).

In this study, we largely relied on detailed case studies and personal experience in the field to estimate the assumed "permanent" composition of the deforested area. For tropical evergreen forests estimates of changes in land-use patterns from satellite images for two different years were used (Cuarón 1991). Secondary vegetation, which accounts for an important share of the deforested area within tropical forests was partitioned between pasture and agriculture; a small fraction was considered to remain as such in the long-term. Table 12 presents the estimated contribution of each conversion activity to total deforestation by forest type.

FIGURE 4
PROCEDURE FOR ESTIMATING CO2 EMISSIONS

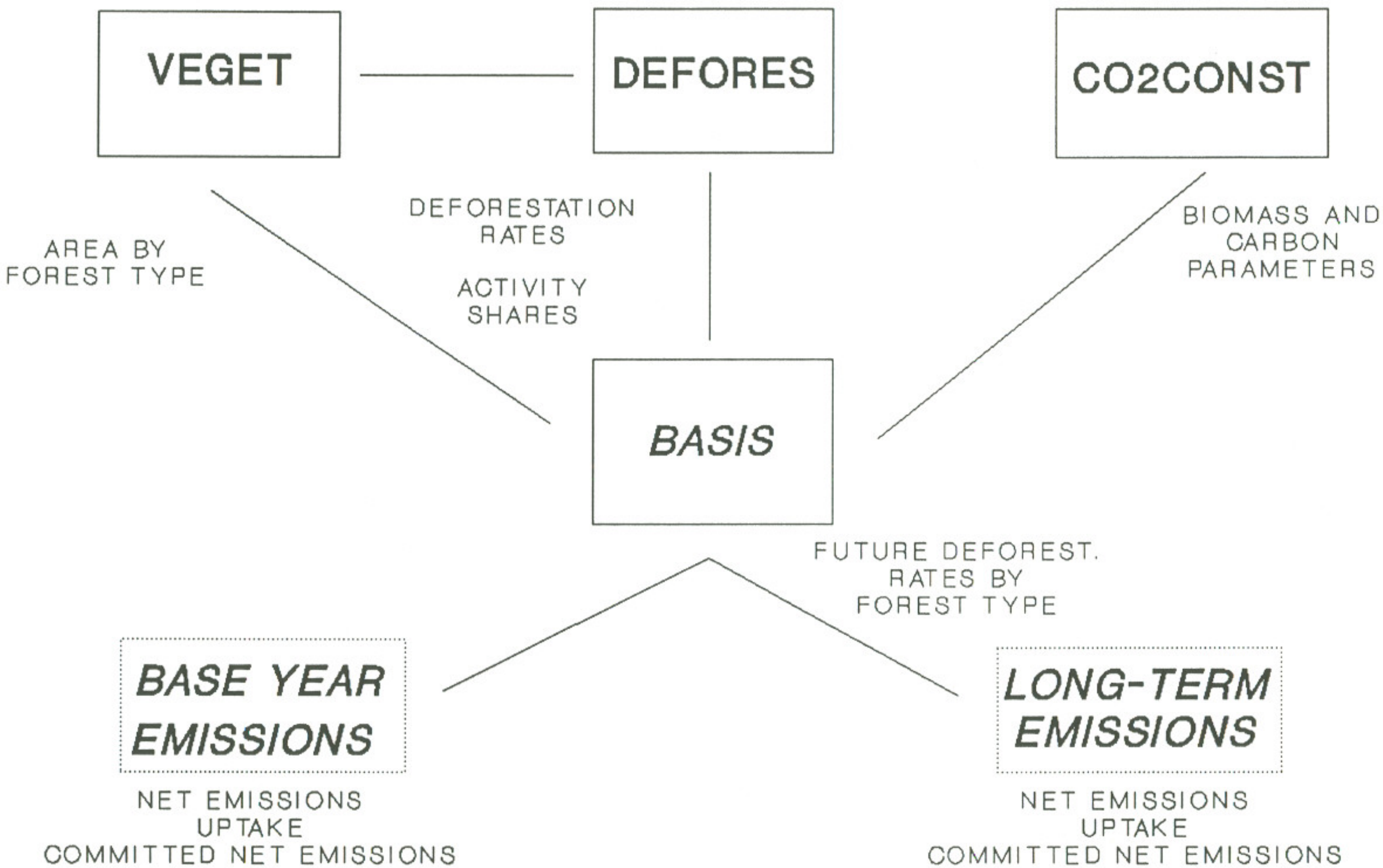


Table 12. Estimates of deforestation and forest fires shares by conversion activity (10^3 ha/yr)

Activity	Temperate coniferous	Temperate broadleaf	Tropical evergreen	Tropical deciduous	Total
Deforestation and forest fires	163	82	237	322	804
Pasture	28%	28%	58%	57%	49%
Agriculture	16%	17%	10%	14%	13%
Harvesting	5%	5%	2%	5%	4%
Forest fires	49%	47%	22%	7%	24%
Other[a]	3%	3%	7%	16%	10%

Source: The estimates of the shares of each conversion activity in total deforestation were derived as follows: (i) Evergreen forests, from Cuarón (1991), adjusted to include forest fires; (ii) Temperate forests and tropical deciduous forests, area affected by forest fires calculated using five-year average figures from SARH (1989b)--here the whole area affected by fires and not only the fraction that will not regenerate is included, see text for more details; own estimates for the remaining conversion activities.

Note: a. Other land uses include forest losses through erosion, road building, etc.

Detailed information on both carbon content of vegetation and soils only was available for tropical deciduous forests (Table 13). For the remaining forest types, basal area, mean tree height and wood density were also taken from primary sources. In these last forest types above-ground biomass inventories were calculated using Cannell's (1984) formula:

$$WT = F * H * G * D$$

where,

WT= total above-ground woody biomass per hectare of stems and branches, including bark, of forest of woodlands,

F = volume (form) factor; ranging from 0.4 for coniferous (14.6 percent branches) to 0.5 for broadleaves and tropical evergreen (19 percent branches),

H = mean tree height,

G = basal area at breast height; and

D = mean wood specific gravity.

A mid-range figure between high and low biomass values obtained from different case studies was selected (see Table 13). Official estimates on forest inventories also were used as references.

Data on combustion efficiencies and carbon releases both from vegetation and from soil disturbances were entirely drawn from the literature (Table 13).

Two indexes are used for the calculation of carbon emissions: annual carbon balance and net committed emissions. The **annual carbon balance** represents the balance between emissions and uptake originating from the forest sector that occur in the base year. It thus includes both the prompt emissions from deforestation and forest fires in the base year plus the delayed emissions coming from historic deforestation (that is, emissions that occur in the base year because of decomposition of woody biomass produced by past deforestation)[5]. The uptake from all growing vegetation in the base year is then subtracted to the emissions to get the annual carbon balance (see Table 14).

Committed net emissions represent the net long-term change in carbon content between the original forest cover and the forest conversion activity (i.e. agriculture, pasture, etc.). It is calculated as prompt plus delayed emissions from current deforestation and forest fires minus prompt and delayed uptake from the vegetation replacing the deforested area or the area affected by forest fires and from the reforested lands (see Table 14). This indicator is necessary in order to make our estimates comparable to those from other sources (e.g., Houghton 1990; WRI 1990). (See also Makundi and Sathaye (1992) for a more detailed discussion on the two indicators).

Table 15 presents the **annual carbon balance** for each conversion activity and forest type. The **prompt carbon uptake** is also included in Table 15. A **"carbon intensity" index** (net emissions per hectare of land deforested) is estimated in order to illustrate the relative impact of each conversion activity and forest type on carbon emissions. The **net committed emissions** and **stored carbon** by forest type are also included in the table. This last indicator helps illustrate the potential cumulative releases of carbon dioxide to the atmosphere.

According to our estimates, Mexican closed forests store about 7.0 gigatonnes of carbon (GtC), from which 53.4 million tonnes of carbon (MtC) were emitted in the base year. Conversion to pasture is responsible for over 60% of the total annual carbon balance. On average, 67 tonnes of carbon were emitted per hectare, with the highest value for conversion to agriculture (74 tonnes/ha). While accounting for only one-fourth of the area affected by deforestation and forest fires, tropical evergreen forests were responsible for 50 percent of total annual carbon balance. Eighty four percent of total emissions come from tropical forests (Figure 5).

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[5] In the absence of data on historic deforestation trends in Mexico, this study assumes that current deforestation rates do not differ very much from past deforestation. Under these circumstances, delayed emissions from present deforestation can be assumed to be equal to delayed emissions from past deforestation; consequently the data obtained for the base year suffices for calculating the annual carbon balance.

Table 13. Biomass and carbon-related parameters of forests used for carbon emissions estimates

Parameter	Temperate coniferous	Temperate broadleaf	Tropical evergreen	Tropical deciduous
General				
Dominant species	Pinus sp	Quercus sp	Terminalia amazonia	Caesalpinia eristachys
Wood density (tonne/m^3)	0.48[a]	0.6[b]	0.6[c]	0.5[d]
Biomass (tonne/ha)				
Total	112[e]	78[e]	288[e]	135[f]
Above	86	60	240	85
Total/above	1.3	1.3	1.20	1.59
Carbon				
Content (%) [g]	50	50	50	50
Total (tC/ha)	165.1	68.5	210.0	97.0
Vegetation	56.0	39.0	144.0	67.5
Soils [g]	109.1	29.5	66.0	29.5
Combustion release [g]				
Biomass carbonized	0.4	0.4	0.2	0.4
Slash-and-burn				
agriculture	0.6	0.6	0.5	0.4
pasture	0.6	0.4	0.3	0.3
Soil disturbance				
agriculture	0.3	0.3	0.3	0.3
pasture	0.3	0.2	0.2	0.2
Uptake [g]				
% Fires reconverted	70	60	80	70

Notes: a. Wood densities of the more than 50 species of Pines in Mexico (Rzedowski, 1991) range from 0.41 to 0.55; the value chosen (0.48) corresponds to the average wood density for the most common species.

b. Corresponds to the average wood basic specific gravity for broadleaves species estimated by Cannell (1984).

c. Mexican tropical evergreen forests do not have a definite dominant specie, there are several tree species that share the dominance; for that we use the average wood density of the most common species reported by Sarukhan (1968) and Bongers *et al.* (1988).

d. Dominant species reported by Martínez-Yrizar (in press), we use an average of the most common species reported.

e. Above ground biomass was estimated applying Cannell's formula (1984) (see text) to data drawn from different case-studies (San Rafael (1985) and SARH (1985) for temperate forests; and Sarukhan (1968) and Bongers (1988) for tropical evergreen forests).

f. Data reported by Martínez-Yrizar (in press).

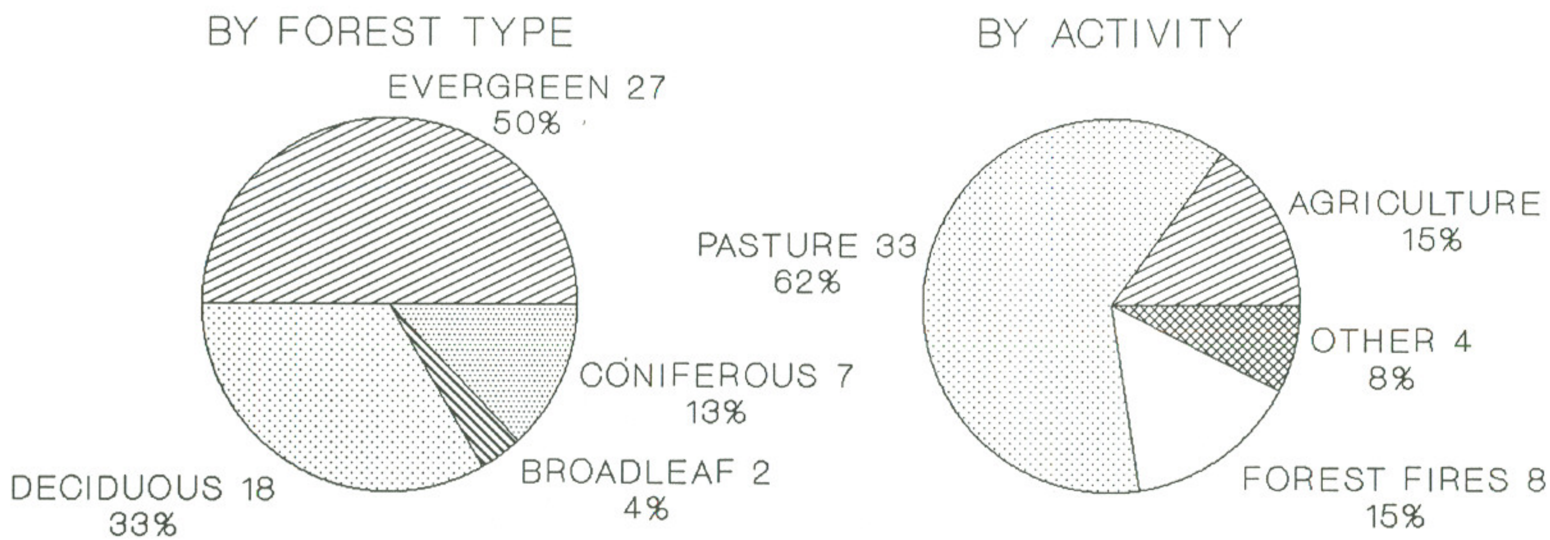
g. Assumed, based on estimates for comparable forest types in other countries (Makundi, 1991; L. Atipanumpai [personal communication]).

Table 14. Carbon emissions and uptake from deforestation and forest fires in Mexico (~ 1985) (MtC/yr)

Indicator	Temperate coniferous	Temperate broadleaf	Tropical evergreen	Tropical deciduous	Total
Emissions					
Prompt (1)	5.4	1.1	13.3	8.1	27.9
Delayed (2)	1.4	0.6	13.9	10.2	26.1
Committed (3) [a]	6.8	1.7	26.9	18.3	54.0
Uptake					
Prompt (4)	0.2	0.05	0.2	0.04	0.5
Delayed (5)	3.4	0.7	3.1	0.8	8.0
Committed (6) [a]	3.6	0.8	3.3	0.9	8.5
Annual Carbon Balance (7) [b] (MtC/yr)	6.5	1.7	27.0	18.2	53.4
Net Committed Emissions (8) [c] (MtC)	3.1	0.6	23.8	17.5	45.5

Note: a. Committed emissions (uptake) are (is) the sum of prompt and delayed emissions (uptake); b. (3) - (4); c. (3) - (6). Totals do not always add up to the first decimal point because of rounding errors.

FIGURE 5. ANNUAL CARBON BALANCE FROM DEFORESTATION AND FOREST FIRES MEXICO MID 1980'S



ANNUAL CARBON BALANCE 53 MtonC/YR

Table 15. **Net carbon emissions from deforestation and forest fires in Mexico (~ 1985)**

Emissions	Temperate coniferous	Temperate broadleaf	Tropical evergreen	Tropical deciduous	Total	(%)
Annual carbon balance (MtC/yr)	**6.5**	**1.7**	**27.0**	**18.2**	**53.6**	**100%**
Intensity (tonne/ha)	40	21	114	57	67	
Agriculture	1.8	0.5	2.9	2.8	8.0	15%
Intensity (tonne/ha)	72	36	136	59	74	
Pasture	3.3	0.8	18.7	10.4	33.2	62%
Intensity (tonne/ha)	72	33	133	56	71	
Other	1.5	0.4	5.4	5.0	12.4	23%
Intensity (tonne/ha)	16	10	72	56	25	
Prompt carbon uptake (MtC/yr)	0.2	< 0.1	0.2	< 0.1	0.5	1%
Intensity (tonne/ha)	1.2	< 0.1	< 0.1	< 0.1	0.4	
Net committed emissions (MtC)	3.1	1.0	23.8	17.5	45.5	100%
Intensity (tonne/ha)	19	13	101	54	57	
Stored carbon (GtC)	2.8	0.6	2.0	1.6	7.0	13080%a
Intensity (tonne/ha)	165	69	210	97	136	

Note: a. Percentage of stored carbon to annual carbon balance.

Carbon releases per hectare differ markedly by forest type, ranging from 21 tonne/ha for temperate broadleaf to 114 tC/ha for tropical evergreen forests. The difference in intensities shows the importance of correctly assigning deforestation figures to the corresponding forest type. The prompt carbon uptake is very low because most deforested area is converted to annual agriculture and pasture, which are characterized by low carbon storage per hectare; also the net area under reforestation programs is still small in Mexico.

Net committed net emissions reach 45.5 MtC (or 57 tC/ha) and are almost mid-range between the figures reported by WRI (32 MtC, WRI 1990) and those reported by Myers (64 MtC, Myers 1989). Using this indicator, the contribution of temperate forests decrease, mainly because of the delayed uptake from the growing forests under reforestation.

Given the uncertainty of some assumptions, we carried out a sensitivity analysis of net carbon emissions. Figures 6a and 6b show the results of the exercise. A set of key parameters (deforestation rates, biomass, soil carbon and carbon release parameters) were selected and given values from -20 percent to 20 percent the current estimate. Deforestation rates proved the more sensitive, with a close to linear response in carbon emissions. Total biomass and release parameters showed less sensitivity. Soil carbon content was found to be the least sensitive parameter (-8 percent to +3 percent variation in emissions for a -20 percent to 20 percent variation in the parameter). When all key parameters are simultaneously varied from -20 percent to 20 percent, net carbon emissions range from 30.3 MtC/yr to 84.7 MtC/yr. We consider this range a good estimate of the uncertainty in current carbon emissions in the country.

5.2. Long-term Carbon Emission Scenarios

Future carbon emissions from the forest sector are very difficult to estimate given the linkages among the economic, technological and social factors involved in the deforestation process. The current economic panorama and the institutional framework regulating access to forest resources are changing rapidly in Mexico, making it difficult to predict future trends in basic economic activities within the country.

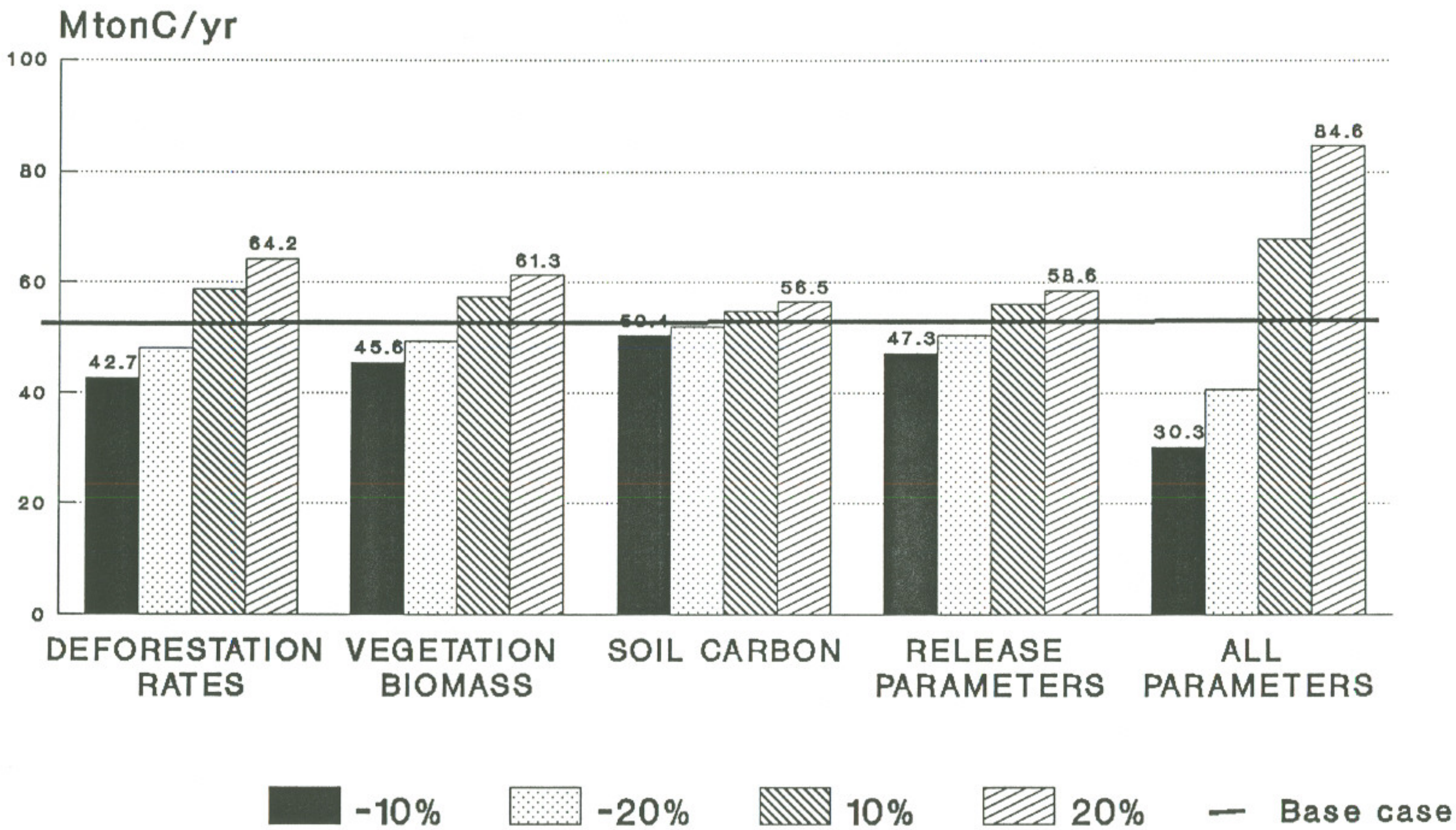
At the moment there is no long-term "forestry plan" in Mexico. A recent report from the forestry department presents the most comprehensive analysis of the long-term prospects for the sector (Castillo *et al.* 1989). The report projects demand for forest products, resource availability and potential production from 1988 to year 2012. Deforestation is assumed to correlate linearly with rural population growth and is adjusted by type of forest according to population densities in forested areas. The study assumes average deforestation rates of 0.63 percent for coniferous forests and of 1.77 percent for broadleaf and tropical forests, for a country average of 1.5 percent/yr between 1988 and 2012.[6] A 30 percent of the base-year vegetation cover is thus thought to be lost by 2012.

The stated scenario is not adequate for our purposes because: (i) our estimates of current deforestation rates by type of forest do not coincide with those from the report; (ii) as explained previously, deforestation is not linearly dependent on population growth. Regions with very low population densities have suffered extensive deforestation. Population certainly should be incorporated into estimates of deforestation rates, but through a more elaborate procedure that better links demographic growth with the dominant mix in productive activities by type of forests.

Given the time constraints and the large uncertainties about current and future deforestation rates, we decided to develop two contrasting scenarios: high emissions (HES) and low emissions (LES). The scenarios are intended to provide the most likely range of emissions given contrasting long-term policies on land-use patterns within the country. We chose 2025 as the

[6] Sixty percent of the deforestation in these three last forest types is thought to occur in deciduous tropical forests, with the remaining 40 percent partitioned between tropical evergreen and temperate broadleaf forests according to their area. This procedure leads to the following actual average deforestation rates between 1988 and 2012: evergreen 1.88 percent/yr; deciduous 1.91 percent/yr; and broadleaf 1.57 percent/yr.

FIGURE 6 SENSITIVITY ANALYSIS
ANNUAL CARBON BALANCE FROM DEFORESTATION AND FOREST FIRES



final year to make the scenarios compatible to those developed for emissions from energy use (Mendoza *et al.* 1991).

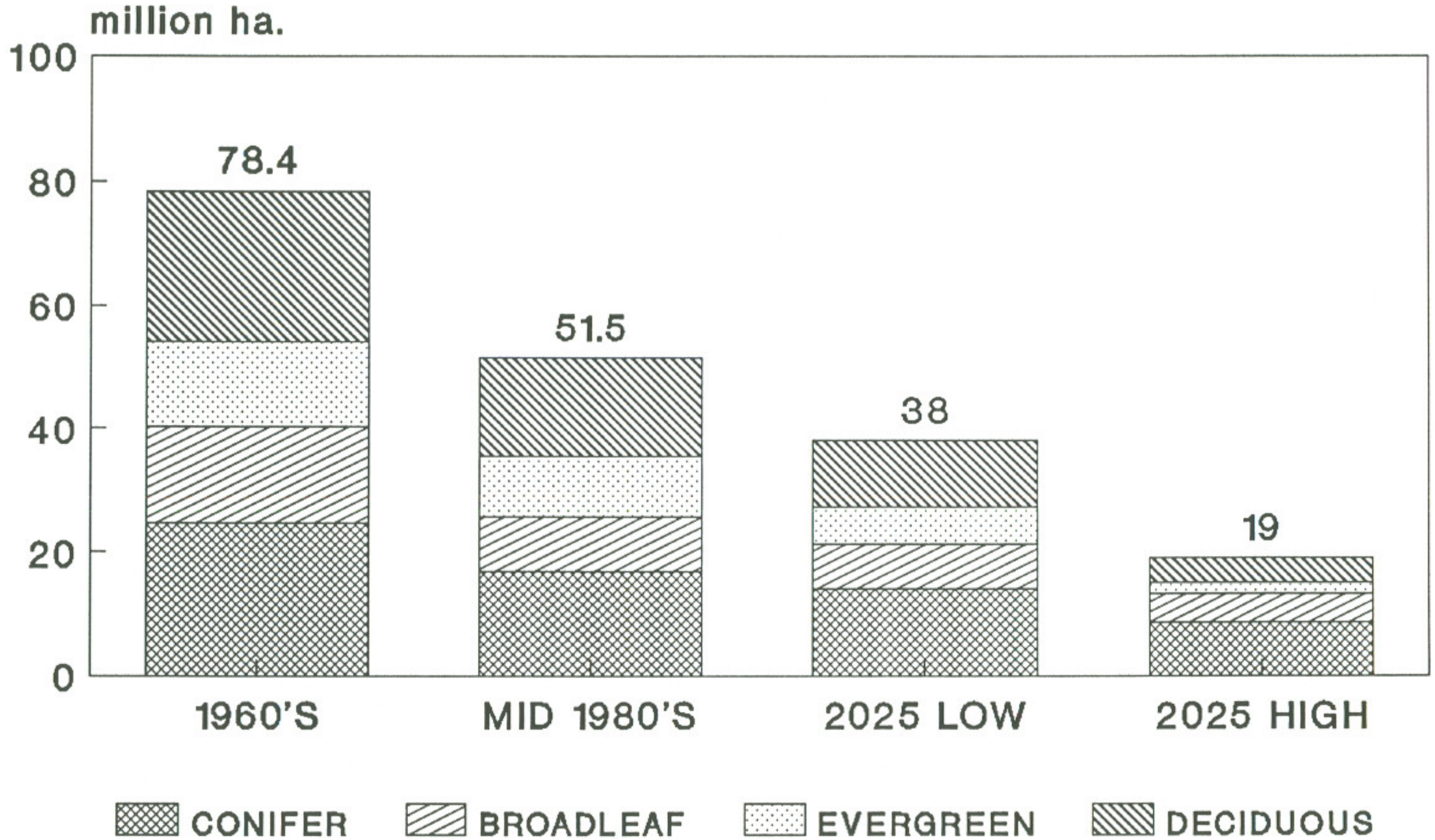
Table 16 illustrates the basic assumptions of each scenario. The HES visualizes a future with little concern for forest conservation. For evergreen forests, deforestation rates are adjusted so that these forests only remain within the existing protected areas. The same resulting scaling factor is applied to the remaining forest types to estimate future deforestation rates. Carbon intensities are kept the same as in the base year (in other words, it is assumed that the present structure of carbon emissions and uptake will continue in the future). The LES assumes a 50 percent decrease in deforestation rates with respect to the current ones, plus a doubling in wood used for long-term purposes and reforestation rates and improved vegetation recovery from forest fires and other perturbations.

Table 16. Main assumptions for carbon emissions scenarios in Mexico

Indicator	Base Year (~1985)	High Emissions (2025)	Low Emissions (2025)
Forested Area (million ha)	51.5	19.0	38.0
Evergreen	9.7	1.7	5.9
Deciduous	16.1	4.0	10.8
Coniferous	16.9	8.7	14.0
Broadleaf	8.8	4.6	7.3
Deforestation rate (%/yr)			
Evergreen	2.44%	4.20%	1.22%
Deciduous	2.02%	3.43%	1.00%
Coniferous	0.96%	1.66%	0.48%
Broadleaf	0.94%	1.61%	0.47%
Conversion activity shares		Same as base year	Same as base year
Carbon Release Parameters		Same as base year	Double proportion wood for long-term use.
Carbon Uptake			
Recovery from Forest Fires	60-80%	60-80%	70-90%
Reforestation		Same rate (in ha/yr) as in base year from 1985 to 2025	Twice the rate (in ha/yr) as in base year from 1985 to 2025

The evolution of forested area under the two scenarios is shown in Figure 7. In the HES only 37 percent of the base-year forested area remains, in contrast with 70 percent for the LES. It should be noted that deforestation rates assumed for the HES are within the range of those found in most case studies (Table 10).

FIGURE 7
EVOLUTION OF FORESTED AREA
MEXICO



By 2025, the annual carbon balance reaches 22.9 MtC/yr in the HES and 16.5 MtC/yr in the LES (Table 17). The reduction in forest cover (HES) and the combination of reduced forest cover and deforestation rates (LES) are responsible for the reduction of carbon emissions in both scenarios with respect to the base year (53.4 MtC/yr).[7] Cumulative emissions are important in both scenarios, as evidenced by the decrease of 1.9 GtC (LES) and 4.5 GtC (HES) in the forests' stored carbon from the base year. Cumulative emissions, also permit a better appreciation of the difference between the HES and LES.

The contribution to delayed carbon uptake from the estimated relatively large area under growing reforestation in 2025 leads to very low (HES) or even negative (LES) net committed emissions in the two scenarios. The result for the LES illustrates that if deforestation is stopped by 2025, Mexico's forests could begin serving as an important carbon sink.

Table 17. Long-term carbon emissions from deforestation in Mexico

Indicator	Base Year (1985)	High Emissions (2025)	Low Emissions (2025)
Annual Carbon Balance (MtC/yr)	53.4	22.9	16.5
Prompt Uptake (MtC/yr)	0.5	0.9	1.5
Net Committed Emissions (MtC)	45.5	2.8	-21.7
Stored Carbon (GtC)	7.0	2.5	5.1

5.3. Overall Carbon Dioxide Emissions: Linking Energy, Industry and the Forest Sector

The overall current and future annual carbon dioxide balance were calculated by adding together the existing estimates on carbon emissions from energy use (Mendoza *et al.* 1991), cement manufacturing (Ketoff *et al.* 1990) and deforestation (Table 18).

The analysis shows that annual carbon emissions increase from 130 MtC/yr in 1987 to 252 in the HES and to 179 in the LES (Figure 8 and Table 18). The current annual carbon balance per capita (1.7 tC/yr) **decreases** by 24 percent in the LES and increases by 12 percent in the HES. Carbon emissions from energy use grow substantially in both scenarios while emissions from deforestation decrease, leading to an important drop in the share of deforestation in total emissions (from 41 percent in 1985-87 to 9 percent (HES) and 10 percent (LES) in 2025). Emissions from cement manufacturing increase by a factor of two in both scenarios, but its share in total emissions remains low.

The implementation of policies to reduce carbon emissions in the LES leads to 73 MtC/yr savings by 2025 relative to the HES. Further savings are possible since, at least in principle,

[7] Long-term carbon emissions were also estimated using the BASIS module.

FIGURE 8
MEXICO CARBON EMISSIONS FROM DEFORESTATION AND ENERGY USE

Deforestation estimates correspond to annual carbon balance deforestation could be prevented and extra carbon savings from energy use are also achievable. As scenario assuming a net increase in the forested area in Mexico would also increase the stated carbon savings.

Table 18. Current and long-term overall carbon emissions in Mexico

Source	Base year (1985-87)		High emissions (2025)		Low emissions (2025)	
	(MtC/yr)	(%)	(MtC/yr)	(%)	(MtC/yr)	(%)
Energy	74	57%	223	89%	156	87%
Deforestation and forest fires	53	41%	23	9%	17	10%
Cement manufacturing	3	2%	6	2%	6	3%
Total	130		252		179	
Per capita (tC/yr)	1.7		1.9		1.3	

Notes: a. Data for energy use from Mendoza *et al.* (1991), emissions for cement manufacturing (that should not be confused with emissions from energy use in cement manufacturing -- already included within energy figures) calculated from Ketoff *et al.* (1990), using current and projected cement output per capita and country population. Emissions from energy use do not include gas flaring.
b. Emissions from deforestation and forest fires represent the "annual carbon balance".
c. Per capita estimates based on the following population figures: 76.6 million for 1985-87 and 144 million for 2025 (Mendoza *et al.* 1991).

The decreasing share of emissions from deforestation and forest fires in the long term might lead to the conclusion that integrating the forest sector in carbon-abating strategies is secondary. This conclusion might prove wrong for at least three reasons:

(i) While an important reduction in **current** overall carbon emissions from energy use or cement production are difficult to achieve given population growth, economic and technological constraints and the fact that Mexico is still building a substantial fraction of its infrastructural needs, most emissions from the forest sector can be avoided without inflicting serious economic losses (and most probably with net benefits to the country). As shown by the results of net committed emissions in the LES, forests can even become an important carbon sink if deforestation is stopped.

(ii) Related to the previous statement, forests are more important because of their **cumulative** rather than their current emissions. If a global international budget on carbon emissions is finally agreed upon, cumulative emissions from forestry might represent an important share of total allowable country emissions. For example, the maximum potential carbon releasable from

Mexican forests is approximately 7.0 GtC. This represents about 2.1 percent of the **maximum total cumulative** emissions that can be emitted in the world without contributing to further climate change (Krause *et al.* 1989). If a global convention on carbon emissions was to be set up on the basis of the previous statement, cumulative emissions from Mexico's forest sector alone would account for more than the overall allowable emissions from the nation as a whole. Therefore, avoiding emissions from forestry might prove important as a way of buying time necessary for the transition from fossil fuels to renewables. In the case of Mexico, this possibility is particularly relevant because the country relies on fossil fuels for more than 90 percent of its primary energy production and has very large oil reserves (Mendoza *et al.* 1991); and

(iii) Forests are important for many other reasons besides carbon storage (Myers 1983; Repetto 1988; MacNeely 1990).

Therefore, it is essential that forestry keeps its place as an important option for potential carbon emissions savings in the future.

This exercise was limited to estimating current and long-term carbon emissions. In the future, however, more comprehensive analyses should examine emissions of other greenhouse gases in order to complete the picture.

6. POLICY OPTIONS: REDUCING CARBON EMISSIONS THROUGH THE SUSTAINABLE MANAGEMENT OF FOREST RESOURCES

A detailed economic and technical analysis of different policy options for reducing deforestation and diminishing carbon emissions is beyond the scope of the present report. Cost estimates of different management options are particularly difficult to obtain. The following discussion only delineates the general elements of an alternative strategy.

It is very unlikely, and probably not advisable, that Mexico follow a "carbon reduction maximization" strategy for its forest resources. Addressing global warming concerns may bring about substantial benefits for the country both in the short and long run. But critical to actually accruing these benefits is the undertaking of a strategy that strikes a balance among the different uses for forest resources: wood, fuel and food for local needs, products for urban areas, biodiversity, climate regulation, watershed protection, education, recreation and others.

The best strategy (meaning the one that maximizes the probability for success in the long-term and is economically realistic) for reducing carbon emissions is one that builds upon the solution of the more immediate needs that forest resources provide to local people and the country.

Reducing deforestation rates and increasing reforestation are the two basic actions in any alternative forest management strategy. There are no intrinsic obstacles hindering the sustainable management of forest resources in the country. Population growth is not the leading factor in the deforestation process and food needs can be largely accommodated within the existing area open to cultivation through a better crop mix. At least in principle, a large land area shows potential for forest use without impinging on other economic activities.

The success in conserving the country's forest resource base, however, will be largely dependent on a deep revision of current rural development and forest sector policies. The basic elements for an alternative long-term oriented strategy include:

(i) *Eliminate the disparity between those who own and those who benefit from the forests.*

Given the social appropriation of most forest resources in the country, community forestry programs should be promoted which allow local residents to benefit from the conservation of forest resources. Technical assistance, as well as support for developing managerial skills and alternative commercialization channels, need to be provided to villages. Successful experiences exist in the country both for temperate and tropical forests, showing the viability of the stated approach (Jardel 1989; Sanabria 1986; Bray 1991).

(ii) *Incorporate ecological principles into forest management activities and strengthen basic and applied research on forest ecosystems.*

Until now the forest sector has followed a "productivist" logic disregarding the long-term effects of management practices. Mexico needs to explore and promote management methods that address the diversity of the country's forest conditions and that take into account the successional dynamics of Mexican forests. This task, particularly important within tropical forests, should include the critical rescue of traditional forest management systems and the promotion of agroforestry schemes (Altieri 1988; Gomez Pompa 1985; Toledo 1989). Rather than maximizing one particular resource (e.g., timber), harvesting should be conducted following a **multiple use** strategy. This would maintain a balance between forest resources for local consumption (i.e., fences and other construction materials, fuelwood, food, medicinal plants, etc.) and for external demand.

(iii) *Diversify forest production through the development of new markets for non-wood products, and the increase in the value added of forest products at the harvesting site.*

Currently, 60 percent of timber extracted from villages is sold "standing" (Jardel 1989). Alternatives that might be considered here include the development of cooperatives for furniture production and other processing of forest resources. The creation of markets for non-wood products (nuts, fibers, rattan, etc.) from tropical forests is also urgently needed. In specific areas, increasing the recreational value of the forests (e.g., promoting eco-tourism) might also help to reduce deforestation. It should be noted, however, that the development of markets alone might actually lead to an increase in deforestation rates (Rye 1991). Quite clearly, such programs for non-wood exploitation depend on the promotion of diversified extraction simultaneously with measures to solve some of the "structural" problems (e.g., unless peasants themselves are assured fair competition with large producers and control over the production and commercialization of the extracted products).

(iv) *Eliminate direct and indirect subsidies to livestock production and reduce its comparative advantages against other less environmentally damaging economic activities.*

Livestock production is responsible for half of the area deforested annually in Mexico. In the past, the expansion of this activity was promoted through very large subsidies (Toledo 1987). While in the last years subsidies have been reduced, cattle ranching still offers peasants -- and large investors -- many comparative advantages (e.g., needs less monetary investment, provides better terms of trade and bears less risks than much agricultural production; provides the cheapest means of consolidating property rights; increases access to credit; involves a very low labor demand that complements other productive activities; serves as a source of savings and cash as cattle can be readily converted to cash (Janvry and García 1988). Until these comparative advantages are removed through adequate macro- and micro-policies, cattle ranching will continue its expansion in the forested areas.

(v) *Promote research and development on alternative bio-energy systems.*

Currently, most demand for wood products is in the form of fuelwood. The increasing fuel scarcity and the problems of extensive and rapid switching to LPG in rural households suggest that fuelwood use might make an increasing contribution to forest degradation in the future. If the conditions of fuelwood use are altered, biomass resources can come to represent an important and renewable source of energy for the rural sector in the long term. Basic elements in an alternative bio-energy strategy include: (a) disseminating more efficient wood-burning stoves in rural and peri-urban areas. Recent international experience in this area shows that through the active involvement of local people and sustained monitoring and evaluation, these programs can be highly successful (Cáceres 1989); (b) increasing access to supplies of fuelwood through agroforestry schemes; (c) facilitating fuel switching in urban areas. It has been shown that usually it is urban and not rural demand, that is responsible for deforestation (Joseph *et al.* 1991). Also it is in urban areas that access to liquefied petroleum gas (LPG) is more reliable; (d) improving the efficiency of fuelwood/charcoal combustion and/or encourage fuel switching to other fuels in rural industries. Bakeries, brick-making and other small industries are widespread in rural Mexico. Despite the fact that fuelwood demand for rural industries is usually more environmentally damaging per unit of consumption than that from household use, they have received scant attention within the country; (e) initiating strong research and development efforts on wood gasification, biomass cogeneration systems and related topics. The existing saw-mills and other forest industries may provide a good starting point for putting pilot projects into practice.

The above outlined actions would also have the side effect of drastically reducing (or even reversing) carbon emissions. Rather than setting carbon emission targets from the beginning, this strategy would also be socially sustainable, maximizing the probabilities of success.

At present, there are factors both favoring and undermining the sustainable management of forest resources within the country. On the positive side, the creation of new legislation aimed at regulating the use of forests and other natural resources (SEDUE 1988) provides a better framework for natural resource conservation. The increasing international consensus on the need to encourage the sustainable use of forest resources will also help to create a climate prone to resource conservation within Mexico. Hopefully, this will increase the international funds available for research and development on alternative forest management strategies.

On the negative side, the continual deepening of the economic and social crisis within the rural sector is an objective force against forest conservation. The social costs of the country's structural adjustment policies have been dramatic and, as shown by many case studies, have accelerated the depletion of natural resources. Only by assuring that the benefits of the expected economic recovery will reach the rural poor will alternative strategies succeed in the long term.

Industrialized countries, largely through multilateral lending institutions, also bear a responsibility for the deforestation process, especially by encouraging large development and cattle-ranching projects during the past decade.[8] Because it is also in their best interests to help maintain existing forest resources, they have the obligation to help solve the problem. Some key actions include facilitating funds for basic and applied research on alternative forest management systems, helping to establish international markets for non-wood exploitation and other measures.

7. CONCLUSIONS: RESEARCH NEEDS FOR FUTURE WORK ON CARBON EMISSIONS FROM DEFORESTATION

The results of this study suggest that about 53.4 MtC/yr were emitted in Mexico from deforestation and forest fires in closed (temperate and tropical) forests in the mid-1980s. Emissions arise from major perturbations to 804,000 ha/yr, which after substracting the area that regenerates from forest fires, leads to a net deforestation rate of 668,000 hectares per year or approximately 1.3 percent of total closed forests.

The development of long-term scenarios shows that the annual carbon balance from deforestation and forest fires will likely diminish in the long term (to 22.9 MtC/yr in the HES for 2025 and 16.5 MtC/yr in the LES for 2025) either because of the reduction in forested area or because of improved policies to reduce deforestation rates and increase carbon uptake. Net committed emissions would decrease by a much larger share, from 45.5 MtC in the base year to only 2.8 MTC in the HES and -21.7 MtC in the LES. Thus, if deforestation is completely stopped after 2025 Mexican forests could even become an important carbon sink. Cumulative carbon savings between the mid-1980s and year 2025 amount to approximately 2.6 GtC (as expressed by the difference in the forest's stored carbon between the LES and the HES).

Overall carbon emissions for Mexico, from forestry, energy and industry, amount to 105 MtC/yr (1.7 tC/capita). This figure, both in absolute and per capita terms, indicates that Mexico's

[8] During 1973 to 1977, for example, the World Bank and the Inter-American Development Bank allocated lending for cattle production in Mexico totalling US$527.4 million. This represented 48.7% of the total lending to cattle production in Latin-America (Toledo 1987).

contribution to global carbon emissions is among the highest for the developing countries (WRI 1990). Emissions are, however, still well below those from industrialized countries (AID 1990). The potential carbon savings, illustrated by the difference between the HES and the LES totals, amounts to 73 MtC/yr.

We have used the best available estimates and relied on primary sources as extensively as possible. Given the uncertainties of the different figures, however, the estimates need to be refined in subsequent analyses.

Priority future actions to improve the present work include:

A. Improving the basic data necessary for more accurate estimates of carbon emissions, such as:

1. Vegetation cover and deforestation rates. A new inventory on forest resources is urgently needed. Future estimates should use satellite imagery. The National Forest Inventory Office of Mexico in conjunction with the U.S. Department of Agriculture already have advanced the development of such a program (using remote-sensing imagery), which should allow for better estimates in the near future.

2. Establish a sustained monitoring program of forest coverage and its temporal patterns and trends. Particularly important will be the determination of the impact of each conversion activity on changes in forest cover.

3. More extensive and reliable estimates on forest biomass and carbon parameters. Given the budget constraints in Mexico, it is important to investigate the possibilities of obtaining most of these estimates by incorporating the required measurements into existing programs of forestry research such as floristic inventories, ecosystem studies, ecophysiological investigations, etc. The existing large databases on tree morphometric measurements in the country also should be used to carry out regression analysis in order to estimate biomass parameters.

B. Conduct research on alternative forest management strategies, by means of:

1. Collecting extensive information on economic and financial costs (including environmental externalities) of different forest management options.

2. Getting data from existing successful experiences on alternative management schemes, both for tropical and temperate forests.

3. Determining the potential area for reforestation by taking into account ecological characteristics and actual and potential competing uses.

Finally, an important objective for future research on carbon emissions should be to achieve a better integration of analyses of emissions from deforestation and those from other economic sectors. This integration will facilitate an assessment of the relative merits and/or costs of different carbon-saving measures from different sectors (e.g., through energy efficiency, improved forest management, etc.) and allow the various measures to be consolidated into a common framework.

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APPENDIX: ESTIMATES OF LAND-USE PATTERNS IN MEXICO

Table A-1 presents available estimates of land-use patterns in Mexico. For every forest type a range of variation between 50 percent and 100 percent in vegetation cover estimates is common. The main sources of discrepancy among the sources include: (a) differences in the criteria used to classify the major vegetation types. Particularly diverging among sources is the definition of grasslands, scrublands, deciduous tropical forests and areas for livestock production; for temperate forests, most discrepancies arise from the assignment of mixed "pine-oak" forests sometimes to broadleaf (Flores and Gerez 1988; SPP 1980) and sometimes to coniferous forests (SARH 1986; Castillo 1989); (b) differences in the objectives of the studies; some sources divide the country area by "potential" vegetation types (Garcia 1991); others distinguish between potential and perturbated vegetation (Flores and Gerez 1988) -- the ambiguities in the definitions of what is considered "perturbated" vegetation makes it difficult to ascribe these areas to other land uses; studies oriented towards forest exploitation do not report land devoted to agriculture, cattle ranching, etc. (Castillo 1989; SARH 1986), while those aimed at determining the potential for agricultural/pasture lands do not accurately disaggregate forests by types (COTECOCA 1984).

Above all, the lack of a recent comprehensive inventory on land-use patterns contributes to the imprecision of estimates.

Our own estimates were developed as follows: (i) state-wise estimates on land-use patterns by COTECOCA (1984) were used as the primary source; (ii) refinements of these estimates -- which included partitioning tropical forests into tropical evergreen and deciduous, and temperate into coniferous and broadleaf, partitioning the reported area for "livestock production" into actual livestock production, open forests and deciduous forest, etc. -- were done through Toledo *et al.* (1989), Synnott (1988), case studies and field experience for tropical evergreen forests; Toledo *et al.* (1989) and Toledo (1990) to partition "livestock production" among open forests, tropical deciduous forests and area devoted to livestock production; and SARH (1986) to determine the area covered by temperate broadleaf forests. Our final estimates are presented in the last column of Table A-1.

Table A-1. Current estimates of land-use patterns in Mexico

Land use	Area (10^3 ha)							
	Flores 1988	Garcia 1991	SARH 1986	Toledo 1989	SPP 1980	COTECO CA 1984	Castillo 1989	This study
Tropical forests	29,173	40,959	29,300	26,274	29,434	12,680	27,960	25,823
- Tropical evergreen	10,308	7,451	2,100	11,696	11,797		1,990	1,648
- Tropical semi-evergreen	1,318	3,560	9,300	e			8,900	8,050
- Tropical deciduous	17,547	25,078	17,900	14,578	17,637		17,080	16,125
- Thorny tropical	a	4,870	d	f				
Temperate forests	23,586	33,697	27,500	17,178	24,077	25,751	26,670	25,753
- Temperate coniferous	10,269	c	18,700	16,822	10,656		18,300	16,974
- Temperate broadleaf	13,318	c	8,800		13,421		8,440	8,780
- Cloud forests	a	771	b	356				
Scrublands	20,695	58,572	67,500		23,711			31,130
Grasslands	21,639				6,819			
Livestock production	g	n.a.		23,528		124,694		79,916
Agriculture	25,967	n.a.		27,542		26,864		27,367
- Rainfed	19,082	n.a.				21,059		
- Irrigated	6,885	n.a.				5,805		
Other uses						6,729		6,729
Total perturbated			17,837	78,844	68,444			
Total reported	190,697	133,228	142,137	156,188	152,485	196,718	54,640	196,718

Notes: a. Included within tropical deciduous forests
b. Included within coniferous forests
c. Included within temperate forests
d. Included within scrublands
e. Included within tropical evergreen forests
f. Included within tropical deciduous forests
g. Included within grasslands and scrublands

REFERENCES

Atipanumpai, L. 1991. Kasetsart University, Bangkok, Thailand [personal communication].

Altieri, M. 1988. Sistemas Agroecologicos Alternativos para la Produccion Campesina. In *Desarrollo Agricola y Participacion Campesina*. CEPAL, Santiago de Chile, pp. 263-276.

Banco de Mexico. 1991. *Indicadores Economicos Sector II, Nov. 1989 - June 1991*. Banco de Mexico, Mexico City.

Bongers, F. and J. Popma. 1988. *Trees and Gaps in a Mexican Tropical Rain Forest: Species Differentiation in Relation to Gap Associated Environmental Heterogeneity*. Ph.D. Thesis. Department of Plant Ecology, Utrech University.

Bray, D. 1991. The Forests of Mexico: Moving from Concessions to Communities. *Grassroots Development* 15(3):10-17.

Briones Villareal, O. Sobre la Flora, Vegetación y Fitogeografía de la Sierra de San Carlos, Tamaulipas. *Acta Botánica* (in press).

Cáceres, R. 1989. *Stoves for People*. Intermediate Technology Publications, Foundation for Woodstove Dissemination, The Center for Mesoamerican Studies on Appropriate Technology, London.

Cámara Nacional de la Industria Forestal (CNIF). 1991. *Memoria Económica 1990-91*. CNIF, Mexico City.

Caro, R. 1987. *Caracterización de la Industria Maderable en el Area de Influencia de la UAF No.6 "Meseta Tarasca."* Eng. Thesis. Universidad Nicolaíta San Nicolás Hidalgo, Uruapan, Mexico.

Caro, R. 1990. La problemática Forestal en la Meseta Tarasca. Presented at Los Problemas Medio-ambientales de Michoacán. El Colegio de Michoacán, Zamora, Mexico, June 7.

Castillo, P.E., P. Lehtonen, M. Simula, V. Sosa and R. Escobar. 1989. *Proyecciones de los Principales Indicadores Forestales de Mexico a Largo Plazo (1988-2012)*. Internal Report, Subsecretaria Forestal, Cooperation Project Mexico-Finland, SARH, Mexico City.

Comisión Técnico Consultiva de Coeficientes de Agostadero (COTECOCA). 1984. *Distribución del Uso del Suelo en las Entidades de la República Mexicana*. Internal report. COTECOCA-SARH, Mexico City.

COTECOCA. 1990. *Delimitación de los Trópicos Húmedo y Seco de México por medio de los Tipos de Vegetación*. Internal report. COTECOCA-SARH, Mexico City.

Cortez-Ortiz, A. 1990. *Estudio Preliminar sobre Deforestación en la Región Fronteriza del Río Usumacinta*. Internal report. INEGI, Mexico City.

Cuarón, A. 1991. *Conservación de los Primates y Sus Habitats en el Sur de México*." Master Thesis. Sistema de Estudios de Posgrado, Universidad Nacional, Heredia, Costa Rica.

Cannell, M.G.R. 1982. *World Forest Biomass and Primary Production Data*. Academic Press, New York.

Cannell, M.G.R. 1984. Biomass of Forest Stands. *Forest Ecology & Management* 8:299-312.

De Ita, C. 1991. Land-use Patterns on a Tropical Deciduous Forest Ecosystem on the Pacific Coast of Jalisco, Mexico. *Agroforestry* (in press).

Dirzo, R. and C. García. 1991. Rates of Deforestation in Los Tuxtlas, a Neotropical Area in South-east Mexico. *Conservation Biology* (in press).

Dirzo, R. and P. Raven. 1991. Inventario Biológico de los Recursos Naturales de México. Submitted to *Ciencia*.

Duran García, R. 1986. *Estudio de la Vegetación de la selva baja subcaducifolia de Pseudophenix sargentii*. Biol. Thesis. Facultad de Ciencias, UNAM, Mexico City.

Food and Agriculture Organization (FAO). 1988a. *An Interim Report on the State of Forest Resources in the Developing Countries*. Forest Resources Division, Forestry Department, FAO, Rome.

Food and Agriculture Organization (FAO). 1990. *Evaluación de los Recursos Forestales de 1990: Informe de México*. FAO, Mexico City.

Flores Villela, O. and P. Gerez. 1988. *Conservación en México: Síntesis sobre Vertebrados Terrestres, Vegetación y Uso del Suelo*. Instituto Nacional de Investigaciones sobre Recursos Bióticos-Conservación Internacional, Mexico City.

García, M.C. 1991. Estado de los Componentes Naturales del Medio Ambiente. In: *Atlas Nacional de Mexico*. Instituto de Geografía, UNAM, Mexico City (in press).

García-Rendon, M. 1988. *Distribución y Estructura de las comunidades arbóreas del Parque Ecológico Estatal Omiltemi, Gro*. Biol. Thesis. Facultad de Ciencias, UNAM, Mexico City.

Gómez-Pompa, A. 1985. *El Problema de la Desforestación en el Trópico Mexicano*. Presented at IX Congreso Forestal Mundial. SARH-FAO, July, Mexico City.

Gobierno del Edo de México, Secretaría de Desarrollo Agropecuario, Protectora e Industrializadora de Bosques. 1990. *Segundo Estudio Dasonómico, Cifras Forestales Básicas, Primera etapa julio 1985-agosto 1989.* Internal report. Gobierno del Estado de México, Toluca, Mexico.

Guzman O., A. Yunez-Naude and M. Wionczeck. 1985. *Uso Eficiente y Conservacion de la Energía en México: Diagnóstico y Perspectivas.* El Colegio de Mexico, Mexico City.

Hao, W.M., M.H. Liu, and P.J. Crutzen 1990. Estimates of Annual and Regional Release of CO_2 and Other Trace Gases to the Atmosphere from Fires in the Tropics. In Goldammer J.G. (ed.), *Fire in the Tropical Biota*, Ecological Studies, Berlin: Springer-Verlag.

Holdridge, L.R. 1987. *Ecología Basada en Zonas de Vida.* Instituto Interamericano de Cooperación para la Agricultura, San José, Costa Rica.

Houghton, R. 1990. The Future Role of Tropical Forest in Affecting the Carbon Dioxide Concentration of the Atmosphere. *Ambio* 19(4):204-209.

Instituto Nacional de Estadística Geografía e Informática (INEGI). 1990. *Resultados Preliminares IX Censo General de Población y Vivienda 1990.* INEGI, Mexico City.

Janvry, A. and J. Garcia. 1988. *Rural Poverty and Environmental Degradation in Latin America: Causes, Effects and Alternative Solutions.* Presented at the International Consultation on Environment, Sustainable Development and the Role of Small Farmers. International Fund for Agricultural Development, Rome, October 11-13.

Jardel, E. 1989. *Politica Forestal, Conservación y Aprovechamiento de los Recursos Forestales de México.* Presented at IX Seminario de Economía Agrícola del Tercer Mundo. Instituto de Investigaciones Económicas, UNAM, Mexico City.

Joseph S., K. Krishna Prasad and H.B. van der Zaan (eds). 1990. *Bringing Stoves to the People.* Foundation for Woodstove Dissemination- Act Press, Nairobi, Kenya.

Ketoff, A., J. Sathaye and N. Goldman (eds). 1990. *CO_2 Emissions from Developing Countries: Better Understanding the Role of Energy in the Long Term. Volume II: Argentina, Brazil, Mexico and Venezuela.* LBL Report 30059, Lawrence Berkeley Laboratory, Berkeley, California.

Krause, F., W. Bach and J. Koomey. 1989. *Energy Policy in the Greenhouse.* International Project for Sustainable Energy Paths (IPSEP), El Cerrito, California.

MacNeely, J.E., K.R. Miller, W.V. Reid, R. Mittermeier and T.B. Werner. 1990. *Conserving the World's Biological Diversity.* IUCN, WRI, CI, WWF-US, The World Bank, Washington, D.C.

Makundi, W. and J. Sathaye 1992. *Carbon Emission and Sequestration in Tropical Forests: A Comparative Analysis Using Country Studies.* Summary Report of the Research Network on Tropical Forestry and Global Climate Change, International Energy Studies, Lawrence Berkeley Laboratory, Berkeley, California, May 1992.

Makundi, W., J. Sathaye and A. Ketoff. 1991. *COPATH: A Spread-sheet Model for Estimating Carbon Flows Associated with Tropical Forest Use.* Presented at the International Workshop on Tropical Forestry and Global Climate Change: Landuse Policy, Emissions and Sequestration. Lawrence Berkeley Laboratory, Berkeley, California, May.

Martínez-Yrizar *et al. Above-ground Phytomass of a Tropical Deciduous Forest on the Coast of Jalisco, Mexico* (in press).

Masera, O. 1990. *Sustainable Energy Scenarios for Rural Mexico: An Integrated Evaluation Framework for Cooking Stoves.* Masters of Sciences Thesis. University of California, Berkeley.

Mendoza, Y., O. Masera and P. Macías. 1991. Long-Term Energy Scenarios for Mexico: Policy Options for Carbon Savings and Main Barriers. *Energy Policy* 10(19):962-969.

Miranda, F and E. Hernández-X. 1963. Los Tipos de Vegetación de México y Su Clasificación. *Soc. Bot. de México.* 28:29-179.

Myers, N. 1983. *A Wealth of Wild Species: A Storehouse for Human Welfare.* Westview Press, Boulder, Colorado.

Myers, N. 1989. *Deforestation Rates in Tropical Forest and their Climatic Implications.* Friends of the Earth, London.

Nieto de Pascual Pola, M.del C. 1987. *Análisis Estructural y composición Forestal de la Sierra del Ajusco.* Biol. Thesis. Facultad de Ciencias, UNAM, Mexico City.

Ordóñez, M.J. 1990. *Areas Naturales Protegidas de México.* Presented at Seminario Ecología para la Comunicación. Centro de Ecología, UNAM, Mexico City, September 1990.

Repetto, R. 1988. *The Forest for the Trees? Government Policies and the Misuse of Forest Resources.* World Resources Institute, Washington, D.C.

Rye, J.C. 1991. Goods from the Woods. *World Watch Paper.* July-August 1991:19-26

Rzedowski, J. 1978. *Vegetación de México.* Limusa, Mexico City.

Rzedowski, J. 1991. Diversity and Origins of the Phanerogamic flora of Mexico. In T.P. Ramamoorthy *et al* (eds). *Biological Diversity of Mexico: Origins and Distribution.* Oxford University Press, New York.

Sanabria, O. 1986. El Uso y Manejo Forestal en la Comunidad de Xul, en el Sur de Yucatán. *Etnoflora Yucatanense* 2.

San Rafael. 1985. *Plan de Ordenación Forestal, Tomo II.* Internal report. San Rafael, Mexico City.

Secretaria de Agricultura y Recursos Hidraulicos (SARH). 1981-89. *Mexico Forestal: Avances de la Produccion Maderable y No Maderable.* SARH, Mexico City.

SARH. 1984. *Comision del Plan Nacional Hidraúlico 1984.* Desarrollo Rural Integral de la Selva Lacandona, Mexico; cited in *Desarrollo y Medio Ambiente en México: Diagnostico 1990.* Fundacion Siglo Veintiuno, Mexico City.

SARH. 1985. *Inventario Forestal del Estado de Oaxaca.* Publicación especial No.58. SARH, México City.

SARH, Subsecretaría de Desarrollo y Fomento Agropecuario y Forestal, Subdirección del Inventario Nacional Forestal. 1986. *Información Forestal de la República Mexicana.* SARH, Mexico City.

SARH. 1989a. *Proyecto Forestal Oaxaca-Guerrero, Mexico-Finlandia.* Internal report. SARH, Mexico City.

SARH. 1989b. *Incendios Forestales, Resultados 1989.* SARH, Mexico City.

SARH. 1990. *Tabla de Datos sobre Perturbacion Forestal Anual 1990.* Internal report. SARH, Mexico City.

SARH. 1991a. *Integración del Programa Nacional de Reforestación. Tema: Recursos Forestales.* Internal report. Subsecretaría Forestal, Dirección General de Política Forestal, SARH, Mexico City.

SARH. 1991b. *Información sobre Incendios Forestales, Reforestación, Aprovechamientos Forestales y Permisos de Aprovechamientos Forestales de Chihuahua.* Internal report. Subdelegación Forestal de Chihuahua, Chihuahua, Mexico, March 1991.

Sarukhan, K.J. 1968. *Análisis sinecológico de las selvas de Terminalia amazonia en la Planicie Costera del Golfo de México.* Thesis. Colegio de Posgraduados, Escuela Nacional de Agricultura, Chapingo, Mexico.

Secretaria de Desarrollo Urbano y Ecologia (SEDUE). 1988. *Ley General del Equilibrio Ecologico y la Proteccion al Ambiente*. SEDUE, Mexico City.

SEDUE. 1989. *Información Básica sobre las Areas Naturales Protegidas de México*. SEDUE, Mexico City.

Secretaría de Programación y Presupuesto (SPP) 1980. Carta de Vegetación y Uso del Suelo. In: *Atlas Nacional del Medio Físico*. SPP, México City.

Synnott, T.J. 1988. *Conservación de Ecosistemas Forestales Tropicales en el Sur-Este de México*. Internal report P.A.F.T. 1988-2000. Mexico City, October 1988.

Toledo, V.M. 1987. Vacas, Cerdos, Pollos y Ecosistemas. *Ecología, Política/Cultura* 3:36-49.

Toledo, V. M., J. Carabias, C. Toledo and C. González-Pacheco. 1989. *La Producción Rural en México: Alternativas Ecológicas*. Fundación Universo Veintiuno, Mexico City.

Toledo, V.M. 1990. El Proceso de la Ganaderización y la Destrucción Biológica y Ecológica de México. In E. Leff (ed.), *Medio Ambiente y Desarrollo en México* 1:191-22.

Tudela, F. 1990. Recursos Naturales y Sociedad en el Trópico Húmedo Tabasqueño. In E. Leff (ed.), *Medio Ambiente y Desarrollo en México* 1:149-190.

World Resources Institute (WRI). 1990. *World Resources 1990-91*. Oxford University Press, New York.