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Mexico

Critical Analysis of the Current Deforestation Rate Estimates

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Acronyms, Abbreviations, and Glossary

ASERCA	*Apoyos y Servicios al Campo*
AVHRR	Advanced Very High Resolution Radiometer
BIOFOR	Biodiversity and Forestry
DR	deforestation rate
ETM	Enhanced Thematic Mapper (of Landsat)
FAO	Food and Agriculture Organization (of the United Nations)
FRA	Forest Resource Assessment (of the FAO)
GIS	geographic information system
ha	hectare
HRPT	High Resolution Picture Transmission (of AVHRR and SeaWiFS)
IGBP	International Geosphere-Biosphere Program
IMTA	*Instituto Mexicano de Tecnología del Agua* (of SEMARNAT)
INEGI	*Instituto Nacional de Estadistica Geografia e Informatica* (National Institute of Statistics and Geography)
INFOR	a generic term for the national forest inventory of Mexico, SEMARNAT
Landsat	a land remote sensing satellite (not an acronym)
Look-up table	a table of equivalencies that defines the relation between classes of two map legends
LU/LC	Land Use/Land Cover
MODIS	Moderate Resolution Imaging Spectroradiometer
MSS	Multispectral Scanner (of Landsat)
NDVI	Normalized Difference Vegetation Index
SARH	*Secretaría de Agricultura* (now SEGARPA)
SeaWiFS	Sea-Viewing Wide Field of View Sensor
SAGARPA	*Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación* (Ministry of Agriculture)
SEMARNAP	now SEMARNAT
SEMARNAT	*Secretaria de Medio Ambiente y Recursos Naturales* (Environment and Natural Resources Ministry)
TM	Thematic Mapper (of Landsat)
UN	United Nations
UNAM	*Universidad Nacional Autonoma de Mexico* (National Autonomous University of Mexico)
UNFCCC	UN Framework Convention on Climate Change
USAID	United States Agency for International Development
WRI	World Resources Institute

1. Background and Overview

As part of Mexico's National Crusade for Forests, the *Secretaría del Medio Ambiente y Recursos Naturales* (SEMARNAT, the Environment and Natural Resources Ministry) was asked to determine the deforestation rate in Mexico so that the government may begin the process of determining how to address the problem. SEMARNAT announced the official deforestation rate in November of 2001. However, SEMARNAT is interested in establishing a procedure to measure national deforestation consistently and reliably.

Current estimates for the deforestation rate range from 75,000 hectares per year to more than 1.98 million hectares per year. This range of estimates reflects differences of purpose to which the information is to be used, variations in the estimates of the baselines, and differences in the time frames for which the estimates were calculated. The range also reflects variations in the methods and models used to compute the estimates.

The Government of Mexico requested assistance from the United States Agency for International Development (USAID) to help develop a consistent methodology for estimating future deforestation rates. ARD, Inc., in association with Grupo Darum, was selected to carry out this assistance through the Biodiversity and Forestry (BIOFOR) Indefinite Quantity Contract managed by USAID/Washington. This document represents one component of that assistance. It reviews the definitions of "forest" and of "deforestation" and discusses how and why different definitions result in different estimates. It also reviews the various estimates of the rate of deforestation in Mexico to identify key limitations and methods to address them.

Forest management, biodiversity conservation, environmental protection, and many other concerns necessarily mean that many government agencies and institutions have an interest and stake in the determination of deforestation rates for Mexico. For this reason, it is critical that any recommendations made as a result of the USAID technical assistance are thoroughly considered and vetted by each of these stakeholders. The Government of Mexico furthermore wants to establish an ongoing process through which such analyses can continue, ensuring a broad-reaching effort to build consensus among all the stakeholders working on these issues. This is being done through a series of workshops and individual consultations, from which all the important decisions and recommendations are developed. This document contains preliminary recommendations resulting from the first of this series of workshops held in November 2001 and the individual consultations held over the last several months. The November 2001 workshop represents the first step in establishing an open and transparent process through which stakeholders can continue to build consensus on how to address the complex set of issues surrounding the development of accurate and credible deforestation rates for the country.

2. Definitions of "Forest" and of "Deforestation"

In its broadest interpretation, deforestation is the removal of "forest." If it is assumed that one can only deforest an area that is considered forested, then in order to understand how "deforestation" is defined, one must also consider the definition of "forest."

2.1 Definition of "Forest"

There is no single correct definition for the term "forest" (or "forestland"). The definition chosen will depend on the **purpose** for which the information is to be used. Internationally accepted definitions of "forest" respond to three general purposes:

- ecological functions and biological diversity,
- environmental protection and carbon storage (or "sequestration"), and
- wood and fiber production.

Each of these requires that the term "forest" be defined in a different way.[1] In the first case, only naturally occurring[2] tree-covered lands may be defined as "forest" since only they sustain a rich diversity of flora and fauna. Orchards and tree plantations would not be considered "forest" for this purpose. On the other hand, for purposes of environmental (soil, water, air) protection and for carbon sequestration, both naturally occurring forests, and orchards and plantations may be defined as "forest," since both contribute to environmental protection and carbon sequestration. For wood and fiber production, "forest" may be defined as *any* tree-covered lands available for wood harvesting, along with non-tree-covered lands that can be brought into production.

Thus, some definitions of "forest" incorporate parameters having to do with human activity or intent ("land use"), while others reflect only those having to do with land cover. Land cover and land use may be differentiated as follows.

- **Land cover** is a biophysical description of the earth's surface. It is that which overlays or currently covers the ground.
- **Land use** is the purpose to which humans put land (e.g., protected areas, forestry for timber products, plantations, row-crop agriculture, pastures, human settlements).[3]

Figure 1 illustrates the difference in interpretation between a definition based on land cover and one based on land use. This image shows Virginia Cedar or Eastern Redcedar (*Juniperus Virginiana*) invading a pasture. Is this forestland?[4]

- **From a land cover perspective**, it would probably not be considered as forest. However, some land cover-based definitions set the thresholds (see below) for trees once they reach maturity. In that case, the land cover could be considered as "forestland."

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1 In Spanish, the term "forest" translates as *bosque* and it has a more limited connotation than the English term. *Bosque* does not include rain forest, mangrove, or desert forest. For this paper, "forest" will be translated as *terrenos forestales.*

2 Not planted or sown by humans.

3 Turner and Meyer, 1994.

4 By some published definitions, this scene shows a native, natural, virgin, protected forest. Virginia Cedar is native to the area, the trees have come in naturally, the trees have not been cut (hence they are virgin), and there is a fence around the area (protected).

- **From a land use perspective**, if the landowner says the land is forest, then it is, even though the trees are very small or may not even exist at all. One cannot infer the landowner's intentions simply by looking at the image.

Figure 1: Invading Cedar

Many of the most commonly used definitions of "forest" combine land cover and land use. In these cases, some areas without trees may be included as forests while other areas with trees (such as orchards) may not be included as forests. Some definitions specify that the land must be used for forestry purposes in order to qualify as "forests."

Two major United Nations (UN) efforts have yielded international definitions of "forest" for purposes of global reporting and country comparisons. The Food and Agriculture Organization's (FAO's) various assessments were directed towards forest production and now include biological diversity aspects. The FAO definition of "forest" includes both "natural forest" and "forest plantations" but specifically excludes stands of trees established primarily for agricultural production, for example, fruit tree plantations. It also excludes trees planted in agroforestry systems. The UN Framework Convention on Climate Change (UNFCCC) and its associated Kyoto Protocol focuses on carbon sequestration. Since no exclusions are listed in the definition, plantations, orchards, and even urban areas may be included. Both the FAO and the UNFCCC define "forest" in terms of land use. In both definitions, areas without trees (i.e., "unstocked") can be considered "forest" if the areas are expected to revert to forest. Timber companies often consider only lands that can be used to grow commercial forest products as "forest" land. Similarly, the U.S. Forest Service's definition of "timber land" is "land that is producing, or capable of producing, in excess of 20 cubic feet per acre per year of industrial roundwood products, and is not withdrawn from timber utilization by statute or administrative regulation." This definition would include some natural forests and some forest plantations, but alone would have limited use for purposes of either biodiversity or carbon sequestration.

For purposes of enumerating forested areas, **key thresholds** are also specified. These often include minimum values for area, tree cover, tree height, and strip width. In other words, a "tree-covered area" is defined as an area greater than X hectares in size, with woody perennials at least Y meters tall, a crown closure (or canopy cover) of at least Z percent, and a minimum strip width of W meters (i.e., excluding narrow forested areas such as wind breaks and riparian buffer zones).

Application of such thresholds is necessary to ensure consistent, objective results. For example, FAO's 1990 *Forest Resource Assessment* (FRA 1990) defined the canopy cover threshold at 10 percent for developing countries and 20 percent for industrialized countries. With FRA 2000, the FAO applied a uniform definition of 10 percent to all countries. The result was an "on paper" increase in the estimated global forest area of 400 million hectares relative to the 1995 (FAO, 1997d) value.[5]

Thresholds used in national estimates vary from 0.01 to 100 hectares for minimum area, one to 80 percent for crown cover, 1.3 to 15 meters for tree height, and nine to 50 meters for strip widths (Table 1).

Table 1: Low and High Thresholds Used by Various Nations (Lund 2001b)

Threshold	Lowest threshold	Countries	Highest threshold	Countries
Area (ha)	0.01	Belgium, Northern Mariana Islands	100	Papua New Guinea
Crown cover (%)	1	Iran	80	Malawi, Zimbabwe
Tree height (m)	1.3	Estonia	15	Zimbabwe
Strip width (m)	9	Belgium	50	Liechtenstein, Taiwan, UK

In summary, the term "forest" should be defined first based on the purpose for which the information is to be used; then in terms of land cover, land use, or a combination of the two; and finally in reference to key thresholds:

Purpose
Land use, land cover, or combination
Key thresholds (W, X, Y, Z)

It is critical that the objective for a particular forest area estimate be understood—estimates made for one purpose may be misleading when applied to another.

Forest Definitions: Advantages and Limitations

While the definition of "forest" should be in terms of the purpose for which the information is to be used, other factors can influence the choice of definition. For instance, applying a land cover definition is easier and less costly to implement than one based on land use. Measurements of land cover may be made from remotely sensed data, aerial photography, "windshield" surveys, or other inexpensive means. Measurements of land use may or may not relate to what one can observe from a distance—they also depend on the intent of the land owner, which may be difficult to assess. At the same time, a land use definition has advantages for planning—one knows how the land is expected to be managed in the future. Oftentimes the definition of "forest" that one selects depends not only on the intended use, or purpose, but also on the ability to gain the required information.

The choice of thresholds must be linked to needs and anticipated data sources. The lower the thresholds, the more lands are likely to be included as "forest." Raising the thresholds will increase the cost due to increased data collection and interpretation needs. If one anticipates using satellite imagery, thresholds

5 The effect is significant for some countries, such as Australia. The estimate for Australia's forest area in 2000 was 155 million hectares, compared with 41 million hectares in 1995, in part because the 2000 estimate included large expanses of sparsely stocked forests that previously had been classified as "other wooded land."

may be constrained by the limitations of a particular sensor, and the choice of sensor is often based as much on budget restrictions as it is on information needs.

2.2 Definition of "Deforestation"

Once the term "forest" has been defined in terms of type and key thresholds, then "deforestation" may be defined as the removal of that forest below the predetermined thresholds. An additional criteria for defining "deforestation" may be that the removal of the forest must be "by humans" to be considered deforestation. For example, the Kyoto Protocol specifies that a land use change has to be "human induced" in order to be defined as "deforestation." In this case, areas that have been denuded of trees because of natural disturbances (e.g., windstorms, volcanic eruptions, fires, or floods) would not be considered as deforested.

Definitions used in national estimates for deforestation vary just as definitions of "forest" vary. Table 2 shows national deforestation definitions by type for a few representative countries. In some cases, there is more than one definition that is commonly used in a country.

Table 2: National Deforestation Definitions by Type for Selected Countries (Lund 2001a)

Country	Removal of land cover	Change in land use	Removal of land cover and change in land use
Bolivia	Yes		
Canada	Yes		Yes
France	Yes		
India			Yes
Italy		Yes	
Malaysia		Yes	
Morocco	Yes		
Nepal	Yes		
Northern Mariana Islands	Yes		
Pakistan			Yes
Papua New Guinea			Yes
Romania	Yes		
Saint Lucia	Yes		
Taiwan (R.O.C.)	Yes		
Thailand	Yes		
Venezuela	Yes		
United Nations	Yes	Yes	

As with the definition of "forest," the definition of "deforestation" must be understood within the context of the purpose for which it is measured. Comparing deforestation rates measured for different purposes can be just as misleading as comparing forest area estimates measured for different purposes. For example, change from an open natural forest to an orchard may result in the same amount of tree cover, but different land use.

Deforestation Definitions: Advantages and Limitations

If "forest" is defined as a land use, "deforestation" is a change in land use and cover does not have to change. If "forest" is defined in terms of a land cover, "deforestation" is the removal of tree cover that reduces it below certain thresholds. Definitions based solely on changes in land cover have the strengths of being easy to determine and understood by the general public. A general weakness is that such definitions may lead the public to overreact to changes that are merely temporary due to land management treatments.

2.3 Summary of Definitions

The term “forest” is defined in terms of the purpose to which the estimate is to be used, and depending on the purpose, in terms of land cover, land use, or some combination of the two, and quantified according to key thresholds. The term “deforestation” is then defined in terms of the removal of forest below those thresholds, and sometimes according to whether or not the removal was “human induced.” Table 3 summarizes these definitions.

Table 3: The Definitions of “Forest” and “Deforestation” (adapted from Lund 2001a)

If primary concern is:	“Forest” will be defined in terms of:	And “deforestation” will be defined in terms of:
Ecological functions and biological diversity preservation	“Naturally” occurring tree-covered lands (not planted or sown by humans) above predetermined thresholds	Removal of tree cover below predetermined thresholds
Environmental (soil, water, air) protection and carbon sequestration	All tree-covered lands above certain predetermined thresholds	Removal of naturally occurring tree cover below predetermined thresholds by humans
Wood and fiber production	All “available” (wood removals permitted) tree-covered lands as well as available and capable non-treed areas	The removal of tree cover below predetermined thresholds and the shift from an available classification to an unavailable classification

It is unlikely that all stakeholders in Mexico will be able to come to consensus on a single definition for “forest” or “deforestation.” In fact, it is not desirable that they do so. As described in this section, it is normal to have multiple definitions for multiple purposes, and for multiple reporting requirements. Rather than a single definition of “forest,” multiple classes of land areas (land use, land cover, or combinations of the two) can be identified, and changes of those classes monitored over time. This approach is discussed in more detail in Annex A.

3. Deforestation Rate Estimates in Mexico

Just as internationally accepted definitions of "forest" and "deforestation" vary according to their purpose, so do Mexico's definitions. For example, Mexico's second national forest inventory[6] defined "forest cover" as "spontaneous natural vegetation" that covers an area at a specific point in time, a useful definition for the purpose of conserving ecosystems. The *Universidad Nacional Autonoma de Mexic*o (UNAM) bases its definitions on floristic composition, which is useful from a biodiversity perspective. UNAM and the *Instituto Nacional de Estadistica Geografia e Informatica* (INEGI) distinguish between temperate forest (*bosque*) and tropical lowland forest (*selva*), but subcategories of these are defined differently. Tables A.2 and A.3 at the end of Annex A list the definitions of "forest" and "deforestation" used in Mexico. The Forestry Law specifies some thresholds (e.g., canopy cover greater than 10 percent, areas greater than 1,500 hectares in extent), but in most inventories and land use/land cover (LU/LC) mapping, certain key thresholds are not defined.

Annex B summarizes almost 40 different estimates of deforestation rates in Mexico that were published between 1978 and 2001. Figure 2 shows some of these values. Estimates of deforestation rates in Mexico range from 75,000 hectares per year[7] to over 1.98 million hectares per year.[8] As discussed in Section 2,

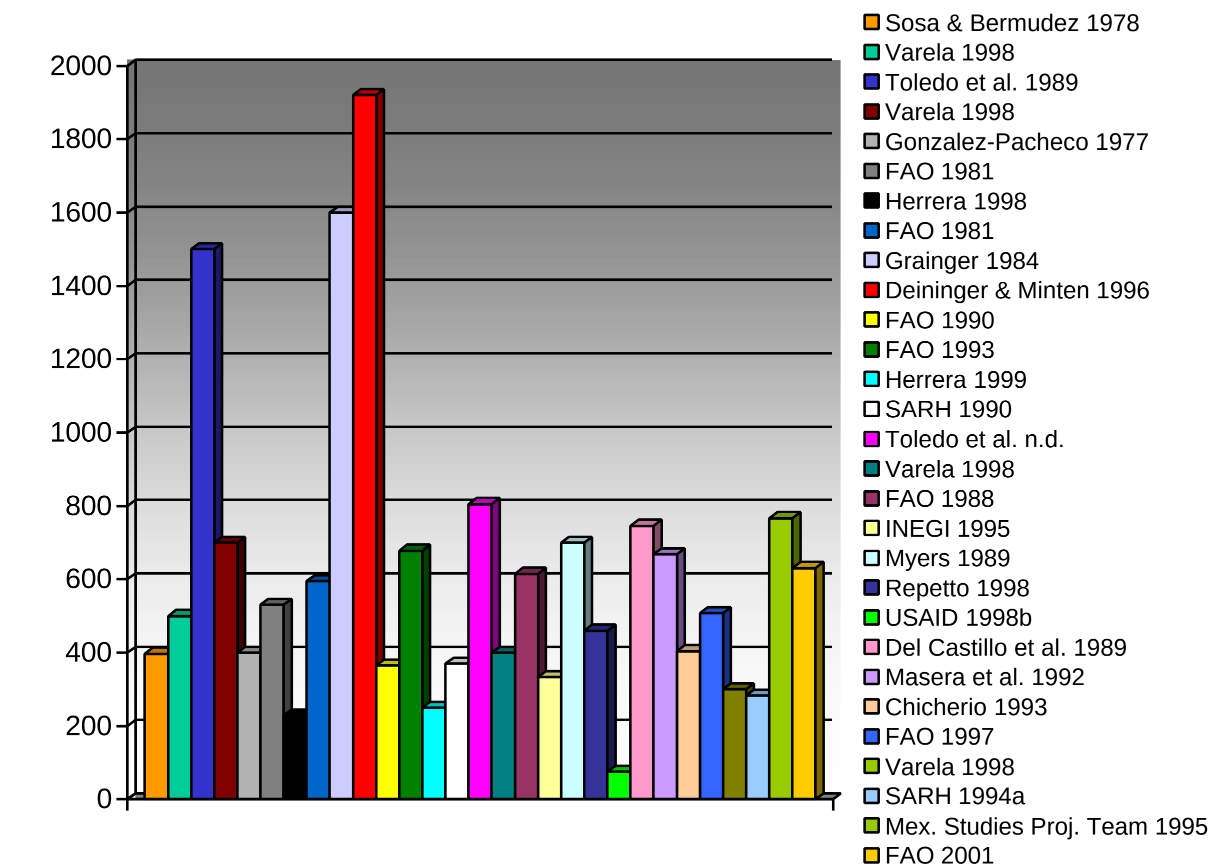

Figure 2: Estimates of Deforestation Rates in Mexico (000 hectares)

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6 SARH 1994a.

7 USAID, 1998b.

this range of estimates reflects differences among the studies regarding the purpose for which the information was to be used. This range also reflects variations in the estimates of the baselines—the underlying amount of forest (see Figure 3)—and the time frames for which the estimates were calculated (see Figure 4), as well as variations in the methods and models used. This latter issue will be discussed in more detail in Section 4.

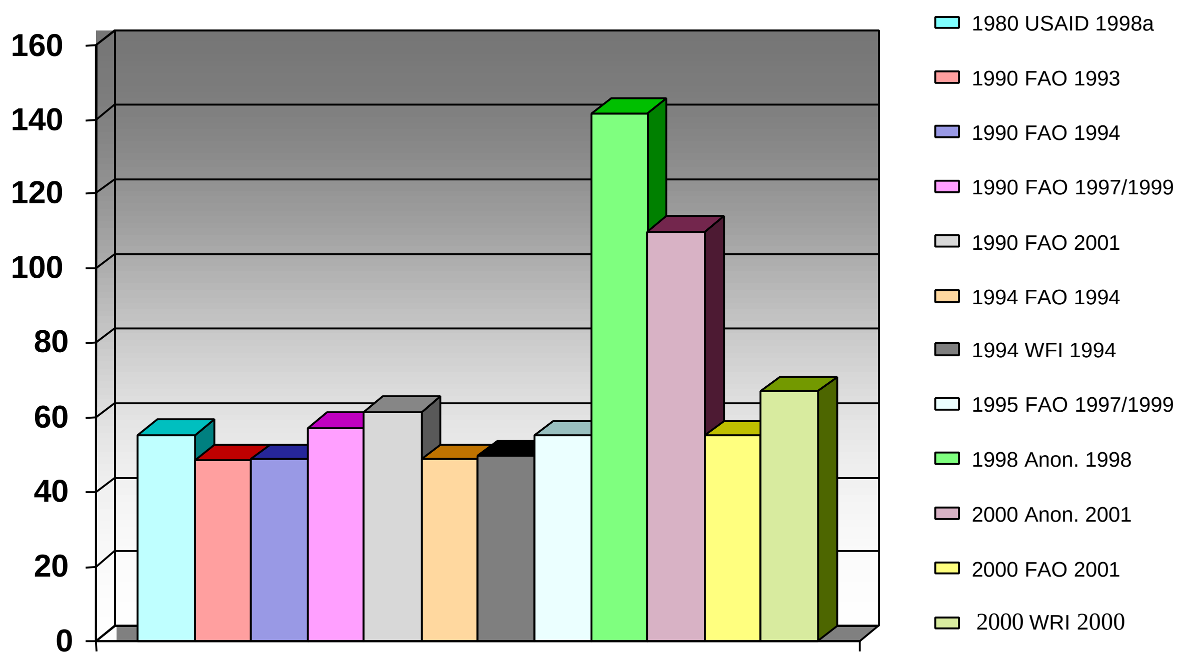

Figure 3: Recent Estimates of Total Forest Area in Mexico (000 hectares)

It is also important to note that one cannot say whether a specific deforestation rate estimate is "right" or "wrong." As calculated for different purposes, using different definitions and through different methodologies, one can only say that a deforestation rate computed for one purpose may not be applicable to use or to compare to another rate computed for another purpose. However, it is also true that the great variety of estimates has resulted in confusion and a general lack of credibility for any of them.

Figure 4 shows a few of the deforestation estimates for Mexico (vertical axis) plotted against the time frames for which they were measured (horizontal axis). It is expected that deforestation rates will vary depending on the time period over which they are measured, due to different economic and climate effects, as well as natural disasters and other human activity. For example, Sosa and Bermudas (1978) estimate of 397,000 hectares per year covered a period of 37 years from 1940 to 1977, while that of Del Castillo et al. (1989) of 746 hectares per year was for the much shorter six-year period from 1988 to 1994. As this figure shows, estimates within the same time period can also vary depending on the baseline and the methodology used to make the estimates. For instance, Deininger and Minten (1996) used a modeling approach to estimate the deforestation rate for the decade between 1980 and 1990 as 1.92 million hectares per year while other estimates for the same decade were much less (e.g., FAO 1990, at 365,000 hectares per year).

[8] Deininger and Minten, 1996.

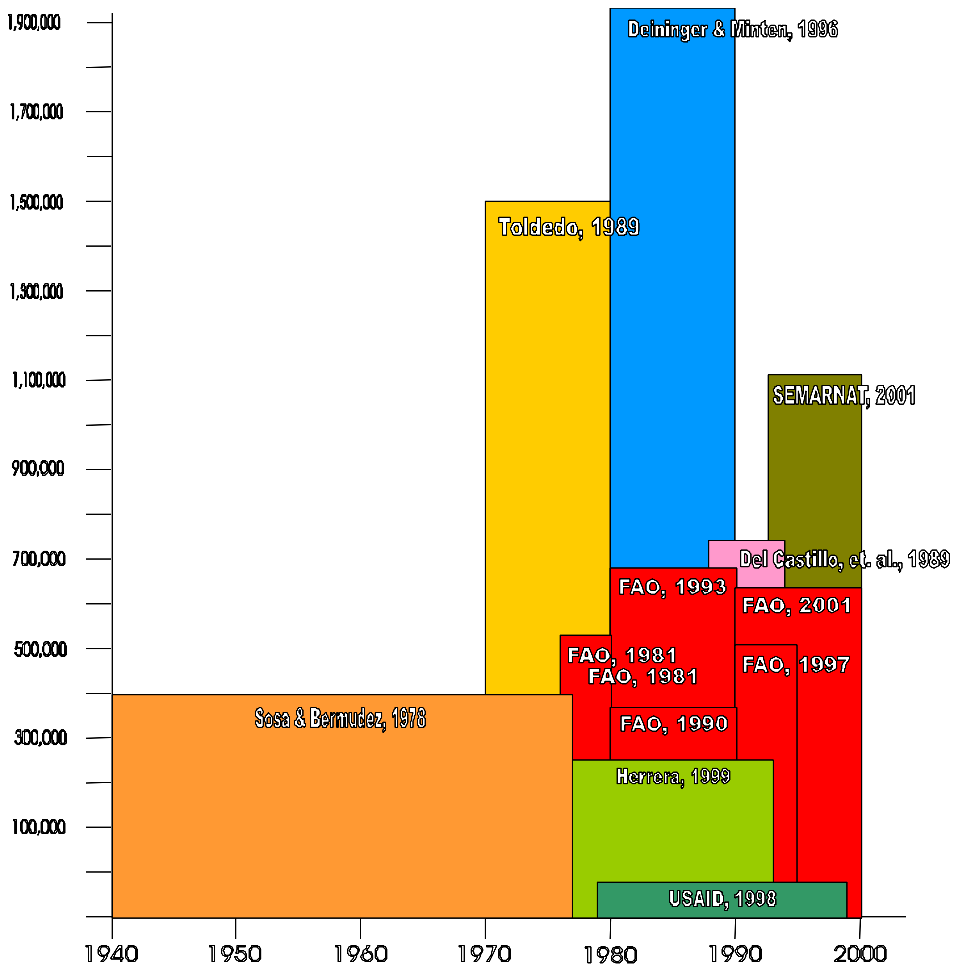

Figure 4: Variation in Deforestation Rates Due to Difference Time Frames

Table 4 shows a comparison of some of these published estimates of deforestation, organized by their methodological approach (see Section 4). Several items are important to note. Most of the deforestation rates in Mexico have been derived from modeling or a combination of modeling and other approaches—and not on year-to-year comparisons of data resources. As will be described in more detail in Section 4, modeling is most appropriate when there is a firm baseline and information is required quickly. But even rigorous models are handicapped by poor data and inappropriate assumptions, and the use of models may result in a loss of transparency when the modeling process is very complex. It is also interesting to note the limited number of data resources used as the baseline. Most of the estimates used the first national forest inventory, the *Inventario Forestal (1964-1980)*. Those estimates that did make year-to-year comparisons were also based on comparisons of maps whose source can be tracked directly to the work of INEGI (more on this in Section 5).

Table 4: Published Estimates of Mexico Deforestation Rates, Years Covered, Data Sources, and Approaches

Published Source	Estimated Forest Area	Deforestation Rate		Period Covered	Mid-year	Data Sources (see Figure 5 in Section 5)											
	000 ha	000 ha/ year	%			INFOR					INEGI						
						1	2	3	4	5	a	b	c	d	e	f	g
Approach: Comparison of inventories																	
SARH, 1994a		283	0.55	1990-2000	1995	X	X										
FAO, 2001	61,511 55,205	631	1.1	1990-2000	1995	X		X									
Approach: Comparison of maps and images																	
SEMARNAT, 2001	32,978	1,128		1993-2000	1997				X					X			
Herrera, 1999		250	0.69	1977-1993	1985							X	X				
INEGI, 1995		333		1985-1991	1988												
Approach: Modeling																	
Del Castillo et al., 1989, Varela, n.d.		746		1988-1994	1991	X											
Deininger & Minten, 1996		1,920	2.94	1980-1990	1985												
FAO, 1981		530		1976-1980	1978	X											
FAO, 1981		595		1981-1985	1983	X											
FAO, 1990		365	0.71	1980-1990	1985	X											
FAO, 1993, 1995; WRI, 1994; Varela, n.d.	48,586	678		1980-1990	1985	X											
FAO, 1997, 1999	57,297	508	0.9	1990-1995	1993	X	X										
Mexico Country Studies Project Team, 1995		767		Unknown	1995	X											
Myers, 1989; Anon., 2001; Varela, n.d.		700		1998	1988	X											
Approach: Other																	
FAO, 1988; WRI, 1992; Varela, n.d. (Approach: Unknown)		615		Unknown	1988	X											
SARH, 1990; 1994b; Mexico Country Studies Project Team, 1995; Varela, n.d. (Approach: Accounting)		370		1980-1990	1985												
Toledo et al., 1989, Varela, n.d. (Approach: Remote sensing, w/ modeling of agriculture (grazing lands)		1,500		1970-1980	1975	X											

4. Analysis of Approaches for Estimating Deforestation Rates

In addition to addressing difference in purposes and therefore applying different definitions of "forest" and "deforestation," deforestation rate estimates also vary depending on the methodology used to compute them. This section discusses six common approaches for estimating deforestation rates.

1) **Comparison of Forest Inventories.** The comparison of forest inventories from two points in time is the most common method used for national estimates and international reporting. When the FAO reports on forest gains or losses for various nations, the data are usually derived from reported national inventories. The estimates are only as good as the inventories themselves and the continuity between the two data sources. All too often, inventory techniques change over time. With a change in methodology, one is seldom sure the data are really comparable.

2) **Comparison of Remotely Sensed Imagery or Image Products.** Images or image products derived from remote sensing[9] can be compared between times to detect and measure changes. This is the most reliable method for monitoring changes in land cover, if the standards and processes are not changed. This method is often based on periodic coverage of the same or similar remote sensing sensors.

3) **Comparison of Map Products.** Maps[10] representing the Earth's surface at two different times can also be compared. If the scales, projections, and legends are the same between two maps, comparing the maps is simpler than comparing two images because one is comparing exact classes, and one knows precisely what has changed (e.g., incursion of agriculture into a previously forested area). The primary limitation to comparing maps is that they are difficult to compare if the purposes for which the original maps were developed differ.

4) **Modeling.** Modeling is used both to predict future changes and to explore "what if" scenarios. The model uses a baseline data set, such as a forest inventory, to provide the starting point (t_0). Variables used often include vegetation, terrain, climate, road and communication infrastructures, population, and socioeconomic factors.[11] Assumptions are made from which to run the model. The results are only as good as the quality of the baseline and variable data, the assumptions made, and the models themselves. In addition, the use of models may result in a loss of transparency when the modeling process is very complex.

5) **Accounting.** Accounting is generally a bookkeeping exercise. A base is established using a forest inventory, mapping process, or other accumulated data. Base statistics are subtracted or added

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[9] The term "remote sensing" can be defined as a set of techniques used to acquire and infer information about the earth's surface with instruments not in physical contact with it. In satellite remote sensing, electromagnetic radiation reflected from the earth's surface is detected and recorded by a sensor as an array of discrete values or "pixels" that appear to the eye much as does a picture or "image" from a digital camera.

[10] A map is a graphic representation of the earth's surface, drawn to scale on a two-dimensional surface. One way to generate a map is through the interpretation of a remotely sensed image to delineate "features" (or classes of objects). These features are represented as points, lines, or—as in the case of land use classes—polygons. A map's legend defines the classes of features being represented, and serves as the key for interpreting the map.

[11] Rieger, for example, uses an ecological model of the deforestation processes based on a set of assumptions describing the Himalayan region to illustrate current forestry trends and to predict future ones. The assumptions include a population growth rate of two percent per annum, an extraction rate of 1,400 kilograms per capita per year, a natural forest density of 360 tons per hectare of timber, and a natural forest growth of five percent per decade. Using these initial conditions, the model was first set in motion for a period of 100 years (Preston, n.d.). See also Annex 4: Bibliography*: Population Dynamics and the Assessment of Land Use Changes and Deforestation, Part 2* in Drigo et al. (1999b).

according to recorded treatments of the land or resources. The reliability of the data depends on the perspective of the person reporting and the faithfulness with which the information is updated.

6) **Combinations of Any of the Above.** Updates in forest area estimates often come from a combination of processes, usually involving forest inventories and modeling or accounting. Estimates that combine methods demand a more systematic approach. They are costly, time consuming, and difficult to implement consistently in the long run. Methods suitable for updating changes under one approach may not be appropriate where several methods interact.

All six methods of developing deforestation rate estimates have been used in Mexico (see Table 4). Five of these methods have been used to develop the published national-level deforestation rate estimates in Mexico. Comparison of remotely sensed imagery has been used at the local level but not at the national level. As Table 4 shows, the method most commonly used in Mexico is modeling.

All of these approaches depend on, and are only as good as, the data that they use ("garbage in, garbage out"). In this regard, Mexico is data rich, with excellent remote sensing coverage and numerous map products. However, for various reasons, many of these data resources have not been used for estimating deforestation. Despite the wide range of values for deforestation rates discussed in the previous section, the estimates themselves are based on only a few key data sources and a greater number of secondary map products. This is discussed in more detail in Section 5.

4.1 Limitations of the Various Approaches

Each of the six approaches noted above has advantages and limitations. The most common limitations may be grouped under the following three categories:

- **Overall limitations** that affect deforestation rate estimates including:
  - Multiplicity of purpose. Comparison across two or more data sets where these data sets have been developed for different purposes.
  - Differing definitions. The definitions of "forest" and "deforestation" may be quite different.
- **Limitations related to the base data**, which include:
  - Accuracy and precision. The potential deforestation rate will depend on the quality of the input. It is useful to distinguish between accuracy and precision. The former measures agreement with a standard assumed to be correct, the latter defines the level of detail provided. It is likely that the most accurate deforestation rate estimate that can be achieved using existing data in Mexico will have the precision of a map product of 1:250,000.
  - Relevance or appropriateness to the purpose. For example, the resolution of the source imagery or the scale of a map product that is appropriate for one purpose will not necessarily be appropriate for another (different) purpose.
  - Interpretation. The identification (or "interpretation") of data into types or classes of objects will depend on the purpose for which the results are intended to be used and on the intent of the interpreter—it will be the interpreter's version of reality. It will also depend on the rigor through which the field checking is carried out.
  - Heterogeneity of the data. Data compiled from different data sources into a single inventory, or from different regional or local inventories into a national coverage, will result in a heterogeneous product that is difficult to use or to compare with other data products.

- Different assumptions. Approaches that rely on modeling (the most common approach used in Mexico to date) will depend on the underlying assumptions made in deriving and executing the model.

- **Limitations that affect the comparison of different data resources**, which include:
  - Different data sources. Care must be taken in comparing two data sources. For example, some data or information products were not designed for the purpose of measuring change.
  - Differences in the legends used for map products. Different legends used in the mapping process (generally reflecting different purposes of the map products) may make comparison between maps difficult or impossible.
  - Differences in the scales of map products. Even with identical legends, comparing maps compiled at 1:1,000,000 with maps compiled at 1:50,000 will be difficult due to differences in polygon aggregation resulting from the different scales.
  - Differences in the methodologies used to derive products from original imagery or field data. Different data collection and compilation methods, and differences in interpretation, will necessarily result in different data products even when the underlying base data is the same.

The following sections briefly describe examples of how the six approaches have been applied in Mexico. Table 5 at the end of this section summarizes how the above limitations affect each approach.

4.2 Comparison of National Forest Inventories

Forest inventories are conducted to inform forest managers about the state of their forests in terms of area, species, age classes, and quantity of wood ("yield"). This information has traditionally been stored in tables or tabular databases. Inventories were conducted using ground surveys with rigorous sampling methods involving an extensive network of field plots. With the introduction of remote sensing, forest inventories are increasingly carried out using a combination of remote sensing and ground surveys. And with the advent of geographic information systems (GIS), the results are often presented as digital data sets.

Calculating deforestation rates from forest inventories can be as simple as subtracting values from a table representing the inventory of one year from the values contained in that of a second year (see Section 4.6). Many of the international bodies that collect information on forests across the globe rely on these national inventories both for total forest cover estimates and for computing deforestation rates. If true forest inventories are compared, one can derive information on changes in volume, production, condition, presence of pests and diseases, or other aspects, in addition to area changes. Thus, this approach is particularly useful if the purpose is one of monitoring wood and fiber production.

Mexico has carried out three activities that are identified by the term "national forest inventories." Technically, they are not complete forest inventories, as they do not include all of the parameters and procedures that are typically part of a forest inventory. Of these, only the first one—the *Inventario Forestal (1964-1980)*—was based on the interpretation of aerial imagery supported by extensive field sampling to establish the location, extent, wood volume, and commercial value of forest stands in Mexico. The first *Inventario Forestal* comes closest to being a complete forest inventory.

The second and third "inventories" were essentially updates of LU/LC maps using remotely sensed imagery and were not, in fact, complete inventories. The second was based on an analysis of low-resolution AVHRR imagery and was published at 1:1,000,000 scale as part of the *Secretaría de*

Agricultura (SARH) *Gran Vision* report.[12] The purpose of this inventory was to produce a quick estimate of the extent of forest lands to support Mexico's information needs at the national level, most of which are related to international treaties.

Mexico's most recent (and third) national inventory was completed in 1994.[13] Called the *Inventario Nacional Forestal Periódico* (1992-1994), it was based on a combination of INEGI LU/LC maps and a visual interpretation of Landsat Thematic Mapper (TM) imagery and field measurements on about 20,000 plots obtained through systematic sampling to determine vegetation type. It produced cartography at a scale of 1:250,000. The purpose of this inventory was to provide Mexico with information on the location, extent, and timber volume of forestlands to support the country's operational needs. This forest inventory only produced location and extent of LU/LC for three-fourths of the country and yielded no data on timber volume.

Strictly speaking, comparison of these forestry inventories for the purpose of estimating deforestation rates is not possible. Only the extent and location of LU/LC classes can be compared. Even this requires careful analysis of the map legends to overcome the limitations imposed by the various surveys. Some published results must be considered in this light. For example, SARH, in its *Gran Vision* report, compared the first and second inventories. Although most of FAO's deforestation rate estimates are based on models, the most recent estimates published by FAO in its *State of the World's Forest Report 2001* (and FRA, 2000) were based on comparison of the third national inventory (*UNAM 1994, Mapa de uso/vegetación)* and the first inventory.

The purposes of both the SARH and the FAO reports were very broad. The FAO 2001 forest situation report was to offer relevant, credible, and up-to-date information to a very broad audience, from policymakers to foresters and to other persons involved in natural resource management, academics, forest industry, and civil society. Similarly, the basic objectives of the *Gran Vision* inventory were to provide a low-cost update to the first forest inventory, provide basic information on forest resources for planning and decision-making, and serve as a benchmark for more detailed periodic inventories in the future.

With respect to definitions, the SARH report illustrates some of the implications of using different definitions. The SARH report defined "deforestation" in terms of a change in land use.[14] "Forest cover" (*cubierta forestal*) was defined broadly as natural forest and was defined in terms of a "given moment" (i.e., it did not address long-term changes).[15] A "forest area" was defined in terms of what the "optimum" use of the area would be.[16] A threshold of 20 percent crown cover was specified for "tree-covered" areas.[17]

The FAO, on the other hand, applied the same standard definitions that it applies worldwide, as described in Annex A. However, most of these definitions are not the same as those used to make the Mexican forest inventories that were used to prime the FAO's models (e.g., "forest" included natural forests and forest plantations, the canopy cover threshold was 10 percent rather than 20 percent, and additional characteristics were specified).

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[12] SARH, 1994a.
[13] UNAM 1994, *Mapa de uso/vegetación.*
[14] "*Proceso de cambio de uso del suelo, de forestal a otro uso*."
[15] "*Término amplio que comprende toda la vegetación espontanea natural (árboles, palmeras, arbustos, matorrales desérticos, hierbas, etc.) que ocupa un área en un momento dado*."
[16] *Área forestal* = "*Terrenos cuyas características topográficas y condiciones ecológicas, permiten que sustente como forma óptima de uso del suelo a la vegetación arborea, arbustiva o herbacea natural*."
[17] *Arbolado* = "*los terrenos arbolados en los que las copas de los árboles cubren más del 20% de la superficie*."

In summary, calculating deforestation rates from forest inventories can in theory be a simple exercise of subtracting values from a table representing the inventory of one year from the values contained in that of a second year. However, in Mexico these required inventories do not exist in the traditional sense. The map products that do exist, and that are often mistakenly termed as "inventories," are not easily compared due to differences in content, methodology, and legends. Conducting a new survey designed to capture change as well as traditional timber data would lay a foundation for a continuous inventory program.

4.3 Comparison of Remotely Sensed Imagery or Image Products

Remotely sensed images can be directly compared to locate areas of change. First the images must be referenced to a common geographic coordinate system, then the arithmetic difference of the two images can be computed (literally, IMAGE2 – IMAGE1). Any areas of change are then identified and interpreted. However, because the pixels (picture elements) are being directly compared, external effects such as sun angle, terrain shadows, and atmospheric haze can affect the results and make interpretation of the difference image extremely difficult or even impossible. UNAM tried this approach for its inventories in 1994 and 2000,[18] but was unsuccessful partially because of these external effects. Moreover, SEMARNAP (now SEMARNAT) required UNAM to measure changes on a number of vegetation classes that could not be mapped using satellite images alone, whether "raw" or processed.

More commonly, image products are first developed and the arithmetic differences of pairs of image products are computed. Image processing intended for use prior to comparing two image products is usually limited to relatively simple computations, especially to vegetation indices such as the normalized difference vegetation index (NDVI).[19] The NDVI is the most common type of "image product" that is used when trying to find changes for *any* type of vegetation. As a ratio, it eliminates many of the sun angle, atmospheric, and other external effects that hinder attempts to apply a direct image-to-image comparison. It results in an image that is essentially classified into two categories: vegetation and non-vegetation. As with direct comparison of images, areas of change are then identified and interpreted.

Taking the difference of two NDVI or similarly processed image products is the most reliable technique for monitoring changes in vegetation cover, as long as the standards and processes used are not changed from the acquisition and processing of one image to the next. This approach provides good estimates of land cover changes. Some land use changes may be inferred. (For example, if an area was covered by trees yesterday, and is now covered with houses, a land use change had occurred.) There is no evidence that this approach has ever been tried at the national level in Mexico.[20]

4.4 Comparison of Maps

Whereas remotely sensed images contain spectral information captured in the form of "pixels," maps contain a rendition of the location and extent of terrain features based on a model of reality. Real features on the ground are depicted or interpreted by technicians. A map is an interpretation of survey points,

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[18] Soriano and Alvarez, 1995; Palacios et al., 2000.

[19] NDVI = (infrared band – red band) / (infrared band + red band).

[20] Evans et al. (1992) used 1990 AVHRR imagery to map land cover for the entire country of Mexico in eight classes, three of which were forest classes. Field information was supplied in the form of INEGI's 1:1,000,000 scale vegetation maps, Landsat TM prints, aerial photographs, and other ancillary information. The accuracy of the resulting land cover image map was 78 percent as tested by a polygon comparison method and 84 percent by a pixel comparison method. Discussions with one of the co-authors (Jose Luis Ornelas de Anda, INEGI, January 2002) indicated that no attempt has ever been made to develop a similar image map for another year for comparison purposes.

aerial photographs, or images that show these "features" represented as points, lines, or polygons. Thus, one way to create a map is to first classify or interpret the pixels in a remotely sensed image into land cover classes, creating a land cover map. Auxiliary information, including expert knowledge, can be included to create a land use map. The resulting LU/LC maps can be compared in a similar way to difference images.

In order for such a comparison to be made, the geographic reference frames, legends, and scales must match. The geographic reference frame is the projection of the three-dimensional surface of the Earth onto a two-dimensional map. The projections must be the same in order for the ground features of the two maps to overlap. A map legend is developed to support a specific interpretation of reality. For example, the same area could be mapped as commercial forest under one legend designed to estimate the economic potential, or as degraded land under a legend designed to highlight wildlife habitat. The purpose of the map defines how the land is classified. If the legend defines classes that do not match the classes of interest, or do not match the classes used in the map to be compared, then comparison of map products will be of limited use in determining change. The scale, in turn, sets limits on the precision of the information that can be extracted from the map.

Finally, differences in methodologies used to derive map products will affect the results, even when the underlying data and legends are the same. This limitation might be present even when long-lived institutions observe rigorous procedures to carry out forest inventories and mapmaking. Consistency in the interpretation of data might be severely affected by changes in personnel and changes in management priorities. Even when maps are made with the desired geometry and scale and with comparable legends, problems can occur. Consistency of data sources within the map is also important. The original source of the data for the INEGI Series I LU/LC maps—the first national forestry inventory, conducted at scales ranging from 1:20,000 to 1:250,000—was notably heterogeneous. Although the Landsat imagery used was all from 1993 and the field data were collected over the period 1994-1996, differences can still be found due to the fact that the interpretation was carried out by regional offices, rather than the central office of INEGI.

If the maps are developed according to identical procedures, the comparison between pairs of map sheets is simple. Overlying one map on the other can quickly identify changes in the extent of the polygons and features.[21] The most common problem encountered with such map comparisons is then related to the accuracy with which the lines were drawn.

Attempting to compare maps developed using different standards, such as different scales, legends, or purposes presents challenges that can make meaningful comparisons impossible. This is the case of the 1:250,000 LU/LC map series of INEGI. This map series was made by the same institution and possibly with the same cadre of experts. But the different legends used in the first and second series prevent meaningful values of LU/LC change to be derived from these two products.

Herrera (1999) calculated a national deforestation rate by comparing the INEGI cartographic Series I and II at a scale of 1:1,000,000. Defining "deforestation" as a reduction in the area covered by trees, i.e., temperate and tropical forests ("*reducción de áreas arboladas, por ejemplo, bosques y selvas*"), Herrera established equivalence between the map classes for the two series. The complexity of the legends for the INEGI Series I and II at a scale of 1:250,000, however, precluded Herrera from developing a more

[21] This method can also be used to update an existing map by overlaying a more recently acquired remotely sensed image. This is, in fact, the preferred method followed by INEGI and SEMARNAT to update their maps since the late 1970s. (UNAM's surveys were done under contract for SEMARNAP).

detailed estimate of deforestation. Teams at UNAM and SEMARNAT faced the same problem when comparing map products from the UNAM 2000 and INEGI Series II maps at a scale of 1:250,000.

INEGI dedicated substantial effort to the design and implementation of the legend for the LU/LC INEGI Series I at a scale of 1:250,000. The major change was the adoption of a legend that relied heavily on land use and the floristic composition of vegetative cover. INEGI decided to develop LU/LC maps at a scale of 1:1,000,000 since this could be accomplished more rapidly. These maps were prepared not by aggregating the 1:250,000 scale products, but as separate surveys, both derived from TM satellite images and with the objective of testing the new methodology.

The legends between these two INEGI scales are not fully compatible. Neither are the legends for the first and second series. INEGI is concerned with the continuity and usefulness of the map series and has designed the legend for its third series to make it fully compatible with the Series II. The legend was modified for the Series II maps and will be further refined for the Series III maps. Where equivalent classes are clearly defined, legend changes can be tracked through “look-up” tables, as is the case for the legends of the INEGI Series II and III maps at a scale of 1:250,000. There is also a look-up table that roughly relates the legends of the INEGI Series II and the UNAM 2000 maps. No useful class equivalence can be established between the UNAM 1994 map legend and any of the INEGI series.

Besides the continuity of its cartographic series, INEGI’s products are fully documented through data dictionaries. There are dictionaries for types of features, colors, lines, scales, and so forth. One of the data dictionaries defines the floristic composition, feature size, and density characteristics that should be included in the LU/LC map series. This kind of detail, as well as the extensive field data and the geometric quality of the maps, make INEGI’s series the most suitable for long-term change measurements. According to INEGI, the LU/LC Series III will use the exact polygons of the Series II with the appropriate updates based on data from Landsat 7 (ETM). The INEGI LU/LC map series will be produced at regular three-year intervals.[22] Such procedural changes for the elaboration of the LU/LC maps will minimize errors induced during the survey.

4.5 Modeling

Modeling is used primarily to predict what the LU/LC change will be in the future, or to explore “what if” scenarios of how changes in baseline conditions will exhibit themselves over time. Variables used often include vegetation, terrain, climate, road and communication infrastructures, population, and socioeconomic factors. Modeling is inexpensive, and very little field work is involved once the model is developed. Modeling is most appropriate when there is a firm baseline and information is required quickly.

As may be noted from Table 4, most of Mexico’s deforestation estimates are based upon the first national forest inventory and modeling. The data in the first inventory were preliminary and heterogeneous with respect to timing, scales, and geographic coverage. Even rigorous models may be handicapped by the heterogeneity of the data sources, as is the case of the deforestation figures issued by SARH and FAO. Other models incorporate information that some observers have found questionable. For instance, the population data commonly used in models for Mexico does not reflect the effects of government policies that have influenced large-scale changes in land use.

For the FRA 1990, FAO used a population-deforestation model to develop a baseline from the older first national forestry inventory. In adjusting estimates from the first inventory to FAO’s international

[22] Takaki, personal communication, November 27, 2001.

definitions and standards, the thresholds for defining “forestland” in Mexico appear to have differed from Mexico’s. Input data was incorrect for three important states.

One of the highest estimates of deforestation is that of Deininger and Minten (1996) who based their estimate on a mathematical model primed with area figures from the UNAM 1994 *Inventario Nacional Forestal Periódico*. It was pointed out above that no reliable equivalence could be established between the legend of this work and other forest inventories (INFOR) in Mexico. However accurate the underlying data, Deininger and Minten’s comparison of forest cover between 1980 and 1990 was criticized in Mexico because of its unique approach to classification of LU/LC, leaving in doubt the identification of areas that had been deforested during that decade. Methodological limitations of these data, and those of earlier forest inventories, are discussed at length in Sorani y Alvarez (1995).

The hypothetical relationships between population growth and tree cover in Mexico have also been questioned. Toledo et al. (1989), drastically increased their deforestation estimate after noting that the expansion of rangeland did not fit results modeled solely on the first forest inventory and population data.

4.6 Accounting

Accounting is generally a bookkeeping exercise. A base is established using a forest inventory, mapping process, or other accumulated data. Base statistics are subtracted or added according to recorded treatments of the land or resources. Accounting is inexpensive, as it is based on existing data or data that is collected during routine operations in other areas (such as forest inventories).

SARH 1990 and 1994 used an aggregation of local numbers and bookkeeping, subtracting areas that were cut or burned. The numbers lacked precision because the regional offices did not quantify illegal cuttings or clearings.[23]

4.7 Combination Approaches

Updates in estimates of forest areas often come from a combination of processes—usually involving forest inventories and modeling or accounting. Using a combination of approaches, one may make maximum use of a broader range of existing data. A combination of methods may be ideal for meeting different needs at various levels (e.g., meeting a national requirement with one approach while supporting operational decisions with another). The existing LU/LC data of INEGI are indeed the result of a combination of interpretation that includes traditional mapmaking with a map updated based on the analysis of satellite images. The land use change is carried out by comparing time series.

Toledo et al, (1989) used a combination of data sources, including the first national forest inventory, remote sensing, and models based upon agriculture and ranching land use data.[24] FAO (1990) also used the first national forest inventory, with additional input from a local SARH delegation and models of population and forest cover modeling. The original data from the first national forest inventory were too heterogeneous and models did not show strong relations.[25] Myers (1989) used data from FAO (1988), which had as input data from the first national forest inventory and modeling of populations, focusing only on tropical forests.[26]

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[23] Ibid.
[24] Ibid.
[25] Ibid.
[26] Ibid.

Table 5: Advantages and Limitations of Different Options for Estimating Deforestation

Approach for Estimating Deforestation	Limitations			Advantages
	Overall Limitations	Limitations in the Base Data	Limitations Affecting Comparison	
Comparison of forest inventories from two points in time	The original inventory dictates the definition of "forest." Locational information may be lacking in inventories that do not use maps or remote sensing. Estimates are only as good as the inventories themselves and the continuity between the two data sources.	Field data often collected over a period of years and cannot be simply summed. Adjustments must be made to bring data to a common date, introducing error. Establishing a new inventory overcomes this problem, but a follow-up inventory is required to then measure change.	If techniques are changed, data may not be comparable. New inventories and re-inventory are very costly.	Makes use of existing data. Provides forest inventory change measures in addition to deforestation estimates. Conducting a new survey designed to capture change as well as traditional timber data will lay a foundation for a continuous inventory program.
Comparison of remotely sensed imagery or image products derived from remote sensing	Limited utility beyond that without additional classification. Continuity of data source is important. External effects (e.g., sun angle, terrain shadows, atmospheric haze) can make interpretation of changes difficult.	Data selected must be appropriate to the task at hand. Images alone may not provide biomass information or other traditional forest inventory data.	Limited to locating areas of change in terms of less or more vegetation. Determining changes in vegetation type or condition requires additional processing and field checking. Must use compatible imagery (sensor, season, etc.) for comparison at a second period. Sometimes such imagery is no longer available.	Most reliable for monitoring land cover changes if standards and processes are not changed. Least expensive method. New imagery need be obtained for only those areas of interest. Comparisons of images can be done by one person or partially automated, eliminating some biases in interpretation and classification.
Comparison of maps	Maps are designed for a particular purpose and support a specific interpretation of reality. A set of maps is only as useful as their legends. The person or institution doing the mapping dictates the definition of "forest."	The extent and rigor of the use of mapping protocols and field checking limit accuracy of underlying data.	Consistency of data sources within the map is important. Classes must match classes of interest and classes used in the map to be compared.	Comparing similar maps is simpler than comparing two images since exact classes are compared. Only changes between classes of interest need be computed. Since the maps are the result of an interpretation, seasonal effects are eliminated from the comparison (albeit not from the original interpretation).

Approach for Estimating Deforestation	Limitations			Advantages
	Overall Limitations	Limitations in the Base Data	Limitations Affecting Comparison	
Modeling to predict what the land cover or land use change will be in the future	Location information lacking. Estimates are only as good as the data, the models themselves, and the assumptions made.	Since most models use LU/LC maps to prime the model and the quality of materials available varies, it is difficult to obtain consistent results.	Even rigorous models may be handicapped by the quality of the data sources.	Least costly method since little field work is involved. Modeling is a useful approach when there is little or no other data. Best when there is a firm data baseline and quick results are required.
Accounting	Reliability of the database depends on perspective of the person reporting and the faithfulness with which the information is updated. Depends on the particular purpose for which underlying data were developed. Not suitable to estimate changes in lands not registered in the appropriate class. Since many land changes are not reported under the official system, this method is particularly weak within the Mexican institutional framework.	SARH 1990 and 1994 used aggregation of local numbers that lacked precision because illegal cuttings and clearings weren't quantified.	Certain classes present problems. For example, the concept of rangeland or grassland from the viewpoint of agriculture does not match that used by environmental groups or SEMARNAT. Areas may be reported several times under different concepts or users or not at all. By comparing different data sets, it is never clear that the evaluation is comprehensive and lacks omissions or duplicity.	Inexpensive, as it is based upon existing data or data that should be noted during routine business operations.
Combinations of any of the above	Demands a more systematic approach. Adding different kinds and sources of data increases complexity. Methods suitable for updating changes under one approach may not be appropriate where several methods interact.	Limitations of the original data and map comparison are just as important for a combination of approaches as they are for any of the above approaches.	There is considerable potential for confusion—for comparing results that might not be at all comparable.	Makes maximum use of a broader range of existing data. Can be used to meet different information needs at various levels, e.g., meeting a national requirement with one approach while supporting operational decisions with another.

5. Data Limitations Effecting Deforestation Rate Estimates

Mexico is rich in data that can be used to estimate deforestation rates, including remotely sensed imagery from the 1970s, 1980s, 1990s, and 2000. While requiring some adjustments, Mexico also has an excellent series of maps from which estimates of land cover change have been and could continue to be made, including the work of INEGI, UNAM, and SEMARNAT. Thousands of geo-referenced ground photos and herbarium specimens have been collected to support both forest inventories and LU/LC maps. These data are useful for a variety of purposes, including noting changes in biological diversity.

In general, three kinds of data are available that could be used in future estimates of deforestation rates in Mexico: remotely sensed imagery, maps, and tabular data from national inventories.

5.1 Remotely Sensed Imagery

Remotely sensed imagery available for Mexico is listed in Table 6. As shown, both low- and high-resolution satellite data are available for the entire country for the last three decades. Full country coverage of individual satellite images, as well as derived image maps and large area mosaics, are part of

Table 6: Satellite Imagery Available for Mexico by Agency

Source and Coverage	Format	INEGI	UNAM IG	ASERCA	IMTA	SEMARNAT	SIGSA	SEDENA
National coverage Landsat MSS	Digital	1980s	1980s		1976, 1986, 1990		1980s	
1:1,000,000	Paper, film	1980s			1990			
National coverage Landsat TM	Digital	1993	1991, 1993	1993[a] 1996	1992	1991, 1993		1993
1:250,000	Image maps	1993	1991					
National coverage Landsat ETM	Digital	1999-2000[b]	1999-2000[b]		2000	1999-2000[b]	2000	
1:250,000	Image maps		1999-2000			1999-2000		
AVHRR Downlink	HRPT		Yes					
OrbView 2 Downlink	HRPT		Yes					
MODIS Downlink			Yes					

MSS = Multispectral Scanner
TM = Thematic Mapper
ETM = Enhanced Thematic Mapper
HRPT = High Resolution Picture Transmission, 1km² resolution

a = partial coverage
b = same data set

the databases of INEGI and UNAM's Institute of Geography. The *Instituto Mexicano de Tecnología del Agua* (IMTA) houses several years of satellite Landsat MSS coverages. These images have been corrected to the geometry of INEGI's topographic map series at a scale of 1:250,000 (image maps).

UNAM has been downlinking HRPT (1 km^2 resolution) from both AVHRR and SeaWiFS sensors for several years. After the forest inventory of 1980, all of the LU/LC map series (less than 1:250,000 scale) were derived primarily from remotely sensed data.

5.2 Maps

Both existing vegetation maps and national inventory data have been used to develop deforestation estimates for Mexico. Figure 5 shows the genealogy of the different map products that have been used to produce deforestation estimates. The original source of these data is the first national forestry inventory, *Inventario Forestal (1964-1980)*. This inventory was conducted at scales from 1:20,000 to 1:250,000, and presented at the national level at a scale of 1:500,000. This work was derived from aerial surveys for the commercial timber regions and completed with Landsat MSS data interpretation for the rest of the land. Because the surveys were conducted in individual states over a long span of time, the resulting inventory is notably heterogeneous. This forest inventory includes national numbers for forest area and timber volume.

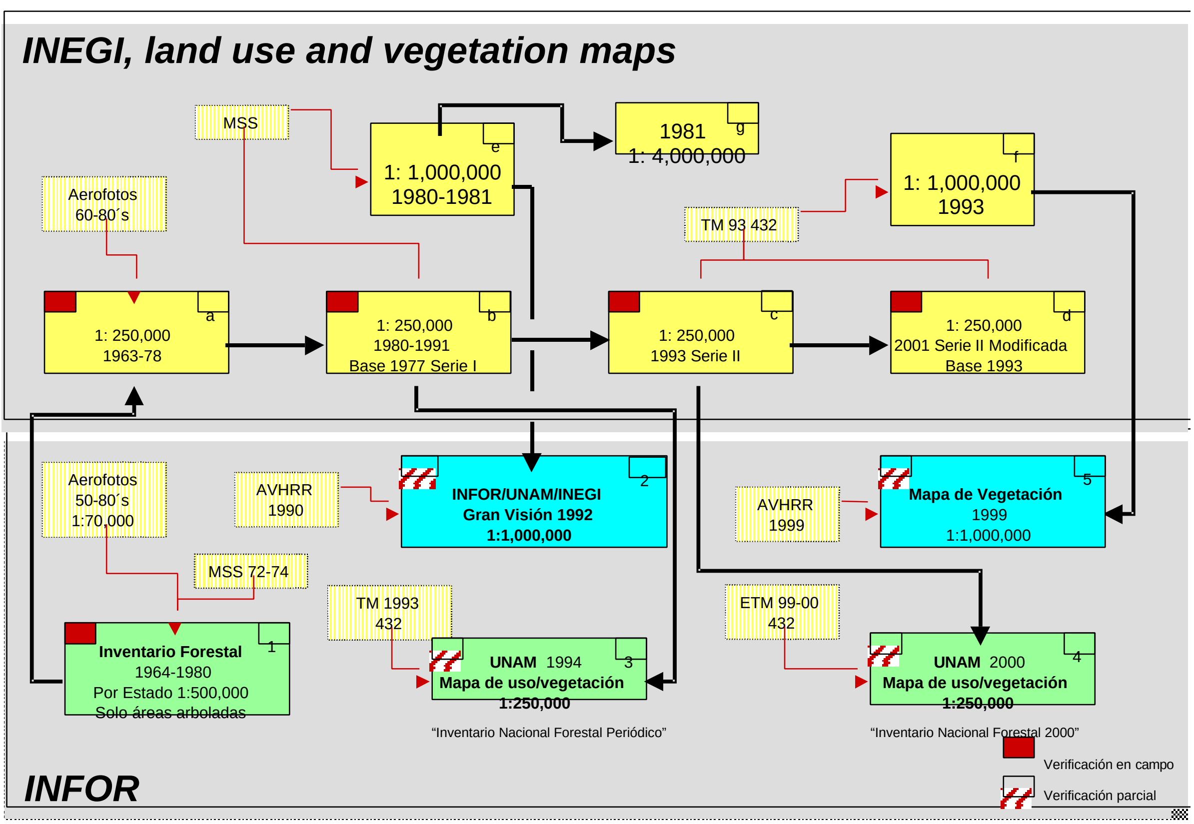

Figure 5: Maps Used to Measure the Rate of Deforestation in Mexico

Of the almost 40 estimates listed in Annex B, the source of the base data could be identified for 16. Of those 16, 13 used the first national forest inventory, the *Inventario Forestal (1964-1980)*. At least 10 of these 13 used models to determine change—they did not make year-to-year comparisons of data sources. Those estimates that did make year-to-year comparisons were also based on comparisons of maps whose source can be tracked directly to the work of INEGI.

The first national inventory was the basis for the first LU/LC maps of Series I produced by INEGI (1963-1978). All of the known map products scaled at 1:250,000 for land use developed by INEGI (labeled INEGI a to g in Figure 4) and those of the so-called forestry inventories of the 1980s, 1990s, and 2000 (numbered INFOR 1 to 5 in Figure 4) are updates and modifications to this map series. All of these derived cartographic products used satellite imagery to update the boundaries of the previously mapped classes.

The LU/LC map series produced by INEGI at a scale of 1:1,000,000 were developed prior to the 1:250,000 series following an independent methodology, both based on the same sets of Landsat TM data. The map series at these scales are not directly comparable. Indeed, according to INEGI,[27] the map legends for successive INEGI series at a scale of 1:250,000 cannot be directly compared. This is not the case for the INEGI map series at a scale of 1:1,000,000 because of the general nature of the scale. The change in LU/LC based on measurements from the maps of this series is perhaps the best possible "deforestation" estimate that can be derived from Mexican cartographic sources.

5.3 Tabular Data

Tabular data available to model deforestation is also available from INEGI, notably from the population census. The basic socioeconomic data regarding population parameters is reported at the municipal level every ten years. *Apoyos y Servicios al Campo* (ASERCA) holds an extensive farmland database.

5.4 Limitations to Use of These Data

All three of these data resources—remotely sensed imagery, maps, and tabular data—should be considered when planning future efforts to estimate deforestation rates in Mexico. When making choices, one must consider the limitations for use of these data.

First, care must be taken in comparing two data sources. UNAM's 1994 "*Inventario Nacional Forestal Periódico*" used INEGI Series I LU/LC maps at 1:250,000 scale as a base. UNAM updated about 70 percent of the country using manual interpretation of false color infrared satellite images (Landsat TM). The remaining maps were simplified from INEGI's originals without undergoing any updating.[28] The first forest inventory was made from aerial photos at a scale of 1:20,000, but only for areas with commercial timber. A national map was compiled and presented as state maps at a scale of 1:500,000 while the extensive blank spaces of the maps were filled in with manual interpretation of satellite imagery in hard copy (Landsat MSS). Because of the resolution of the images, different features can be interpreted from aerial photos (1-meter resolution) than from MSS (70-meter) or TM data (30-meter). This problem is particularly acute in areas with fragmented patterns of land use, or where selective cutting prevails over clearcuts, as is the case in much of Mexico.

Similarly, the legend used in a map reflects the purpose of the map. The legend of the series of LU/LC maps of INEGI at 1:1,000,000 and 1:250,000 are so different that a unique correspondence between like classes at the two scales cannot be unambiguously established. The legend used to survey commercial

[27] Oral communication in November 2001.
[28] Soriani and Alvarez, 1994.

timber, with less than 20 classes, is difficult to compare with the more than 670 classes contained in INEGI's LU/LC maps. It should be noted that even when one institution with clearly defined standards produces map series, there are changes in the legends of progressive series as the mapping concepts evolve through the decades.

Toledo et al. (1989) produced a deforestation rate estimate for Mexico using the tabular data of SARH (INFOR was the responsibility of SARH, now the *Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación* [SAGARPA]) as a variable in a deforestation model. The total rangeland area provided by SARH in the late 1980s was distinctly larger than what could be inferred from the contemporary "forestry inventories." This unique result, derived from an independent source (SARH) of tabular data, underlines the fact that most mapping products had not been thoroughly updated.

6. Conclusions and Recommendations

As we have seen, the purposes for which estimates of deforestation rates are used vary, as do methodologies, time frames, and baselines of measurement. The resulting estimates of the deforestation rate in Mexico range from 75,000 hectares per year to more than 1.98 million hectares per year. In theory, all of these estimates could be correct for the purposes for which they were designed, or all could be incorrect. The result has been confusion and a general lack of credibility for any of the estimates. Since there is no single "correct" definition of "forest" or of "deforestation," there will always be a range depending on the needs of the user. However, consistency of methodology and baseline can contribute to reducing the variation at least for a specific purpose and definition.

To help develop consensus on a methodology to measure deforestation in the future, an initial workshop for key stakeholders was held on November 27, 2001. The program facilitated contributions from a core group of stakeholders from government and the academic community. Other workshops will follow with a broader group of national and regional stakeholders; the first of which will be held on January 31, 2002.

A number of points were agreed upon by consensus at the November 2001 workshop regarding the best approach to generate basic data on deforestation. These points address, in a preliminary way, issues of purpose, definitions of "forest" and "deforestation," existing data, and procedures for measuring change. Participants identified actions that would help move the process forward in a way that continues to build consensus and collaboration.

6.1 Recommendations

The November 2001 workshop recommendations rest on a general concept that **"deforestation" is primarily a change in land use**. A land use definition was proposed to address a two-fold purpose. First, users in Mexico need deforestation data to **support operational programs** addressing a variety of purposes related to forestry, environmental protection, and social and economic development. To this effect, **regional data at a scale of 1:250,000** are required. Second, **Mexico must comply with international commitments.** For this, **national deforestation data at a scale of 1:1,000,000** are in order. The resulting **recommended methodology would compare specific classes of the LU/LC maps of INEGI**. Since the applications to which the deforestation estimates will be used vary and cut across multiple agencies, **interagency coordination will be critical**. Similarly, **a consistent set of standards (or *norma*)** will be required for meaningful data sharing, both between central government agencies and from local and regional governments to the central government.

6.1.1 Multiple Purposes

The information on change that Mexico requires is broader than a single measure of deforestation can provide. The November 2001 workshop participants agreed to focus on change estimates for four core purposes: timber production; biodiversity conservation; carbon sequestration; and environmental protection, especially the management of hydrological resources.

As we have seen in Section 2, each of these purposes will require a slightly different definition of "forest," and therefore of "deforestation." For this reason, rather than attempting to come to consensus on a single definition for "forest" or for "deforestation," the stakeholders agreed to develop a methodology that would support multiple definitions for these multiple purposes. The collection of detailed information about land classification will allow this. Rather than a single definition of "forest," multiple classes of land areas (land use, land cover, or combinations) will be identified, and changes of those classes monitored over time. Presentation of the results in a change matrix (see Table A.1b in Annex A) enables estimation of class-to-class changes between two dates of interpretation, with the particular sets of classes selected to reflect the desired purpose. The inclusion of carbon sequestration and biodiversity conservation in the list of core purposes calls for including land use (and not just land cover) classes.

6.1.2 Comparison of Maps

The November 2001 workshop participants elected to use the LU/LC maps of INEGI at 1:250,000 scale and their corresponding data dictionaries as the basic area and location information for estimating changes in land use and land cover. By using LU/LC maps from INEGI, a number of advantages can be obtained over other approaches.

- **Clearly defined procedures to ensure accuracy**. INEGI has clearly defined procedures to develop its map series. These procedures are published and thoroughly documented. They involve strict control on the geometric properties of the maps, in the type and characteristics of features that can be included in maps at various scales, and in the training and supervision of surveyors and interpreters. These procedures and the skills and training of INEGI staff serve to ensure accuracy in the final product, while the control of only including relevant characteristics of features at appropriate scales ensures the precision of the final product.
- **Resources and a mandate to ensure continuity**. INEGI has the resources and the mandate to continue to develop high-quality LU/LC maps. It has done so for the last three decades and it is expected that INEGI will continue to do so. The problem of long-term continuity for baseline data is thereby addressed, not by creating a new procedure or by forcing a new responsibility into an established agency, but by following the mandate of the Mexican law and working closely with INEGI to support and enhance existing efforts.
- **Rigorous use of field and satellite data that increases user confidence**. INEGI uses remotely sensed images to update its maps. This valuable information is added to the LU/LC polygons that are defined on the basis of floristic composition and vegetation structure with a solid and widely accepted conceptual framework. The existing procedure calls for the use of the preceding LU/LC 1:250,000 map polygons in digital format to be modified only insofar as changes can be documented from both satellite and field data, thus minimizing the introduction of non-sampling errors. The rigor of INEGI's field work contributes to the confidence of users in its map products.
- **Consistency**. For the purpose of estimating change rates, the November 2001 workshop participants also agreed that only maps that had been validated in the field and with legends equivalent to INEGI's Series II maps would be used. The use of INEGI map products carries two advantages in this regard:
    - INEGI is consolidating its production of maps so that the Series III will be produced first at 1:250,000 scale and then by aggregation compiled at 1:1,000,000 scale. This will ensure that estimates of both national and regional change figures are consistent.
    - Compatibility of legends between Series II and III will also be ensured. This compatibility will be observed in future series that will be developed in five-year cycles.

6.1.3 Interagency Coordination

The November 2001 workshop participants recognized the need to support ongoing forest information management over the long term through collaborative mechanisms and support systems. For example, the cost of the field survey is a determining factor for any mapping project. A survey carried out merely for the purpose of estimating deforestation is not cost-effective. INEGI has requested input from

SEMARNAT to further redefine the field survey of its LU/LC Series III. This presents an opportunity to optimize the use of scarce resources to provide verification in the field of gathered data.[29]

Cost could also be reduced if SEMARNAT works closely with INEGI for the elaboration of the Series III maps. INEGI's program for the LU/LC series is a five-year cycle with some 20 percent of the country surveyed each year. Conducting the forest inventory on a tandem schedule with INEGI's program could have the valuable benefit of allowing SEMARNAT to better budget and program the work of the forest inventory.

By using the INEGI maps with a common set of standards, SEMARNAT and other users will also be able to work jointly with INEGI on the interpretation of forest classes during the mapmaking process so that polygons are depicted in way that is useful for measuring change. The agreements to make this possible are already in place.

6.1.4 Consistent Set of Standards (*Norma*)

Finally, a consistent procedure with a clearly defined set of standards will facilitate the sharing of data between and among government agencies and other users. Careful attention to the three areas described above—definition of purposes, comparison of maps, and interagency coordination—will provide the technical foundation upon which SEMARNAT can draft a corresponding regulation (*norma*).

6.2 Action Steps

To move forward in a way that continues to build consensus and facilitate collaboration, the participants also agreed to a number of action Steps.

6.2.1 Multiple Purposes

A key component in a methodology for supporting multipurpose definitions of "forest" and "deforestation" will be to develop a look-up table to relate the Series II INEGI classes to the legend required for the National Forest Inventory. The recommended action from the November 2001 workshop was to use the SEMARNAT change matrix 93-2000 as the basis for the identification of change categories. Specifically, this could be carried out through the following steps.

- Step 1 - Develop an area summary for each class to determine sampling intensity (a minimum of two plots per strata).
- Step 2 - Define the steps involved going from INEGI's Series II.
- Step 3 - Identify the deforestation information that will be possible from this comparison. Will it meet Mexico's needs?
- Step 4 - Determine the cost of comparing the Series II data sets with other products, on a pilot basis.
- Step 5 - Identify and determine the costs of potential alternative ways of determining deforestation rates that may be less expensive.

[29] According to SEMARNAT (Lopez-Forment, November 2001) the average cost for each field sample is US $200. The number of samples required for the forestry inventory will be at least 20,000, since it amounts to a new inventory. The total for the field work forest inventory will be at least US $4,000,000. An estimate of change can be carried out with more modest resources.

Step 6 - Explore the possibility of classifying "forest" polygons according to canopy closure at three levels (e.g., greater than 80 percent, between 50 and 80 percent, and under 50 percent). Assess the value of canopy closure estimates for addressing biodiversity purposes as well as timber production potential purposes.

6.2.2 Comparison of Maps

The 1:250,000 scale maps of INEGI were selected by the participants in the November workshop to serve as the basic area and location information for estimating changes in land use and land cover. The next steps will be the following.

Step 1 - Identify ways in which the maps can be enhanced to respond better to long-term monitoring of changes in land use and land cover.

Step 2 - Identify and summarize the contents of the INEGI data dictionaries regarding classes, widths, areas, and so forth in order to enhance the ability of the maps for monitoring change.

Step 3 - Develop 1:1,000,000 scale LU/LC maps by aggregating the corresponding 1:250,000 maps.

Step 4 - Use INEGI's modified Series II LU/LC maps as a baseline for estimating land use change and deforestation rates.

Look-up tables must also be established that relate the categories of INEGI's Series II maps to those of future work, in order to ensure the long-term usability of the approach. The next steps in establishing useful look-up tables are to

Step 1 - Identify the INEGI classes that satisfy the information needs for each of the four key purposes.

Step 2 - Identify how these classes should be clustered into meaningful categories for measuring changes relevant to each purpose.

Step 3 - Hold a workshop with INEGI and other interested institutions to develop the table(s).

6.2.3 Interagency Coordination

In order to support ongoing forest information management over the long term, the November 2001 workshop participants identified the following steps.

Step 1 - Those responsible for inventories in natural resources should support and monitor INEGI's progress on the development of the Series III maps and share information as appropriate.

Step 2 - Change should be estimated every five years, using LU/LC maps. To do so, it will be necessary to

Step 2.1 develop a methodology for estimating deforestation rates that are compatible with natural resource monitoring and forest inventory efforts, and

Step 2.2 ensure continuity of staff and funding.

Step 3 - Consider updating the forest inventory.

In addition, it was agreed at the workshop that the Government of Mexico should allocate resources to fund and implement long-term surveys and to maintain an extensive network of permanent field plots that provide the statistically sound field sampling required.

6.2.4 Consistent Set of Standards (*Norma*)

SEMARNAT has expressed its intention to formalize a methodology for consistent measurement of deforestation rates. The results of the present process will form the basis of the technical document that SEMARNAT will present for the elaboration of an official regulation (*Norma Oficial Mexicana*).