TIME-SERIES FOREST CHANGE,

LAND COVER/LAND USE CONVERSION,

AND SOCIO-ECONOMIC DRIVING FORCES

IN THE PETEN DISTRICT, GUATEMALA

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1. Introduction

Impacts on the global environment resulting from human activity are occurring at extraordinary magnitudes, rates, and spatial scales. The potential consequences of land cover and land use change are of global concern, affecting climate and atmosphere, hydrology and nutrient cycles, biodiversity, productivity, sustainability, and the international economy. This study addresses issues in monitoring land cover and land use change in the forest of Guatemala's northern frontier. The District of El Petén contains rich biological diversity in vast lowland tropical forests and freshwater wetlands. Together with adjacent forests in Mexico and Belize, the region known as *La Selva Maya* (**Figure 1**) represents the largest contiguous tract of tropical moist forest remaining in Central America. From A.D. 250 to 900, the forests of the Petén provided the biological foundation for the Classic Mayan period, one of the most developed civilizations of the time. To protect the forest, it's biological diversity, and it's cultural heritage, the Maya Biosphere Reserve (MBR) was created by Guatemalan congressional decree in 1990.

Until recently, the Petén has supported a low population relative to the more crowded and heavily deforested southern highlands of Guatemala. The traditional life of these people has included mainly shifting cultivation agriculture and the harvest of non-timber forest products. This "forest society" of the Petén (Schwartz, 1990), and the livelihood of its people, is inextricably linked to the fate of the forest. This forest, despite legal protection, is being destroyed at an alarming rate. Forest is continually being cleared and its resources greatly taxed as human migration and the expansion of the agricultural frontier threatens the people and environment of the northern Petén (Sader *et al.*, 1997). A thousand years ago, a postulated combination of factors including population growth, political instability and warfare, overuse of resources, climate change, and environmental destruction likely led to the collapse of the ancient Mayan civilization. A similar combination of factors threatens the forest and its inhabitants today, despite a much lower population and a much shorter time frame (Sever, 1998).

2. Land Cover / Land Use Change Research in the Petén

Given the importance of land cover and land use change data in conservation planning, Sader and colleagues (Sader *et al.*, 1994; Sader *et al.*, 1997; Sader 1999; and Sader *et al.*, In Press) have monitored over ten years of deforestation in the MBR via time series satellite image analysis. The University of Maine, the University of Delaware, Conservation International (CI), and NASA – Marshall Space Flight Center, have engaged in a cooperative research project supported by the NASA Land Cover / Land Use Change (LCLUC) Science Program, to study land use change dynamics in the MBR. Other cooperators in the region include the U. S. Agency for International Development (USAID), the Guatemalan Consejo Nacional de Areas Protegidas (CONAP), and other non-government organizations (NGO's), such as the Nature Conservancy (TNC) and the Wildlife Conservation Society (WCS). This research has provided regularly updated forest change maps for the MBR, a key component of CI's forest monitoring and evaluation program. Land cover and land use change analysis has included the identification and spatial distribution of second growth vegetation, the development of a 20+ year forest conversion history database, and the collection and analysis of house-hold level information to address the socio-economic context for land use change in four rural communities.

This progress report documents the project status as it approaches completion of its third year. The major activities of the third year have focused on:

1. continued update of forest change maps for NGO conservation planning and policy development (now six dates from 1986 to 1999),
2. a proposed monitoring system for the MBR integrating Landsat-Thematic Mapper (TM) at level 1,
3. the development and testing of satellite forest change detection techniques for transfer of technology to NGO's,
4. the development and analysis of a forest clearing and regrowth database,
5. analyzing the effects of landscape variables on forest clearing, and
6. the linking of community-level socio-economic data to the land cover / land use change analysis.

This report reviews the development and analysis of the land cover change and socio-economic data, and highlights the significant results. Publications and other output products resulting from this project and related research are included. Finally, a discussion of the challenges for future research inspired by the work follows the progress report.

2.1 *Updated Forest Change Maps for the MBR*

This research project has a strong cooperative component with international and local NGO's. The development of the time-series forest change detection maps of the MBR are considered by CI and USAID to be their most powerful education and monitoring tool (Kristensen *et al.*, 1997; Reining *et al.*, In Press). The satellite change detection methods developed in this research has been adopted by CI as the first level of a three level biological monitoring system for their international programs (Reining *et al.*, In Press). Because the forest change detection maps are eagerly anticipated by Guatemalan government agencies and international NGOs alike, we have updated the forest change detection maps twice (1997 and 1999) (**Figure 2**), at the request of CI, CONAP, and USAID. The maps were distributed to all cooperators in digital and hard copy form and the results were presented at a regional meeting in Flores, Guatemala in December, 1999. In addition, we prepared a land cover map from 1997 Landsat-TM for the MBR and cooperated with CI in developing a Maya region map also including Mexico (Yucatán Peninsula and Chiapas) and Belize.

2.2 *A Proposed Monitoring System for the MBR*

A forest monitoring framework using Universal Transverse Mercator (UTM) grid cells to report forest change estimates derived from time-series satellite imagery was established for the MBR (Sader *et al*., In Press). Five dates of Landsat-TM imagery were acquired and digitally processed to quantify forest change for four time periods: 1986 to 1990; 1990 to 1993; 1993 to 1995; and 1995 to 1997. Time-series change estimates were reported for 215 grid cells, approximately 100 sq. km each (**Figure 3**).

For the period between 1990 and 1997, after designation of the MBR, 61% of the cells had little or no forest clearing detected (<0.1% per year) and 12.5% had from 0.1 to 1.0% annual forest clearing. In addition, 21.4% of the cells were found to have 1.0 to 4.0% forest clearing per year while approximately 5.1% had annual forest clearing rates exceeding 4.0%. The accuracy of detecting forest clearing was 86.5% overall (Kappa, 0.82).

Estimates of forest change are reported for all MBR management units for each time period between 1986 and 1997 (**Table 1**). The forest change results indicate the locations of deforestation "hotspots" where agricultural expansion is moving from the designated buffer zone into the multiple use zone (MUZ) and core areas of the reserve. The baseline survey and the establishment of the UTM grid network provides an inventory and sampling framework for future satellite-based estimates of forest and land cover / land use conversion to be monitored over time. The UTM grid is proposed as the first level in a multi-level ecological monitoring scheme for the MBR (Kristensen *et al.*, 1997; Reining *et al.*, In Press), a remote and largely inaccessible region where there are few permanent landmarks.

2.3 *The Development and Testing of Satellite Change Detection Techniques*

One objective of the research was to develop an accurate and efficient change detection method. In addition to achieving a satisfactory level of change detection accuracy, it was important in this study that the methods be easily transferable to local government agencies and NGOs, such as CI / ProPetén, working in the region. This was crucial to meet the objective of developing effective methods for updating change detection maps to support conservation-based decision making by local participants. This goal was accomplished through training sessions provided by the research team in Guatemala and the U.S. (NASA - Stennis Space Center).

Methods were employed to normalize multiple dates of imagery through radiometric connection (Eckhardt *et al.*, 1990; Hall *et al.*, 1991). The radiometric normalization technique proved easy to perform. All imagery (7 dates from 1974 to 1997) used in this study were radiometrically corrected to avoid potential occurrences of “false change” resulting not from forest clearing or vegetation regrowth but from differences in atmospheric, soil, vegetation, and illumination conditions.

A technique to generate reference points, by visual interpretation of color-composite Landsat images, for Kappa-optimizing thresholding (Fung and LeDrew, 1988) and accuracy assessment was reported (Hayes and Sader, manuscript in review). Without existing historical reference data for the study area, the visual interpretation method reported by Cohen *et al.* (1998) was the best option for developing reference data for error matrices.

Three change detection methods were performed on the three most recent dates of imagery (1993, 95 and 97): normalized difference vegetation index (NDVI) image differencing, principal component analysis, and RGB-NDVI change detection. An error matrix developed with a random sample of visually interpreted reference points was used to compare the accuracy of these methods with kappa and significance tests (**Table 2**). The RGB-NDVI method (Sader *et al.*, In Press) was selected for its high degree of accuracy (85.4% overall accuracy) and ease in interpretation. Within the scope of a larger research effort, the accuracy assessment of these three methods provided justification for further use of the best technique (RGB-NDVI) in analyzing land cover and land use change in the context of socio-economic driving forces in the region. Furthermore, the RGB-NDVI method was preferred for its simplicity in technology transfer to local NGOs and government agencies for future satellite-based land cover and land use monitoring.

2.4 *The Development and Analysis of a Forest Clearing and Regrowth Database*

An objective of this research was to advance the ongoing study of deforestation in the MBR by bringing together an archive of time-series satellite data with past and present information concerning the ecological, spatial, and socio-economic determinants of land cover and land use change. Specifically, a forest conversion history database, derived from satellite image land cover classifications and change detection analysis, was created to monitor the rates and extent of forest clearing over a twenty-three year period. The database was used to quantify rates of forest clearing and regrowth, analyze patch, landscape, and proximity metrics, and identify land cover and land use pathways.

The image processing and change detection methods developed and tested in the techniques study were applied to two dates of Landsat Multispectral Scanner (MSS) and five dates of TM imagery, spanning from 1974 to 1997. The study area encompassed a portion of the MBR covering all or parts of 21 forest concession units, including portions of the MUZ, the buffer zone and core areas (parks and reserves), and corresponding to the locations of the four communities studied in the socio-economic household survey (**Figure 4**).

While some large, remote and inaccessible areas of the reserve experienced little or no clearing over the time periods in the study, forest clearing was concentrated at high rates in other units. Results have shown increasing forest clearing rates over time, corresponding to human migration and the expansion of the agricultural frontier in the department of Petén. Despite the granting of legal protection to the region within the study area in 1990, clearing rates continued to rise, with the highest rates occurring in the most recent time period in the analysis, 1995 to 1997. As population pressure increased and access to land became more limited, analysis of patch statistics suggests an overall trend of clearing a greater number of smaller patches over time (**Figure 5**). Communities that were less dependent on farming as a source of income (e.g. Carmeilta) had less forest clearing over time as well as more balanced forest clearing to regrowth ratios (i.e. 1:1 or less) (**Table 3**). Area cleared to area regrown ratios across the management units show high rates of clearing relative to regrowth in newly established communities (e.g. Buen Samaritano and Paso Caballos) and in the Buffer Zone, where preference for clearing high forest for pasture development exists (Schwartz, 1998). Interpretations concerning regrowth strategies in the newly established communities was limited by the lack of time to observe regrowth trends following the recent clearings.

2.5 *Effects of Landscape Variables on Forest Clearing*

Exploratory models were built and analyzed to examine the effects of various landscape variables on forest clearing. The use of different models shows the effects of scale on the analysis, with each model creating different issues in model building and each providing different information (Hayes, unpublished M.S. thesis). Results, as expected, show the interaction of the different explanatory variables influencing clearing over time. The relationship of forest clearing within management units was not constant over time. Different management units showed different relationships of forest clearing with variables such as forest cover type and distance to access (roads and river corridors). A strong relationship between forest clearing and distance to access was demonstrated, with three-quarters of the clearing in the study area since 1986 occurring within three kilometers of roads (**Figure 6**). More clearing occurred further from roads during later time periods as farmers moved deeper into the forest to find land to clear. In some communities, farmers are known to walk several kilometers to their farm plots (Schwartz 1998). General trends in clearing by forest cover type suggest a preference for clearing in high forest types, and an avoidance of low-lying, seasonally flooded *bajos* (**Figure 7**). As forest became scarce closer to access, fallow fields are cleared in greater percentages than proportionally available, but fallow was not cleared in significant amounts to offset the continued clearing of high forest (Hayes, unpublished M.S. thesis).

2.6 *The Linking of the Socio-Economic Data to the Land Cover / Land Use Change Analysis*

In 1997, a ground-level study to determine the socio-economic forces driving land use strategies was initiated to compliment the remote sensing studies to monitor land use conversion in the MBR. The four communities in the socio-economic study included Centro Campesino in the Reserve's buffer zone, Buen Samaritano in Laguna del Tigre National Park, and Carmelita and El Cruce A Dos Aguadas in the MUZ. The people of these settlements are represented by a range of ethnic groups (**Table 4a**), social backgrounds, and religious affiliations and employ a variety of adaptive strategies and land use techniques. Schwartz (1998) provides a detailed discussion of the methods and results of the socio-economic survey and the factors affecting land use and adaptive strategies among the four communities. The study analyzed land use decisions at the household level within the context of population pressure, migration history, ethnic and religious contexts, poverty, agrarian and extractive activities, and social and biological problems in farming, among other factors.

Socio-economic data can be used to complement satellite image analysis of land cover and land use change, and vice-versa. Such data can facilitate comparisons of and explanations for patterns detected on the imagery (Lambin, 1994; Turner II *et al.*, 1994). Several potential sources of agreement between the database derived from the satellite image analysis and that of the socio-economic survey were examined. For example, such sources included total area of forest cleared in each community, average clearing size for each community, and the proportion of clearing from previously used fields compared to clearing from forest (**Table 4**). Centro Campesino cleared less fallow than was proportionally available and the residents are known to clear more high forest for pasture development (Hayes, unpublished M.S. thesis, Schwartz 1998). Although there are some discrepancies in the exact numbers, the general trends between communities were found to agree between the results of the household survey and the remote sensing database. Explanations for lack of agreement between remote sensing and socio-economic survey results may include possible remote sensing database error, and confusion between clearings for planting crops (*milpa* or shifting cultivation farm plots) and permanent agriculture (e.g. pasture). Furthermore, respondent answers to the survey in 1997 may be time sensitive and may have been approximated in many cases (e.g. size of farm plot) and there exists the potential for unclear answers due to the known legal and political implications of the survey questions (Schwartz, 1998).

Comparison of the trends in the remote sensing data with socio-economic survey data suggests that population alone is not a good predictor of land use dynamics within these four communities (**Figure 8**). The distribution and use of area in clearings and fallow appears to be linked to the length of time since establishment of a community, its typical farming practices, and the degree to which activities other than planting crops is used to support household well-being (Schwartz, 1998; Hayes, unpublished M.S. thesis). In turn, these factors are linked to ethnic background and migration history, level of poverty, and access to land, among others. Schwartz (1990, 1998) provides more detailed discussions of these linkages (**Figure 9**).

3. Continuing Research

The dramatic land cover change occurring over the past decade can be partially explained by the Petén's high rate of population growth (natural growth and immigration combine for a staggering 9.5% population increase per year, recently estimated by CI social analysts). However, the political instability in the region and lack of land tenure in the community concessions makes it extremely difficult to model LCLUC pattern from the pixel level.

Lacking definitive land ownership boundaries (such as the *ejido* system in neighboring Mexico), there is currently no foundation for spatially integrating household survey data with individual farm plots (which are often several kilometers away from the residence). Therefore, we have relied on landscape-level analysis and macro-level biophysical and socio-economic drivers, the latter derived from descriptive data collected in the four community concessions (Schwartz 1998).

Continuing research in the project's third year is attempting to explain differences in landscape measurements and community-level household survey data that may be attributed to confusion of pasture land use and annual cropping patterns. Fieldwork is ongoing to locate known pastures that are otherwise difficult to distinguish on the satellite imagery.

Synthetic Aperture Radar (SAR) studies, originally proposed to analyze second-growth vegetation distribution, have to date been delayed by the lack of suitable available imagery. A September, 1996, JERS (L-band) data set was recently acquired, along with a 3 arc-second digital elevation model (DEM) for the Petén region. Vegetation data have been collected in early second growth forest plots. In addition, we have identified second growth patches of various estimated ages from the time-series forest conversion database. The objective is to analyze SAR backscatter data and merged TM-SAR relationships to predict regrowth age class and above-ground biomass. The field plots will be used as both training and validation sites (independent of one another). From this, we plan to test regionally and locally developed allometric equations to estimate biomass, analyze forest age-class and structure relationships, and evaluate the strength of the correlations.

As part of this on-going work, additional data has been collected concerning vegetation cover and land use on a sample of farm plots, as well as updated information on adaptive farming strategies from farmer interviews. Several manuscripts will be prepared from the results of these continuing studies.

4. Literature Cited

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5. **Publications and Output Products**

5.1 *Manuscripts related to the project*

Hayes, D.J., 1999, Remote Sensing for Monitoring Land Cover and Land Use Change in the Maya Biosphere Reserve, Guatemala. Unpublished M.S. Thesis, University of Maine, Orono.

Hayes, D.J. and S.A. Sader, manuscript in review, Change Detection Techniques for Monitoring Forest Clearing and Regrowth in a Tropical Moist Forest (submitted to *Photogrammetric Engineering and Remote Sensing*, January 2000).

Hayes, D.J., and S.A. Sader, Developing a forest conversion history database to explore the temporal and spatial characteristics of land cover change in the Maya Biosphere Reserve, Guatemala (manuscript in preparation, March 2000).

Hayes, D.J., S.A. Sader, and N.B. Schwartz, Land cover and land use in four community concessions of the Maya Biosphere Reserve, Guatemala (manuscript in preparation, March 2000).

Reining, C.P., P. Kristensen, D. Irwin, S. Sader, J. Musinsky, C. Soza, J. Nations, T. Sever, Land use / land cover change detection: using remote sensing and aerial photography to monitor landscape level deforestation trends in Guatemala's Petén region. In: Ottke, C., P.J. Kristensen, D. Maddox and E. Rodenburg (eds.), *Monitoring for Impact: a Handbook with Lessons from 13 Conservation NGOs*. Joint Publication of World Resources Institute, Conservation International, and Global Forest Watch, Washington, D.C. In Press.

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5.2 *Seminars and Lectures*

S.A. Sader, Land cover and land use change research in Guatemala, and new initiatives in Central America, Environment and Development in Latin America, Florida International University (invited, February 1999).

S.A. Sader, Satellite forest monitoring, Senior Colloquium Series, Colby College (invited, October 1998).

5.3 *Training Provided to Cooperators*

Land Cover Mapping (2 CI – ProPetén, 2 – CONAP), Flores, Guatemala, June 1998.

Change Detection Mapping (1 CI – ProPetén, 1 – CONAP), NASA-Stennis Space Center, Mississippi, September 1999.

5.4 *Presentations*

Hayes, D.J., S.A. Sader, N.B. Schwartz, T.L. Sever, and C. Soza, Preliminary Results: time-series forest change, land cover / land use conversion and socio-economic driving forces in the Northern Petén District, Guatemala, 3rd NASA Land Cover and Land Use Change Science Team Meeting, Airlie House, Warrenton, Virginia (May 18-21, 1999).

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5.5 *Press Conference*

La Biosfera Maya Desde El Espacio: una vision actual (with Conservation International and Consejo Nacional De Areas Protegidos, Guatemala City, November 1998)

5.6 *Maps and Output Products* (delivered to CI and USAID)

Imagen de Detección de Cambios de Cobertura Boscosa para la Reserva de la Biosfera Maya, Petén, Guatemala; Aňos: 1986, 1990, 1993, 1995, 1997. (January 1998)

Imagen de Detección de Cambios de Cobertura Boscosa para la Reserva de la Biosfera Maya, Petén, Guatemala; Aňos: 1986, 1990, 1993, 1995, 1997, 1999. (December 1999)

Vegetation and Land Cover Map (1997) of the Maya Biosphere Reserve. (February 1999)

Maya Biosphere Reserve Land Cover Map, 1997, contributed to Conservation International for development of *La Selva Maya* land cover map. (February 2000)

6. <u>Tables and Figures</u>

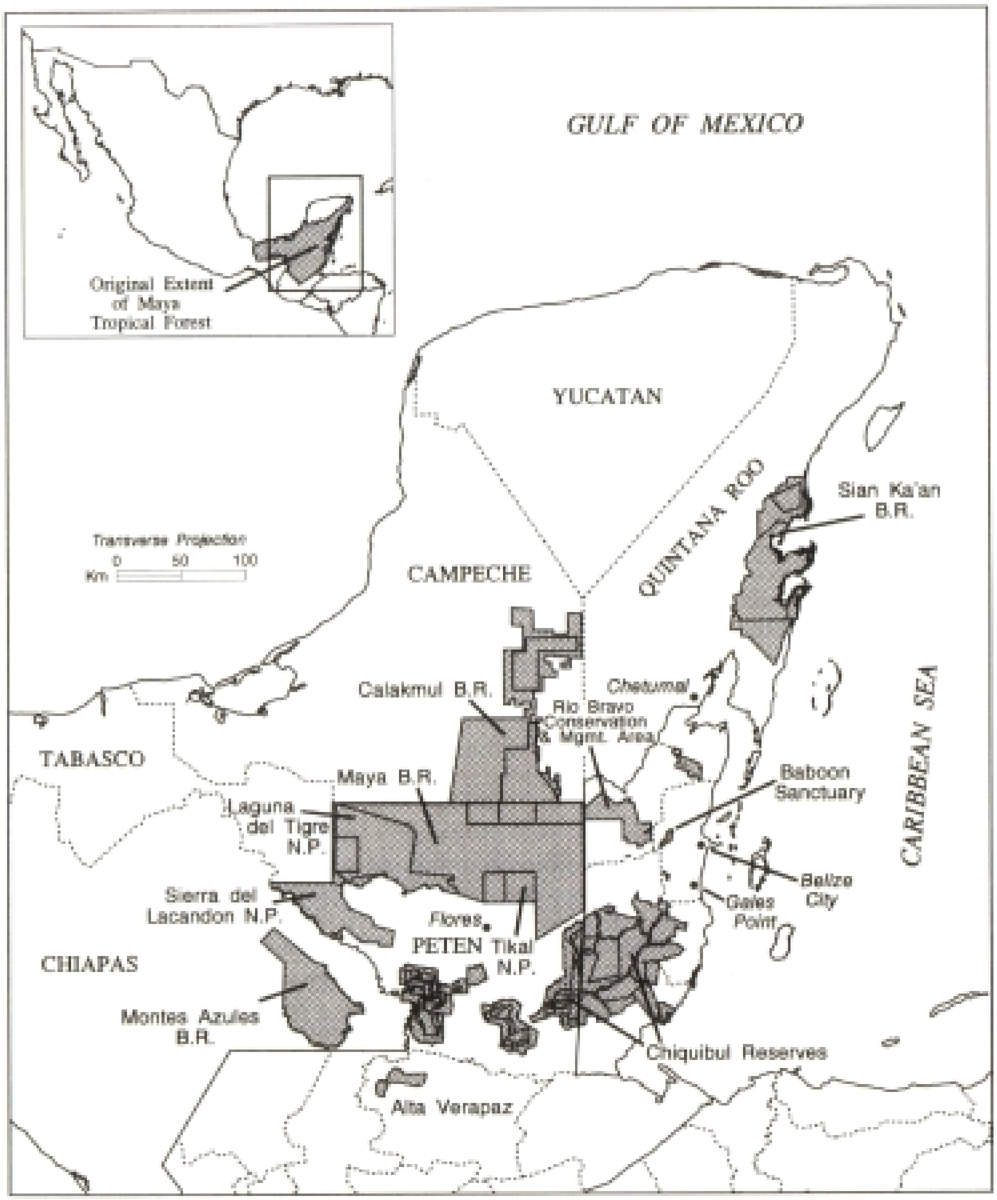


Figure 1. *La Selva Maya*: The Petén District of northern Guatemala, showing its location at the southern extent of the Yucatán Peninsula, and in relation to the protected areas of the Maya Forest (from Nations, J.D., R.B. Primack, and D. Bray. 1998. Introduction: the Maya Forest. In *Timber, Tourists, and Temples*. Primack, R.B., D. Bray, H.A. Galleti, and I. Ponciano (eds.). Washington, D.C.: Island Press).

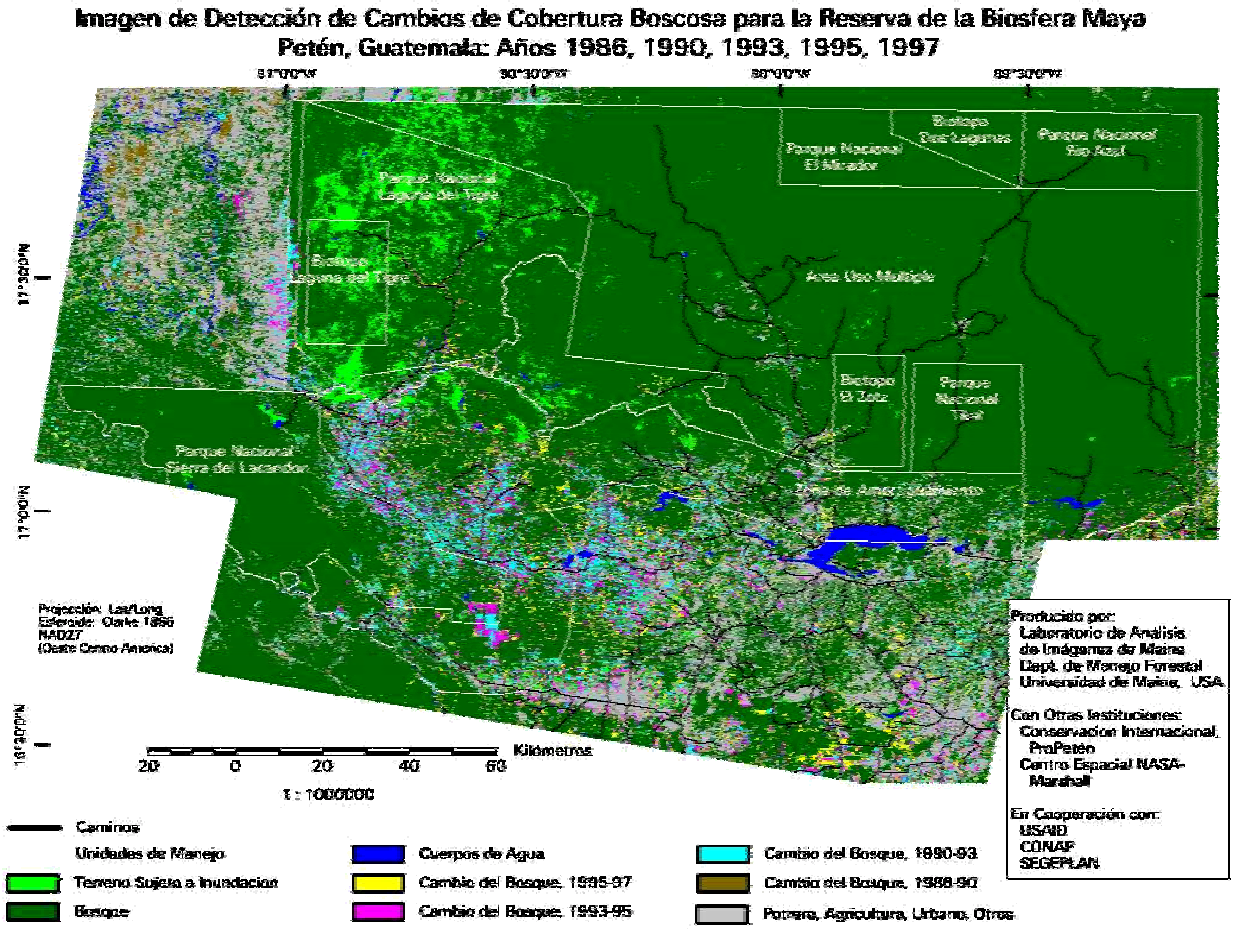


Figure 2. Forest change detection map for the Maya Biosphere Reserve, 1986 to 1997, delivered to CI and USAID, January 1998.

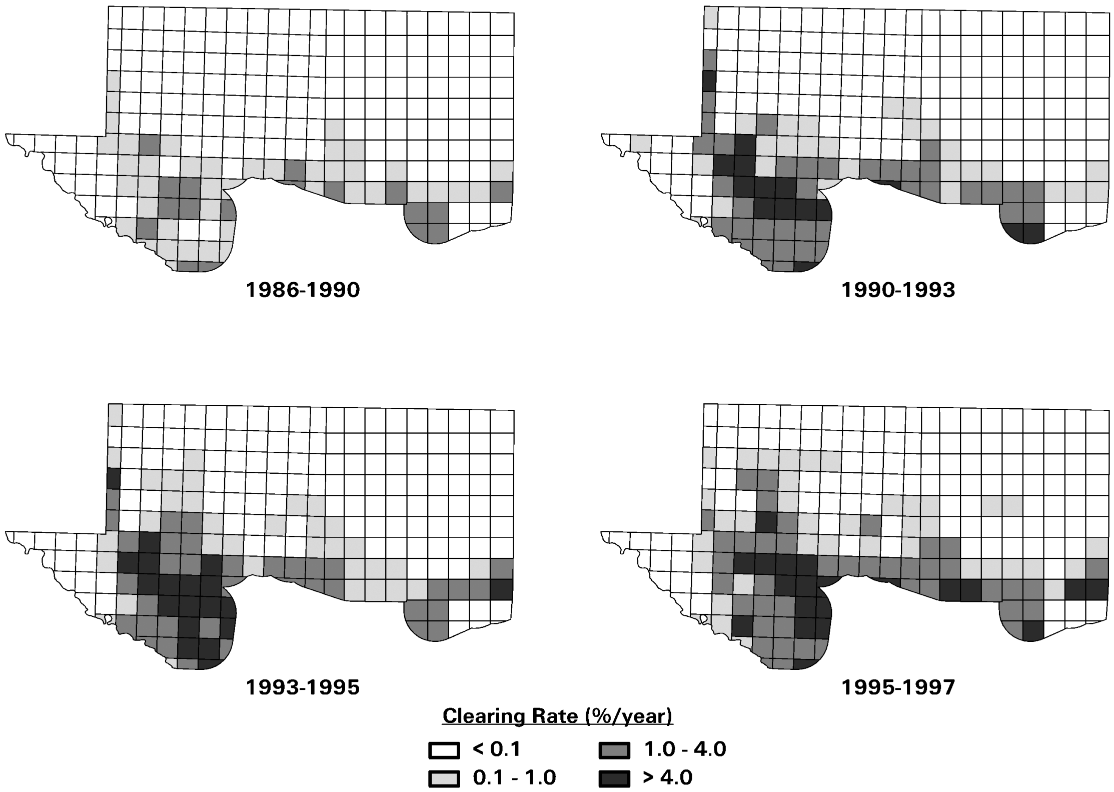


Figure 3. Forest change estimates for 100km2 UTM grid cells covering the Maya Biosphere Reserve and Buffer Zone.

Table 1. Estimates of Annual forest clearing rates (% of forest cleared per year) for the management units of the Maya Biosphere Reserve and Buffer Zone.

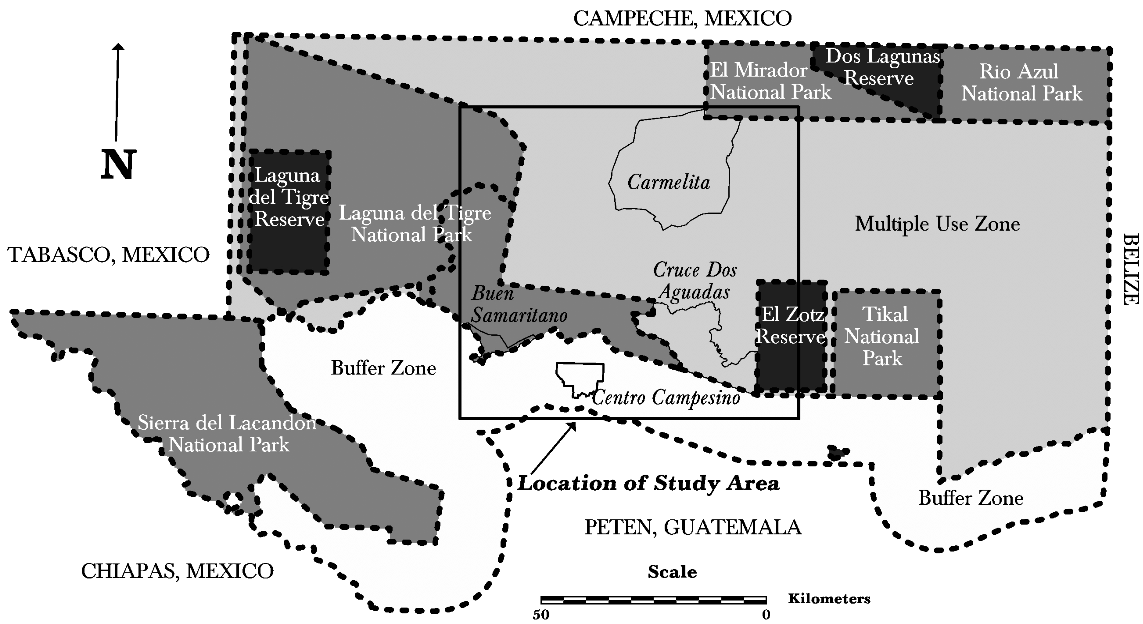
Management Unit	Forest / Wetland Area (1986) (ha)	% of Total	1986-1990	1990-1993	1993-1995	1995-1997
Cerro Cahui Reserve	555	0.03%	0.20	0.06	0.00	0.26
Dos Lagunas Reserve	30,719	1.54%	0.00	0.00	0.00	0.00
El Mirador NP	55,148	2.76%	0.00	0.00	0.00	0.00
El Zotz Reserve	34,934	1.75%	0.04	0.05	0.03	0.18
Laguna del Tigre NP	289,912	14.49%	0.01	0.06	0.28	0.57
Laguna del Tigre Reserve	45,168	2.26%	0.00	0.00	0.01	0.08
Rio Azul National Park	61,763	3.09%	0.00	0.00	0.00	0.00
Sierra del Lacandon NP	191,867	9.59%	0.13	1.18	1.26	0.78
Tikal NP	55,005	2.75%	0.00	0.00	0.00	0.00
MUZ	826,351	41.31%	0.05	0.16	0.25	0.25
MBR Totals	**1,591,422**	**79.56%**	**0.04**	**0.23**	**0.33**	**0.36**
Buffer Zone Totals	**408,973**	**20.44%**	**0.74**	**2.71**	**3.76**	**3.28**
Total Area	2,000,395					

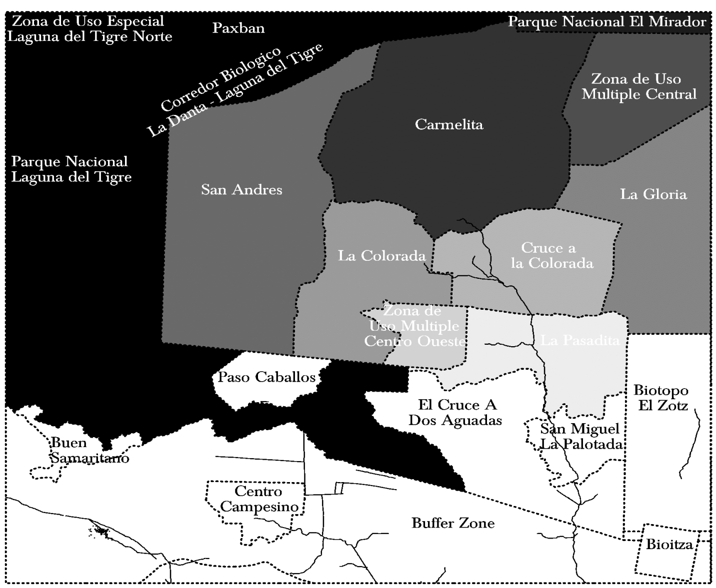
Table 2. Results of the accuracy assessment and comparison of three change detection methods. User's (U) and Producer's (P) accuracy are reported for each class, as well as the overall accuracy and kappa statistic for each method. A Z-statistic, derived from each error matrix, was used to compare the methods statistically. The change detection methods were compared for their ability to identify seven land cover change classes from three dates of Landsat-TM imagery.

Change Class	NDVI-DIFF		PCA		RGB-NDVI	
	U	P	U	P	U	P
cleared bef. 93, regrow95-97	58.33%	50.00%	25.00%	28.57%	66.67%	85.71%
cleared bef. 93, regrow 93-97	80.56%	93.55%	75.76%	80.65%	100.00%	77.42%
regrow 93-95, cleared 95-97	91.30%	87.50%	82.14%	95.83%	82.76%	100.00%
cleared 93-95, no regrow	96.43%	81.82%	91.67%	66.67%	93.75%	90.91%
cleared 93-95, regrow95-97	77.42%	85.71%	70.97%	78.57%	88.00%	78.57%
cleared 95-97	82.76%	92.31%	80.65%	96.15%	96.00%	92.31%
no change	78.26%	73.47%	73.81%	63.27%	75.00%	79.59%
Overall Accuracy		81.95%		74.15%		85.37%
KAPPA		0.7857		0.6946		0.8262
Z-stat		24.63		19.32		28.05

Test statistic (Z) for pairwise comparison of two independent error matrices:

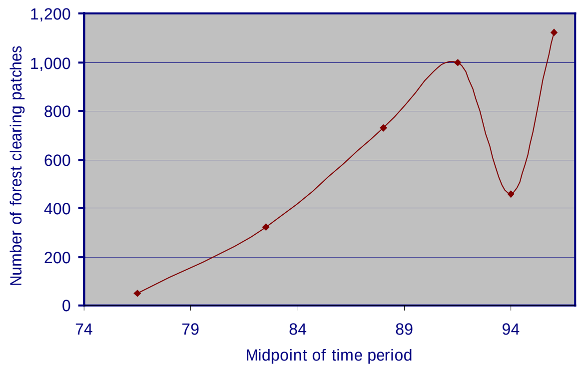
matrices	K1	var(K1)	K2	var(K2)	Z
ndvi_diff vs. pc3	0.7857	0.0010	0.6946	0.0013	1.893
ndvi_diff vs. rgb_ndvi	0.7857	0.0010	0.8262	0.0009	0.932
pc3 vs. rgb_ndvi	0.6946	0.0013	0.8262	0.0009	2.829





Sensor	Date	Bands
MSS	14 February 1974	1,2,4
MSS	15 February 1979 6 February 1979	1,2,4 1,2,4
TM	14 April 1986	3,4,5
TM	17 April 1990	3,4,5
TM	19 May 1993	3,4,5
TM	22 March 1995	3,4,5
TM	12 April 1997	3,4,5

Figure 4. Location of the study area, within the Maya Biosphere Reserve and including 21 forest concession units and four communities surveyed in the socio-economic study, for which the forest conversion history database was constructed. Landsat-TM image (WRS 20/48) acquisition dates are also shown.



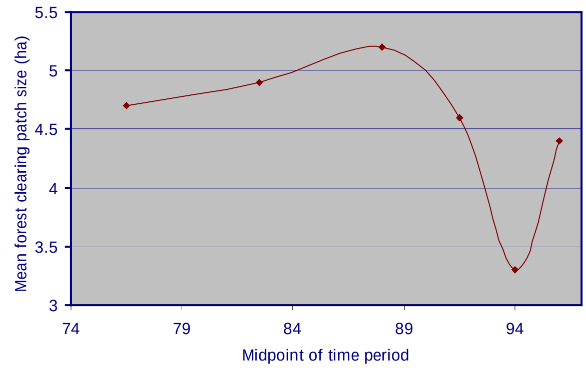


Figure 5. Number of forest patches cleared, 1974 – 1997 (left), and mean forest clearing patch size (ha) for each time period (right).

Table 3. Area cleared to area regrown ratios for each concession unit, each time period, 1986-1997.

UNIT	86-90	90-93	93-95	95-97	TOTAL
Biotopo El Zotz	0.96	0.60	1.24	2.28	**1.02**
Buen Samaritano	0.00	x	26.20	2.14	**5.80**
Buffer Zone	5.24	1.83	0.83	4.05	**2.38**
Carmelita	0.15	0.37	0.79	x	**0.28**
Centro Campesino	7.35	1.56	0.22	1.30	**1.82**
Cruce a la Colorada	0.49	0.76	1.02	7.17	**1.03**
Cruce Dos Aguadas	1.17	1.52	0.75	6.36	**1.68**
La Colorada	0.83	1.10	2.69	1.94	**1.21**
La Pasadita	1.86	1.15	0.52	3.90	**1.49**
Paso Caballos	x	x	x	10.08	**11.87**
PN Laguna del Tigre	x	1.09	x	3.65	**4.16**
San Miguel Palotada	14.68	0.77	0.62	3.28	**1.60**
TOTAL	**2.82**	**1.57**	**0.88**	**4.10**	**2.05**

x =no regrowth

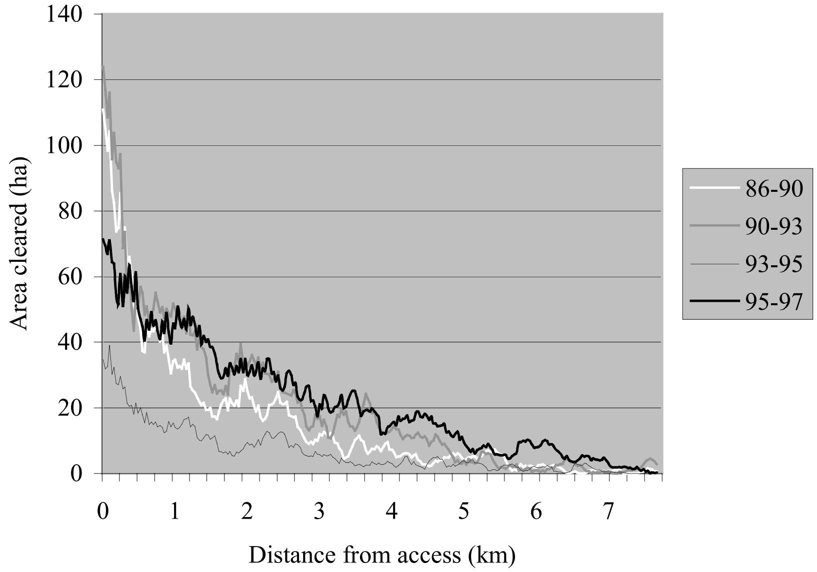


Figure 6. The relationship of forest clearing and distance from access (roads and rivers) over time (1986-1997).

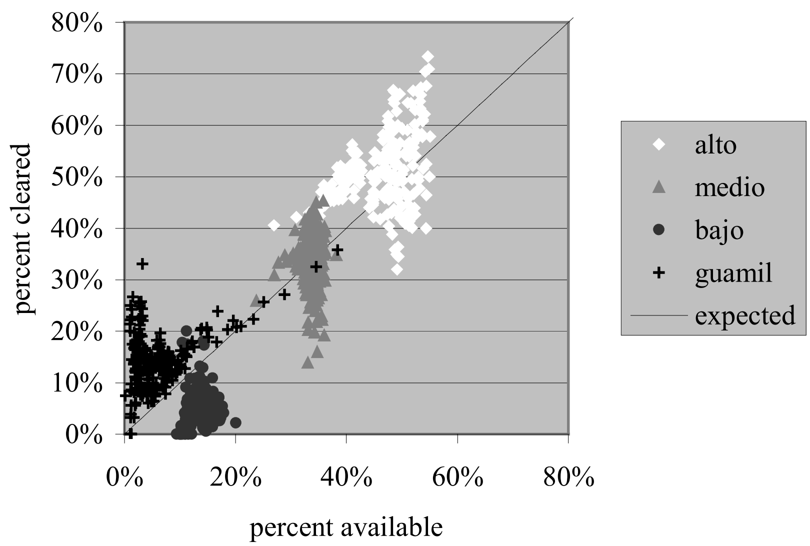


Figure 7. The relationship of forest clearing by cover type to proportional availability of each cover type at 1-pixel (30m) intervals from access.

Table 4. Household survey respondent data (1997) and comparison with 1997 land cover derived from the satellite image database.

a) Information on the survey respondents of the sample population.

	Ethnicity by % of sample population			Median years of residence in current settlement	Average monthly income*
	Chorti	Q'eqchi	Ladino		
Buen Samaritano		55.6%	44.4%	4	Q301-450
Carmelita			100.0%	31	Q901-1,200
Centro Campesino	97.0%		3.0%	12	Q151-300
Cruce Dos Aguadas	1.0%	43.1%	55.9%	12	Q451-600

*Q: (Guatemalan Quetzal)

b) Respondent information regarding land use.

	Most important source of income (% of sample)		
	farm	Non-timber forest products	Other
Buen Samaritano	100.0%		
Carmelita	15.4%	73.1%	11.5%
Centro Campesino	100.0%		
Cruce Dos Aguadas	85.3%	10.8%	1.0%

c) Agreement between the number and mean size of clearing patches in the satellite image database with the average milpa size reported by respondents from each community.

	from survey		**from database**		
	House-holds	mean ha in milpa	(ha) per household	mean patch size (ha)	# per household
Buen Samaritano	37	5.0	6.14	5.74	1.1
Carmelita	57	2.7	1.45	4.06	0.4
Centro Campesino	66	3.5	4.67	4.05	1.2
Cruce Dos Aguadas	251	4.8	3.64	4.54	0.8

d) The percentage of all milpas that were established in previously used (fallow) fields: agreement between survey responses and the time-series database.

	from survey			**from database**			
	total # of milpas	# from fallow	%	total # of patches	# from fallow	% (of patches)	% (of total area cleared)
Buen Samaritano	18	2	11.1%	55	0	0.0%	0.0%
Carmelita	15	13	85.7%	21	13	61.9%	84.6%
Centro Campesino	33	18	54.4%	120	24	20.0%	18.7%
Cruce Dos Aguadas	98	77	78.6%	281	76	27.0%	20.4%

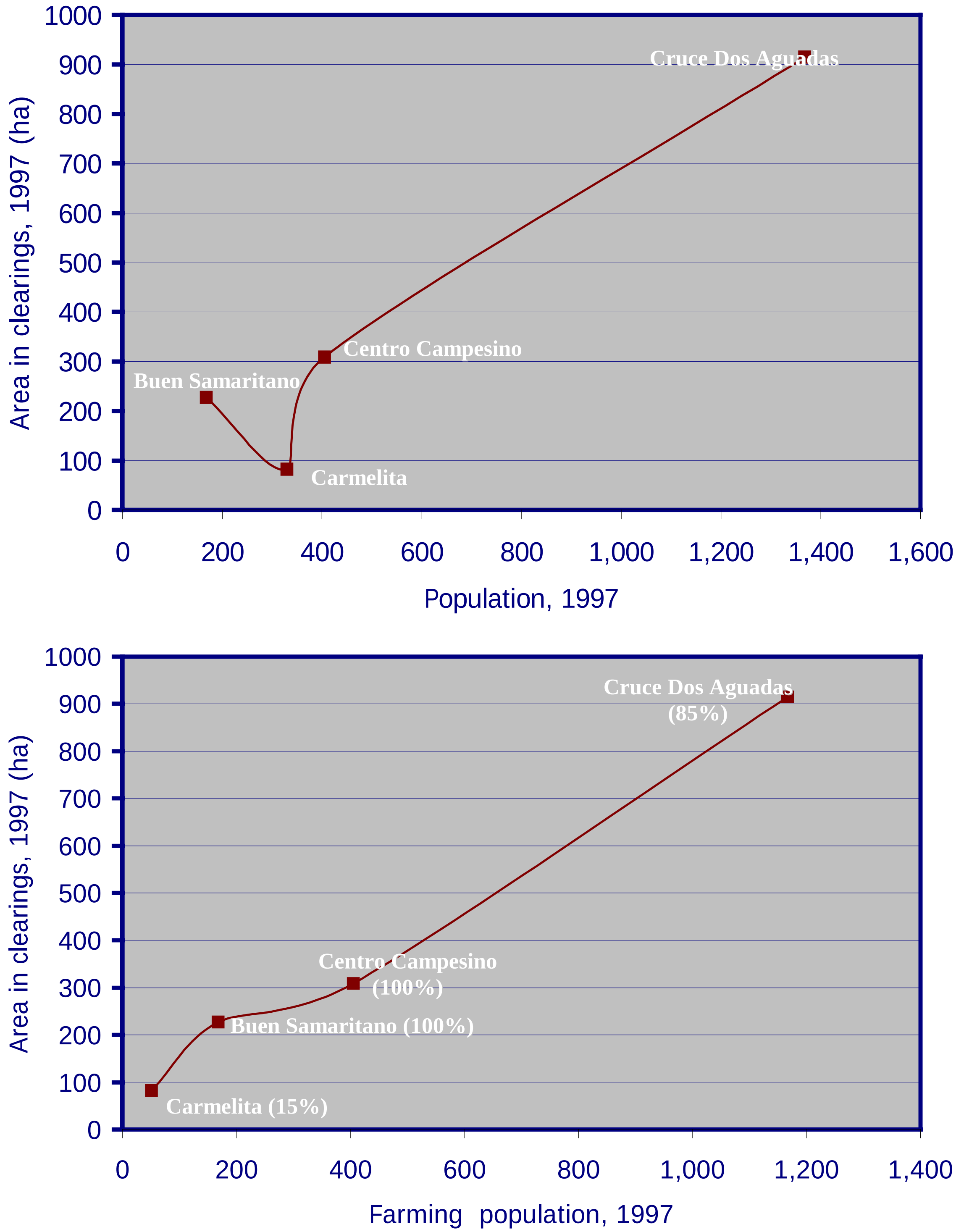


Figure 8. The relationship of area in clearings from the satellite image database to population (a) and estimated number of people whose major source of income comes from farming (b) for each community.

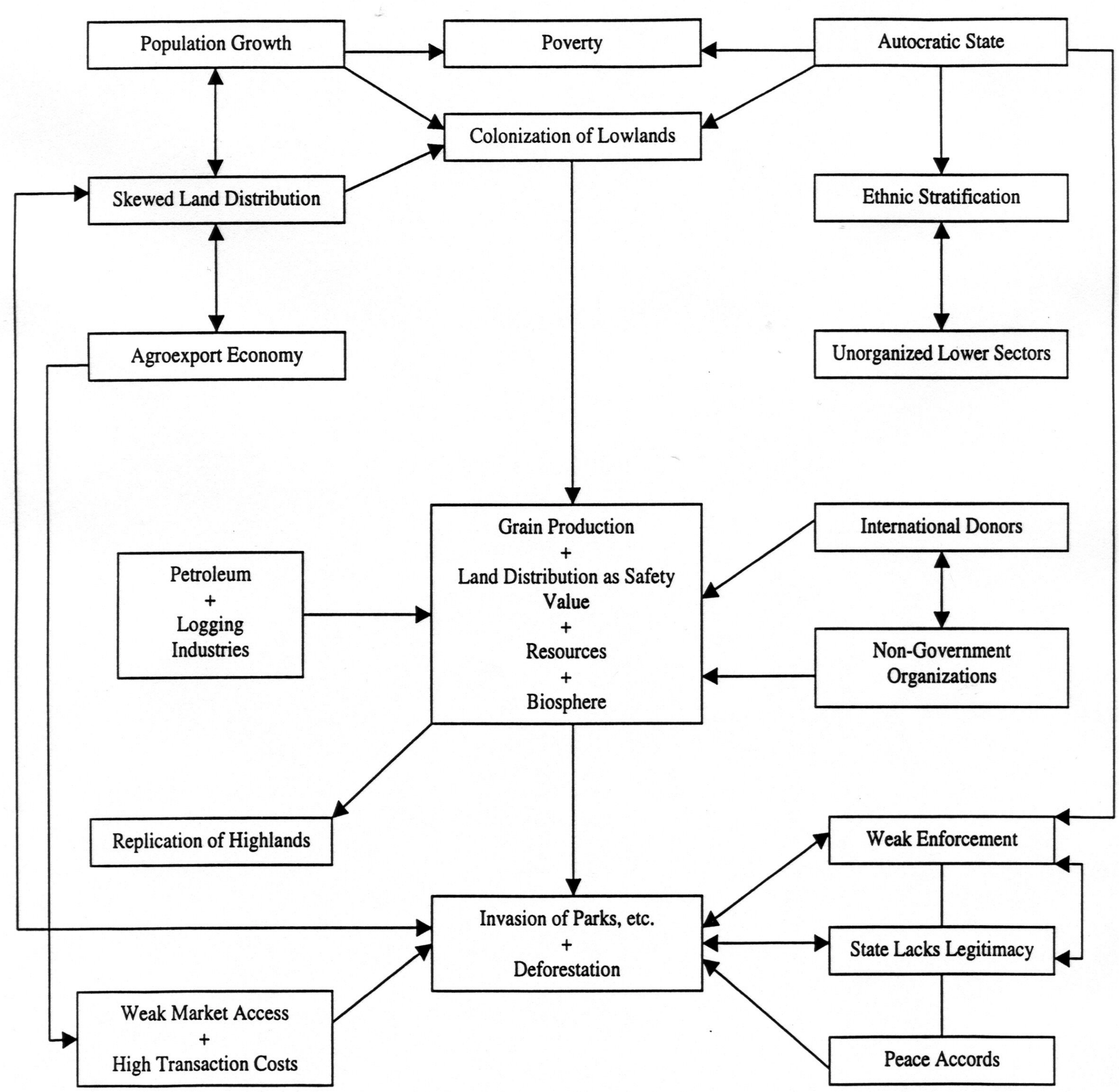


Figure 9. Socio-economic and political influences on land cover and land use change in the Maya Biosphere Reserve, Guatemala (Schwartz *pers. comm.*).