

STATISTICAL STRATEGIES FOR GLOBAL MONITORING OF TROPICAL FORESTS¹

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INTRODUCTION

The Food and Agricultural Organization (FAO) of the United Nations is conducting a global assessment of tropical forest resources, which will be accomplished by mid-1992. This assessment requires, in part, estimates of the total area of tropical forest cover in 1990, and the rate of change in forest cover between 1980 and 1990. This paper describes: (1) the strategic process used to select the statistical and remote sensing methods that accomplish this objective, (2) general details and expected precision of the selected method, and (3) recommendations for monitoring and assessment actions after 1992.

DESIGN ALTERNATIVES CONSIDERED

Four fundamentally different design alternatives were considered:

- (1) Collection of existing data, primarily national forest inventories, supplemented with regression models that predict forest extent and rates of deforestation as functions of eco-floristic classifications and human population density.
- (2) Digital classification of course-resolution satellite scenes from 1990 that completely image the world's tropics. All terrestrial 1.1 km² AVHRR pixels for the world's tropics are classified into two categories: forest or non-forest. Regression models from the first alternative would be used to estimate rate of deforestation between 1980 and 1990.
- (3) Visual interpretation of a randomized sample of high-resolution satellite images (which are treated as permanent plots) for 2 dates (1980 and 1990), with a sampling intensity of 5 to 40 percent of the world's tropics. The entire photographic image for each sample scene is classified into 7 to 14 different categories of terrestrial cover.

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- (4) Visually interpreted classification of a high-resolution satellite images that completely cover the world's tropics.

FAO has already accomplished the first alternative, the second and third alternatives can be accomplished by mid-1992, and the fourth alternative would require at least 5 to 10 years to complete.

EVALUATION CRITERIA

These four alternatives were compared with the following 12 evaluation criteria. Each criterion reflects FAO objectives.

Given the controversial nature of tropical deforestation, and the contradictions among existing global estimates, FAO must produce (1) scientifically objective and credible estimates that can be trusted by various national and international institutions. If estimates used to support policy considerations are suspect, then technical methods used produce the estimates become a central issue; this diverts attention from more important issues, and hinders development of consensus among institutions. Therefore, the FAO design should use (2) statistically acceptable methods. Estimates should be reasonably (3) precise, and include a quantitative and objective (4) measure of reliability to evaluate precision. Estimates should be statistically (5) unbiased, or nearly unbiased relative to the precision of the estimates.

The FAO assessment requires more than a description of the current status and trends in the global condition of tropical forests. The assessment also requires an understanding of the processes that have caused the current condition, effects of current policies and likely outcomes of policy changes. Therefore, the FAO statistical design should help institutions better (6) understand the causes and effects of deforestation, and eventually afforestation and reforestation practices. This can be accomplished, in part, by development of quantitative models that predict the expected rate of deforestation based on social, technological, and environmental variables. Model predictions can be scientifically compared to observed rates of deforestation. Where the expected and observed rates reasonably agree, the predominant causal factors are likely included in the model, and there is more confidence that the major processes are adequately understood. Where the agreement is poor, additional study is required to hypothesize the cause of the disagreement, and incorporate additional predictor variables in the model. Reliable models are necessary to (7) analyze future policy issues. The monitoring design should support this evolution of understanding.

Global monitoring is a massive task that requires effective cooperation among FAO, several other international institutions, and many national institutions. This requires convincing motivation for each cooperating institution to contribute to joint efforts. Therefore, the FAO design should have (8) utility to developing nations, which often require better mapping, inventory, and assessment of their national forest resources, including a stable institutional base to support these activities. For similar reasons, the design should have (9) utility to international institutions. One of the implications of this is the ability to (10) address global environmental issues, such as biomass, biodiversity, and opportunities for reforestation and afforestation.

The FAO design must have a (11) high probability of success to support its global tropical forest resource assessment. In the longer-term, global monitoring should be conducted on a regular cycle to support assessments of existing and future policies. This requires a design that is (12) adaptable to changing funding levels, both increases and decreases.

As will be discussed later, none of the 4 design alternatives is clearly superior relative to all 12 evaluation criteria. The short-term selection of one alternative necessitates compromises among FAO objectives, and their associated evaluation criteria. However, in the longer-term, components of all 4 alternatives might be combined into a global monitoring system that adequately satisfies all objectives. This would preserve the value of investments in a design that is specialized for short-term objectives.

STATISTICAL ISSUES

Any system for credible global monitoring of tropical forests will have certain complexities that involve many statistical issues. Many of these issues are discussed in detail in Czaplewski (1991). However, some of the more important issues are summarized in this section.

Sampling error is a well known source of uncertainty in sample surveys. This primarily affects the third design alternative, which uses a sample of high-resolution satellite scenes. However, all 4 alternatives are affected by substantial sources of non-sampling error.

Land uses are rapidly changing in many tropical regions. The value of past data is slowly lost because of changes in land use, such as conversion of forest to agricultural uses. In statistical terms, these changes introduce bias when past data are used to estimate current conditions. The magnitude of this bias shifts with time, at different rates depending on the rate of change in land use. The magnitude of this bias can be estimated with models that predict the expected rate of change, and the bias can be corrected if the model predictions are unbiased. However, models introduce an additional component of uncertainty, known as random prediction error.

The last three design alternatives use satellite data; many of the existing national inventories used in the first alternative also use satellite data. Missing data is a chronic problem with satellite images. Most images have some small cloud patches that are largely distributed randomly. Many tropical regions are dominated by clouds at most times, but adequate satellite images with minimal cloud cover are usually available over during a 1 to 3 year interval. However, some areas have perpetual cloud cover, especially in equatorial Africa. In addition, many historical satellite scenes have not been archived, and are not available, especially coarse-resolution satellite data.

Classification of land cover and land uses with satellite data is not a perfect process, and many sites are misclassified. This causes misclassification error in estimates of the percentage of a region occupied by different cover categories. For example, let $\underline{Y}$ equal the remotely sensed percentage of deforestation in a region, and $\underline{X}$ equal the true percentage of

deforestation. The remotely sensed percentage is the following mathematical function of the true percentage:

$$\underline{Y} = [\underline{H}_A \underline{X}] + [(1 - \underline{H}_B) (100\% - \underline{X})] \quad (1)$$

where $\underline{H}_A$ is the proportion of sites classified as deforested that are truly deforested, and $\underline{H}_B$ is the proportion of sites classified as forest that are truly forest. Equation (1) shows that misclassification will bias area estimates from remote sensing; the remotely sensed percentage ($\underline{Y}$) will not equal the true percentage ($\underline{X}$) unless there are no omission errors, i.e., $\underline{H}_A = \underline{H}_B = 1$, or effects of omission errors exactly compensate, i.e., $(1 - \underline{H}_B) (100\% - \underline{X}) = (1 - \underline{H}_A) \underline{X}$. Assume classification accuracies are high for all cover types (e.g., $\underline{H}_A = \underline{H}_B = 0.95$). If deforested areas truly cover 10 percent of a region, then the remotely sensed estimate will be 14 percent (see equation 1). In this example, the remotely sensed percentage will be 1.4 times larger than the true value. If a small percentage of a common cover type is misclassified as a rare cover type, then the area occupied by the rare type will be overestimated, unless there is a high rate of omission error in classifying the rare type. The magnitude of misclassification bias is discussed in more detail by Czaplewski (1992). Misclassification bias might explain some of the disturbing discrepancies between current estimates of deforested area made with coarse-resolution satellite data by several international institutions, and independent estimates made with photo-interpretation of high resolution satellite data by national institutions. Unexplained discrepancies reduce the credibility of all estimates.

Statistical calibration techniques can be used to remove the bias caused by misclassification bias. Calibration cannot identify misclassified pixels. Rather, calibration is a probabilistic technique; it uses proportions of imperfectly classified pixels in a sample of reference plots to estimate conditional probabilities of various types of misclassification, and these estimated probabilities are then used to predict the true percentage of each cover type given the remotely sensed percentages. For example, equation (1) can be solved for the true percentage of deforestation ($\underline{X}$), given the remotely sensed percentage ($\underline{Y}$) and the estimated conditional probabilities of correct classification ($\underline{H}_A$ and $\underline{H}_B$). Since a sample of reference data is used to estimate these conditional probabilities, the estimates of $\underline{H}_A$ and $\underline{H}_B$ will contain sampling errors, and the estimated percentage of deforestation will include propagated errors from the calibration model. A sample of high-resolution satellite scenes is well suited as reference data to calibrate course-resolution satellite estimates. Hay (1988) discusses this general situation in more detail.

Statistical calibration requires accurate estimates of misclassification probabilities using reference plots from the region, and this requires accurate registration of high-resolution reference plots onto the lower-resolution imagery. Registration error will cause error in the estimates of the conditional probabilities of correct classification ($\underline{H}_A$ and $\underline{H}_B$) in equation (1). This error will be propagated through the calibration model, and cause error in calibrated area estimates. Accurate registration can be difficult in certain landscapes, and effective quality control is required to minimize this source of error.

Classification of land cover into multiple categories presents a multivariate estimation situation. The sum of all cover categories equals exactly 100 percent of a region. Independent univariate estimates for each category will not necessarily add to 100 percent, which can reduce credibility. In addition, the estimation error variance for the sum of all cover categories equals exactly zero (because the sum of all cover types equals exactly 100 percent), even though area estimates for each category will have a non-zero variance caused by random sampling, prediction, or propagated errors. Therefore, the estimation error covariance matrix should have many negative covariance terms off the diagonal. For assessment purposes, different cover categories are often combined into less specific categories, and the estimation error variance for a combined category will be reduced if the negative covariance terms are properly considered. Also, the additivity constraint can make multivariate estimators more precise than independent application of univariate estimators to each category. However, the statistical methods for multivariate estimation are less well developed than those for univariate estimation.

A systematic sample might improve statistical efficiency. However, systematic sampling might unknowingly align with systematic features within strata, and variance estimates for systematic sampling are more problematic than for random sampling. These factors reduce credibility somewhat. It is also easier to intensify future random sampling in small increments if funding levels increase, but intensification is geometrically difficult with systematic sampling.

The statistical efficiency of a sample of high-resolution satellite data scenes might be increased by sampling with probability proportional to size (PPS). The "size" of each possible sample unit could be defined as the expected rate of deforestation, or the expected extent of forest, within each potential sample scene. These expectations are available from FAO models and geographic information system, which contains existing continental-scale maps and national inventories. However, a PPS sample will cause inefficiencies if the FAO sample is used as permanent plots in a long-term monitoring program. For example, a sample unit with high rate of deforestation between 1980 and 1990 might have a low rate between 1991 and 2000 because the forest resource in that sample unit might be depleted by 1990. Also, PPS requires proper consideration of the unequal probabilities of sample unit selection when fitting regression models, which might be used in future calibration estimators or deforestation models; weighted regression should be used, with weights inversely proportional to probability of selection. PPS will produce unbiased estimates. However, sample units with high rates of expected deforestation are selected with higher probabilities than sample units with low expected rates of deforestation. This fosters a misperception among non-statisticians that PPS will produce overestimates. Even though this perception is not based on statistical theory, this perception can reduce credibility of PPS estimates.

Other statistical issues are discussed by Czaplewski (1991), which are summarized here. Several alternative area sampling frames can be used for high-resolution satellite data, or calibration for misclassification bias with course-resolution satellite data: sub-national geo-political units, high-resolution satellite scenes, map sheets, aerial photographs, and field plots. Each potential frame has advantages and disadvantages. Efficiency of sampling

designs for high-resolution satellite data, or calibration of course-resolution satellite data, can be improved with stratification; there are numerous criteria that can be used with available data to stratify, and each potential set of criteria have advantages and disadvantages.

EVALUATION OF ALTERNATIVE STATISTICAL DESIGNS

None of the 4 design alternatives listed at the beginning are clearly superior given all evaluation criteria; this implies that some objectives will be satisfactorily served, while other objectives will not be fulfilled, at least in the short-term. Therefore, selection of a design implies judgements regarding the priority of evaluation criteria.

The most important short-term objective is production of credible global estimates of deforestation rate (ha/year) between 1980 and 1990, and secondarily on credible global estimates of the areal extent (status) of tropical forests in 1990. To be credible, the estimates must be scientifically sound, unbiased, and reasonably precise. Some degree of consensus is required among national and international institutions in order to implement policies that affect management of tropical forests. Consensus is best nurtured by credible information, and FAO is one of the few institutions capable of providing this information in a timely fashion. Until some consensus is achieved, changes in the current management of tropical forests are unlikely. Therefore, high priority should be placed on production of credible information within the near future.

The first design alternative is use of existing national inventories and deforestation model. It uses ad hoc methods similar to those used by FAO in 1980 for its previous assessment of tropical forest resources. This alternative produces estimates of unknown precision that include unknown levels of bias. The expectation is that these estimates will be reasonably precise and unbiased. This expectation cannot be scientifically defended. In fact, this alternative has already been implemented by FAO. However, FAO has decided to continue its progress by pursuing a complementary alternative that provides more defensible information.

The existing FAO data base has great value in that it can be used to more efficiently implement other design alternatives that are more credible to other institutions. This data base has also been used to model the rate of deforestation using empirical data on deforestation from existing national forest inventories, estimates of human population for sub-national units, and maps of eco-floristic zones. This model is one initial step to better understand factors affecting the process of deforestation, which can help assess effects of policies on tropical forests. Therefore, past FAO efforts on this alternative serve a useful purpose, and the value of these past efforts can be enhanced by progressing to a more scientifically credible strategy.

The second design alternative uses course resolution satellite data to estimate the status of tropical forest cover in 1990. However, classification of 1.1 km² AVHRR pixels into a forest or non-forest category is not considered a reasonable definition of truth by most national institutions; therefore, the credibility of data produced by this alternative is suspect.

This alternative cannot estimate the rate of deforestation between 1980 and 1990 because historical images near 1980 were not acquired or archived. This alternative might be used to make biased estimates of total deforestation to date for regions where the past extent of forest is known. However, a deforestation model is required to estimate deforestation between 1980 and 1990, as in the previous alternative. Since the precision and bias of this model is not known, this alternative is not recommended for estimating deforestation in the short-term.

Misclassification errors will bias course-resolution satellite estimates of tropical forest cover in 1991. Without a sample of higher-resolution data, the magnitude of misclassification bias is can not be statistically estimated. Course-resolution satellite estimates can be calibrated for misclassification error, using existing forest inventories of sub-national units (e.g. Iverson 19??). However, this requires a non-random sample of sub-national units to build the statistical calibration model. There will be differences in dates of sub-national inventories, and probably differences in definitions and measurement protocols. Therefore, the scientific credibility is suspect, and can not be recommended for FAO objectives.

Course-resolution satellite data can be calibrated for misclassification error, using a sample of High-resolution satellite scenes. Presently, no institution has provided the necessary high-resolution satellite data that are needed to calibrate for misclassification bias. Therefore, this alternative is not recommended for short-term implementation, although this recommendation would change if the accurately classified calibration plots were available in the future.

This alternative does have several short-term benefits. It provides a description of the geographic distribution of land uses that have caused deforestation. This helps focus national and international assessments and policy concerns in specific geographic areas. It also provides a picture of the current situation that can be rapidly and effectively communicated to policy-makers and concerned publics. Furthermore, the present extent of tropical forest cover is one of several important predictors of deforestation in the FAO deforestation model. Even biased estimates of forest extent will improve application of the FAO deforestation model to relatively small geographic areas (e.g., sub-national units) where current data on forest extent is not available.

Several international institutions are in the process of implementing this alternative, and results for the world's tropical forests are expected in the near future. FAO has attempted to assist these other institutions by facilitating archival of 1990 AVHRR digital images for the entire tropics.

The third design alternative is a statistical sample using high-resolution satellite data. It emphasizes a scientifically credible, design-based statistical sample of high-resolution satellite data scenes for estimating

area extent of tropical forests in 1990, and the rate of deforestation between 1980 and 1990.

This alternative does not use the FAO deforestation model to estimate deforestation between 1980 and 1990. Rather, it uses a randomized sample of high-resolution satellite data scenes (i.e., permanent plots) for which 1980 and 1990 images are available. This alternative assumes that credible estimates of change in forest extent for each sample unit between 1980 and 1990 can be visually interpreted by comparing images for the same sample unit at two dates. This assumption is considered reasonable because many international institutions consider less detailed interpretations of coarse-resolution satellite data as truth, and many national institutions currently map their forest resources with visual interpretation of high-resolution satellite data.

This alternative considers a randomized sample of high-resolution satellite data scenes, which is expected to have high scientific credibility. However, the precision of this alternative depends on the sample size of plots used to estimate forest extent in 1990, and the rate of deforestation between 1980 and 1990. If this sample size is too small for a given region, then this alternative will not be credible because the precision of the estimates will be unacceptable. Preliminary estimates of sampling error have been made using the current FAO data base, and acceptable levels of precision are expected using 100 high-resolution satellite data scenes for a global estimate (Czaplewski 1991); however, more intensive sampling is needed multi-national regions. This alternative is discussed in more detail in the next section.

The fourth design alternative is complete mapping of the tropics with high-resolution satellite data. This alternative emphasizes national objectives, but it also produces data for international objectives. A non-random sequence of cartographic units (i.e., map sheets) are visually interpreted by national institutions, using high-resolution satellite scenes, until entire nations are completely mapped. This will take 2 to 10 years for any single nation. Then, map sheets are re-interpreted using more recent imagery to estimate rates of areal change such as hectares of deforestation.

This alternative requires complex geo-statistical methods to produce relatively unbiased estimates of known precision. The non-random sequence requires a deforestation model to update areal estimates for older map sheets. However, the bias and precision of model predictions might objectively quantified using remeasurements of some map sheets each year for multi-national regions.

Although this alternative has desirable long-term features, this alternative requires functional national institutions that do not currently exist in tropical nations, and it will take years to develop such institutions. Complex model-based geo-statistical methods are vulnerable to legitimate scientific criticism, which reduces the international credibility of this alternative. However, the third alternative (i.e., randomized sample of high-resolution satellite data) facilitates an evolution towards this fourth design, which better serves national objectives.

STATISTICAL DESIGN SELECTED BY FAO

All 4 alternatives except one lack the immediate credibility that is needed to improve the current situation that faces FAO and the international community. Therefore, FAO has chosen a design based on a randomized sample of high-resolution satellite data scenes for estimating the extent of tropical forests in 1990, and the rate of deforestation between 1980 and 1990. This alternative places highest priority on credible estimates of tropical forest extent in 1990, and rates of deforestation between 1980 and 1990. This alternative produces the most credible estimates in the short-term, assuming a sufficiently large sample of satellite scenes can be interpreted.

The first alternative, i.e., accumulation of existing data, has already been implemented by FAO, but the sample of high-resolution satellite scenes is required to improve credibility of these estimates. Other international institutions are implementing the third alternative, i.e., coarse-resolution satellite data, but these institutions will not likely produce credible estimates of deforestation between 1980 and 1990. The fourth alternative, i.e., complete land cover and land use mapping of the global tropics, has many desirable features in the long-term, but this alternative can not be completed in time for the FAO assessment. However, the selected alternative is a short-term design that will serve more long-term objectives, which are discussed in the next section.

The principal weakness of the high-resolution satellite data alternative is the potential lack of precision from a small sample size of high-resolution satellite data scenes, which is caused by cost and logistical requirements. Based on preliminary data in the current FAO data base, it appears that reasonable continental estimates of the status of tropical forest cover in 1990 can be estimate from a global sample size of 117 high-resolution satellite scenes, as shown in the following table.

CURRENT ESTIMATE OF SAMPLING PRECISION
± x% AT 95% PROBABILITY LEVEL

<u>REGION/STRATUM</u>	<u>CONFIDENCE INTERVAL</u>	<u>LANDSAT SAMPLE SCENES</u>
LATIN AMERICA	± 5%	40
AFRICA	± 8%	47
ASIA	± 8%	30

However, the confidence intervals for rate of deforestation between 1980 and 1990 are expected to be 1.5 to 2.0 times larger than confidence intervals for status in 1990. Also, confidence intervals for more detailed classifications of land cover and type of change will be greater. These factors will limit the spatial detail of the initial FAO assessment; reasonable precision might only exist for the global estimates, which would preclude detailed assessments for continental or sub-continental regions. More spatial detail is needed for global assessments, and opportunities to improve precision by building upon the FAO system are briefly discussed in the final section.

RECOMMENDATIONS FOR FUTURE GLOBAL MONITORING EFFORTS

Although a statistical sample of high-resolution satellite scenes appears best for short-term FAO objectives, the other 3 alternatives have certain advantages for mid-term and long-term objectives. A far-better course of action would be the eventual combination of the strengths of each alternative into a single, continuous system for monitoring and assessment of tropical forest conditions. Without a continuous system, policy decisions are based on information that loses credibility over time. The selected FAO design should be considered as a short-term step towards achieving a continuous system that combines the desirable features of many alternative monitoring procedures. Some of the opportunities for evolution towards better monitoring systems of the future are discussed in this section.

In cooperation with other international institutions, FAO's sample of high-resolution satellite data should be used to calibrate course-resolution satellite data estimates of tropical forest extent, which are now being developed by other international institutions. Calibration for misclassification bias would reconcile inconsistencies and increase credibility of estimates from all participating institutions. The advantages of the spatial detail in course-resolution satellite data estimates could be combined with the advantages of unbiased FAO global estimates. Unbiased estimates of forest extent in 1990, with known precision, could be produced for all sub-national units with the sub-national unit boundaries stored in the FAO geographic information system. However, precision for small regions could be low, and nonlinear relationships between multivariate course-resolution satellite data and high-resolution satellite data estimates for individual high-resolution satellite data scenes could present statistical difficulties.

FAO should calibrate its FAO deforestation model. Model predictions of deforestation could be compared with direct observations of deforestation from interpretation of 1980 and 1990 sample high-resolution satellite data scenes. The differences between model predictions and remotely sensed observations can be used to calibrate for model prediction bias, and the calibrated estimates would have known precision. This is related to calibration for misclassification bias. The calibration estimator could be applied to deforestation estimates from the deforestation model for all sub-national units, even those for which high-resolution satellite data sample estimates were not available. This would greatly enhance the spatial resolution for unbiased FAO estimates of deforestation.

The sample size of high-resolution satellite data scenes should be increased after the initial FAO assessment is produced. High-resolution satellite data imagery for 1980 and 1990 would be used to produce more precise estimates of deforestation between 1980 and 1990, and status in 1990. For example, the global assessment might be based on 100 high-resolution satellite data scenes, but another 100 sample scenes might be interpreted in 1993, another 100 sample scenes in 1993, and another 100 sample scenes in 1995. This will continually improve the precision of the statistical estimates over the next few years for global estimates and estimates for subregions.

The sample of high-resolution satellite scenes should be continuously monitored after the initial FAO results are produced in 1992. This is one step towards achieving the FAO objective for continuous monitoring of tropical

forests. For example, high-resolution satellite data scenes imaged in 1995 might be acquired for a portion of high-resolution satellite data sample scenes for which 1980 and 1990 high-resolution satellite data imagery was interpreted. Changes in forest cover and land uses between 1990 and 1995 would then be interpreted to produce a statistical estimate of deforestation between 1990 and 1995. The following year, high-resolution satellite data scenes imaged in 1996 might be acquired for a different portion of high-resolution satellite data sample scenes to produce a statistical estimate of deforestation between 1990 and 1996. An interpenetrating cycle of remeasurements of high-resolution satellite data would permit annual estimates of deforestation. The details of this progressive development of a continuous monitoring design require considerable thought and planning, but this might be deferred until the immediate FAO objectives are met. This would require more complex statistical estimators that incorporate a deforestation model in order to correctly treat a time series of remeasurements for high-resolution satellite data permanent plots. Also, a time series of high-resolution satellite data will permit calibration of future course-resolution satellite data estimates of deforestation.

Course-resolution satellite data estimates should be combined with model predictions of deforestation. If the other actions given above are accomplished, unbiased estimates of deforestation for all sub-national units will be available from calibrated course-resolution satellite data estimates and calibrated predictions from the FAO deforestation model. Both types of estimates for each sub-national unit will be unbiased with known precision, but the two estimates for each sub-national unit will be different because of random errors propagated from the statistical calibration models. However, the two estimates for each sub-national unit can be combined into a single, more precise estimate with a multivariate composite estimator.

In cooperation with many institutions, FAO should maintain the data base for existing data for sub-national units. This includes summary results of future forest inventories conducted by individual nations, and other estimates of forest extent, deforestation, reforestation, afforestation, and human population density. The FAO geographic information system that contains sub-national unit boundaries and thematic maps of forest status should also be maintained. This data base has already been built by FAO, and has been essential in the development of the FAO deforestation model. Improvements in the deforestation model require maintenance of the FAO data base. The deforestation model is essential for several of the actions above; also, the deforestation model is expected to be an important tool in future policy analyses for tropical forests. Additional tabular and geographic data should be acquired and maintained, such as road densities.

Forest mapping by national institutions should be supported. This is important for development of forest resource monitoring, assessment, and management at the national level. This can also benefit international monitoring and assessment activities. If national and international institutions can share the same information base, then credibility and successful coordination are more likely. The first step in this process is developing or strengthening national institutions that can consistently perform these functions, and transferring the necessary technologies to these institutions.

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