

*Time-series Forest Change, Land Cover/Land  
Use Conversion, and Socio-economic Driving  
Forces in the Petén, Guatemala*

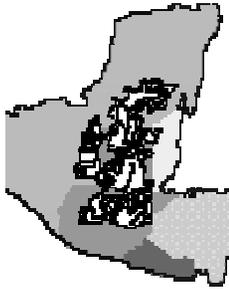
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# **Introduction**

***With all the publicity given to deforestation in the Amazon Basin (and deservedly so, this region has the greatest area deforested each year), few people realize that Central America has the second highest deforestation rate in %/yr (1.5), behind only S.E. Asia (1.6%/yr) -- according to FAO statistics 1993.***

# **Presentation Outline**

- *The Maya Biosphere Reserve: Background*
- *Project Objectives*
- *Cooperators, Activities, Data and Products*
- *Project Development*
  - *Image Processing / Change Detection Methods*
- *Analysis and Early Results*
  - *The Land Cover / Land Use History Database*
- *Discussion / Future Research*



## Guatemala Geopolitical Context

- *The Petén, Guatemala's largest department, is located in the lowland tropical moist forest at the southern extension of the Yucatan Peninsula...*
- *The region has a low (but growing) population compared to the deforested and highly populated southern highlands*

# **The Maya** **Biosphere Reserve**

***Spanning 1.6 million hectares of northern Guatemala, the Maya Biosphere Reserve (MBR) is an area of lowland tropical forests and expansive wetlands. Together with adjacent forests in Mexico and Belize, the area known as the Selva Maya constitutes the largest contiguous tropical moist forest remaining in Central America.***

# **The Maya** **Biosphere Reserve**

***The MBR was established in 1990 in order to preserve the remaining forest and the extensive biodiversity that it holds. The reserve is home to many rare and important plant and animal species including mahogany, Spanish cedar, chicle, jaguars, tapirs, white lipped peccaries, the scarlet macaw, harpy eagles, and various monkeys.***

# **The Maya** **Biosphere Reserve**

***This region is also the heartland of the ancient Mayan civilization, vestiges of which remain today. Tikal National Park (next slide...) is a designated UNESCO World Heritage Site and serves as an important scientific window into Mayan history as well as a popular destination for visitors from around the world.***



# **The Maya** **Biosphere Reserve**

***The Petén supports an expanding population that relies on the forest for its survival and well-being. Attention from international organizations (NGOs) and government agencies has aimed at fostering sustainable development and conservation programs.***

# **The Maya** **Biosphere Reserve**

***The forests of the Petén, that for centuries rebuffed development attempts, are suddenly being destroyed at an alarming rate (next slide...). Serious threats include: slash & burn agriculture, cattle ranching, illegal logging, wildlife poaching, oil and gas development, road construction, and population growth (including refugee migration and immigration of landless peasants).***



# **Land Cover / Land Use Change**

## **Pathways**

- ***Pressure on the Petén, external factors:***
  - *lower population density than the crowded and already deforested southern highlands*
  - *availability of cheap land, lack of land tenure*
  - *more stable political climate since end of civil conflict, migration more favorable*
  - *government encouraging settlement of the “agricultural frontier” of the Petén*
  - *external market incentives for oil development, logging, hunting, and wildlife poaching*
  - *lax enforcement of protected areas*

# **Land Cover / Land Use Change**

## **Pathways**

- ***Typical progression of forest conversion:***
  - ***Access: oil development, logging road***
  - ***migration of landless farmers***
  - ***clear forest of valuable hardwoods***
  - ***slash and burn, clear forest for milpa***
  - ***squat on land, tend milpa for 2 years***
  - ***leave for fallow (how long? do they return?)***
  - ***without land tenure and following the loss of productivity in the milpa, the land may be acquired by wealthier families and often undergo permanent conversion to pasture***

# **Project Objectives**

***There is little systematic and reliable information on areas and rates of deforestation in the MBR. Because the expansive, remote and inaccessible nature of the reserve makes collecting ground data difficult and often infeasible, remote sensing data and image processing techniques have come to be relied upon for the generation and analysis of this information.***

- ***Develop a land-cover/land-use database that spans more than twenty years (1974 to 1997);***
- ***Quantify forest clearing rates by time period and the proportion of land area converted to different land-cover types at each time period;***
- ***Determine the spatial distribution and abundance of second growth vegetation and estimate crop-fallow ratios in different management units and communities;***
- ***Determine the socio-economic factors that influence humans to make decisions that result in land-cover conversion;***
- ***Determine the spatial geometry of landscape disturbance through analysis of forest fragmentation and the relationships to socio-economic factors;***
- ***Other: Examine the relationship between radar backscatter and second growth age class canopy structure.***



# **Cooperators, Activities, Data and Products**



**Maine Image Analysis Laboratory  
Department of Forest Management  
University of Maine, Orono, USA**



**NASA-Marshall  
Space Flight Center**



**CI-ProPetén  
Flores, Guatemala**



**U.S. Agency for  
International Development  
Consejo Nacional de Areas  
Protegidas, Guatemala**



**TNC- Guatemala  
Program**

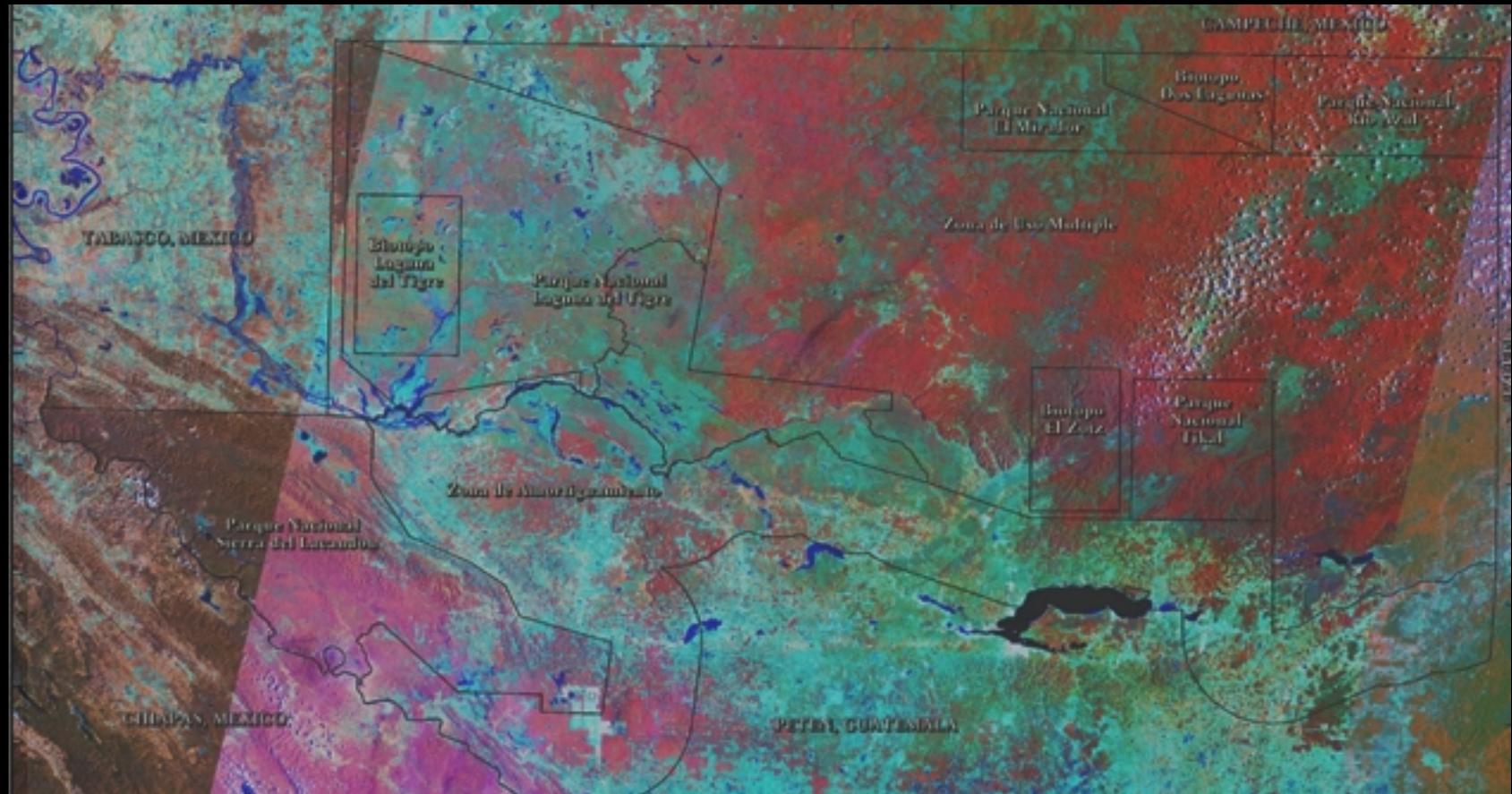


**Wildlife  
Conservation Society**

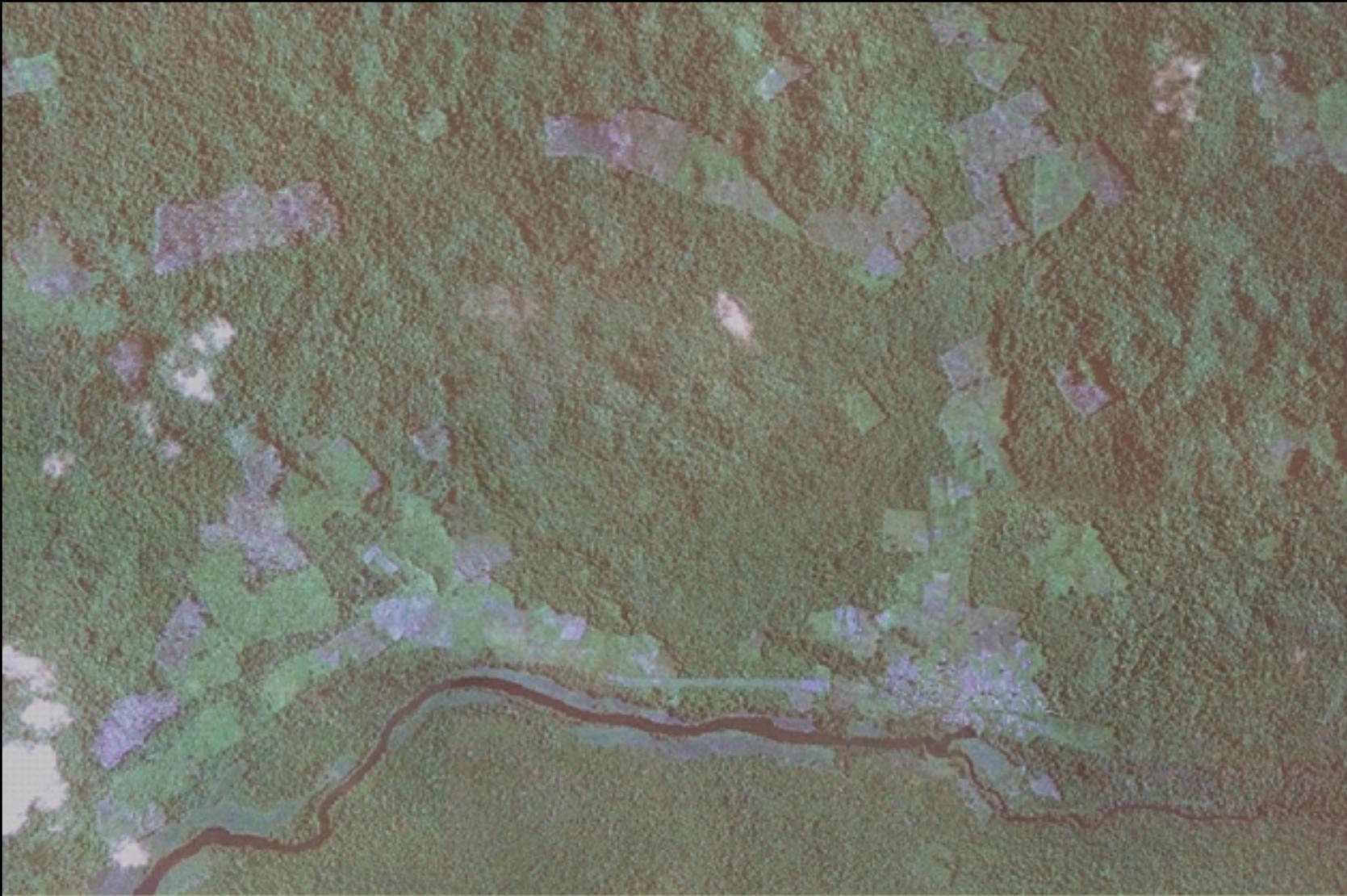
# **Cooperators, Activities, Data and Products**

***Satellite image change detection techniques were used to develop data on forest clearing rates in the MBR, to facilitate data transfer to local interests, and provide a base-line for future monitoring. Seven dates of Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) imagery covering the MBR were acquired, spanning 1974 to 1997.***

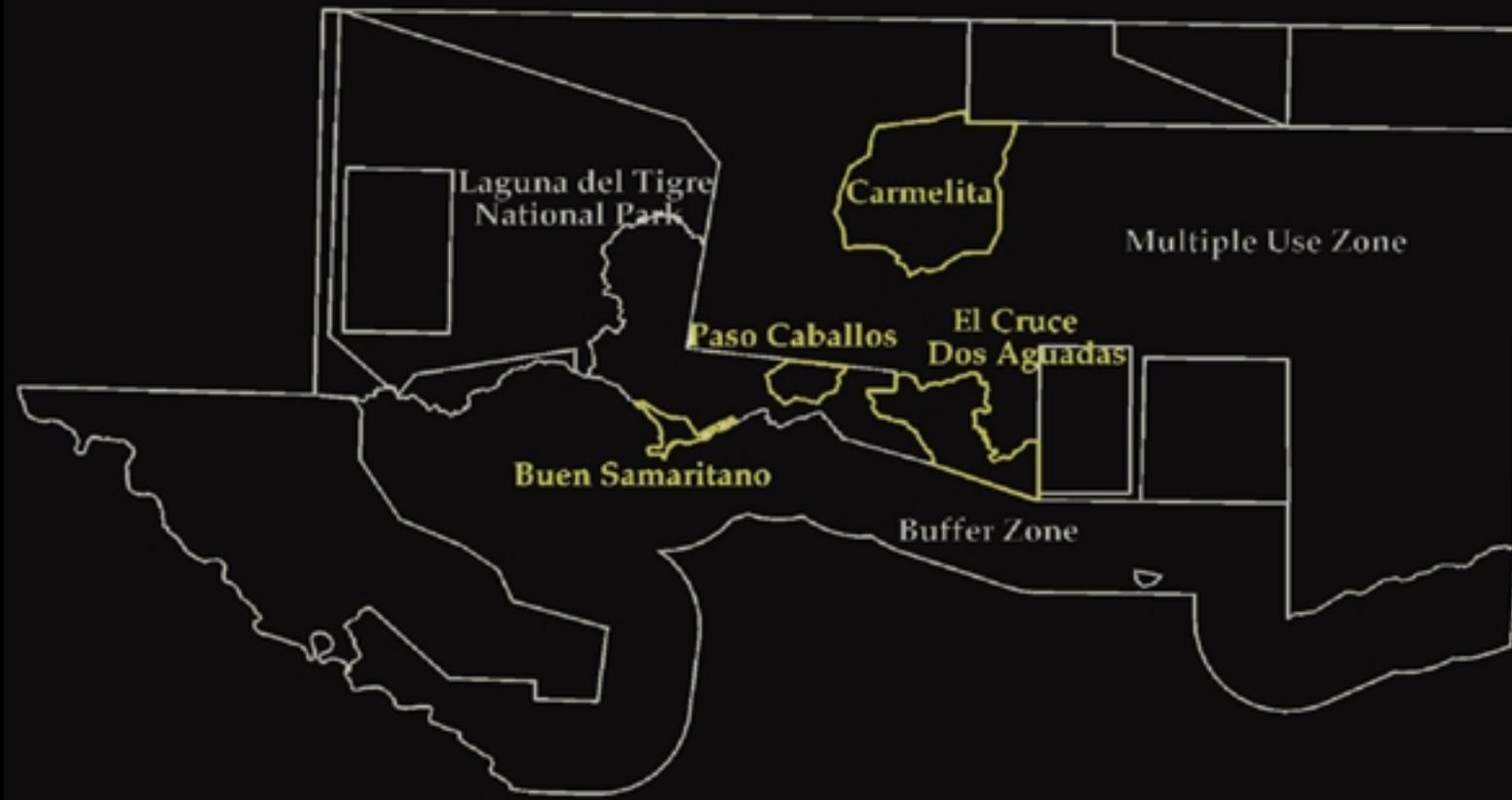
# 1997 Landsat TM RGB 453 Satellite Image Color Composite of the Maya Biosphere Reserve, Petén, Guatemala



# 1997 1m Resolution Air Photo Mosaic, Village of Paso Caballos



## Community Concession Boundaries / Socio-economic Study Areas



# **Study Area Profiles**

- ***Carmelita***
  - ***Ladino***
  - ***Oldest, most stable (population and well-being) of the four community study areas***
  - ***mostly non-farmers, emphasis on non-timber forest products (NTFPs)***
  - ***smaller milpas (crops), longer fallow periods***
  - ***root and tuber crops; corn, beans, and squash in milpas; convert guamiles (second growth) instead of primary forest for milpas***

# **Study Area Profiles**

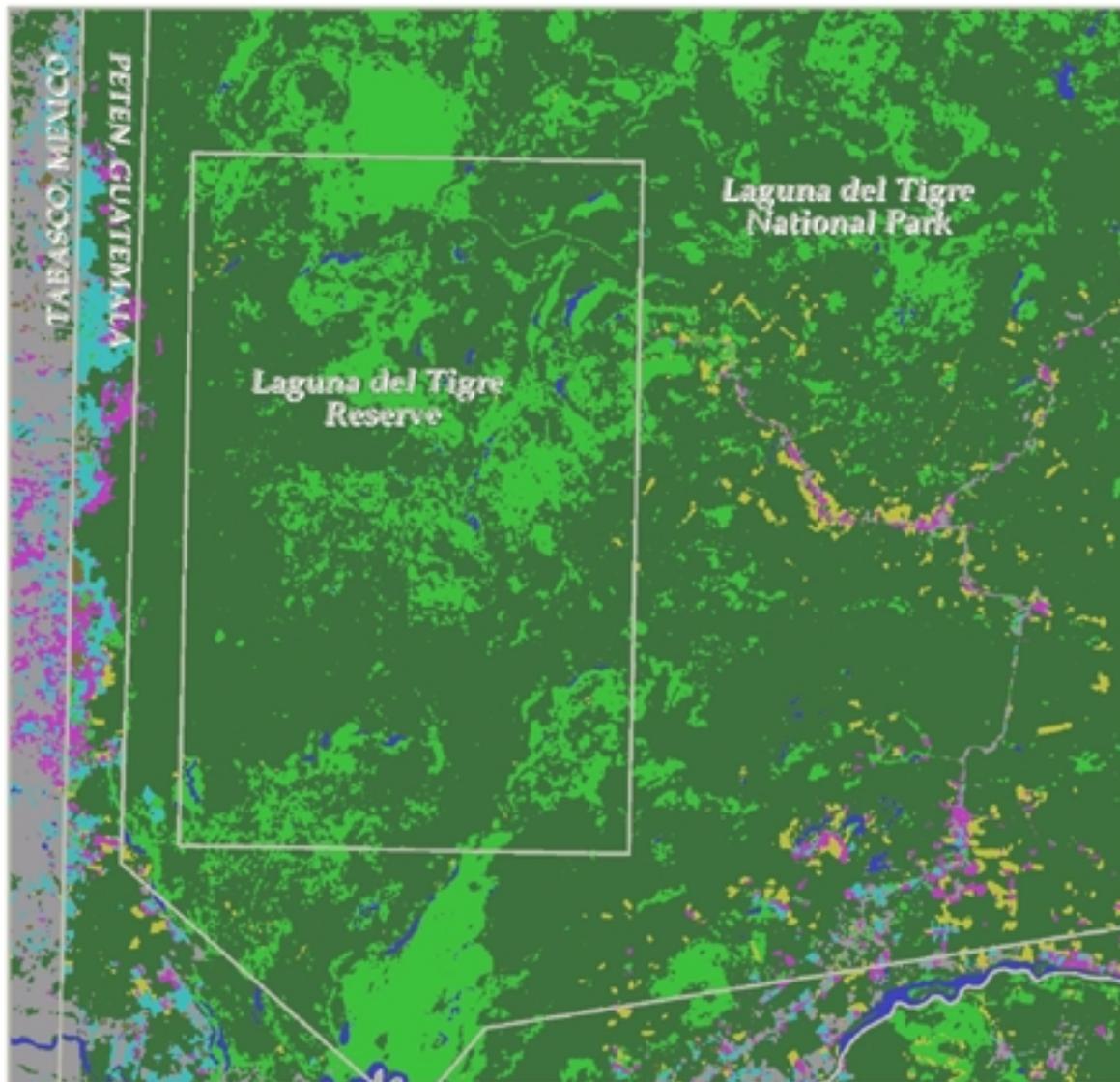
- ***El Cruce Dos Aguadas***
  - ***50% Ladino, 50% Q'eqchi relocated from southern Petén***
  - ***largest community; stable***
  - ***church, ethnicity important***
  - ***larger than avg. milpas (esp. Q'eqchi)***
  - ***Q'eqchi use velvet beans (frijol obono), a nitrogen fixer, in milpa: results in less herbicide, one crop per year but longer cropping period (7 years vs. 2 year average)***

# **Study Area Profiles**

- ***Paso Caballos and Buen Samaritano***
  - ***Ladino / Q'eqchi; relocated from other regions of the Petén and the Guatemalan Highlands***
  - ***newest communities, least stable***
  - ***large milpas, corn mono-cropping***
- ***The Petén, on average (Schwartz 1990):***
  - ***1 ha of milpa to feed family of 6, depending on number of animals; average milpa 2.5 hectares***
  - ***2 crops/year for 2 years (dry season has 50% yield of wet season); fallow 3-4 yrs, declining***

# Products

*The normalized difference vegetation index (NDVI) was used to detect changes in the forest canopy between dates. A change detection map was developed to show spatial and temporal trends in forest clearing. 100km<sup>2</sup> cells based on the Universal Transverse Mercator (UTM) grid system were used for landscape-level reporting and analysis of deforestation rates over time.*



**Forest Clearing,  
1986-1997**

**Laguna del Tigre  
National Park**

- wetland, savanna
- forest
- water
- change 1995-97
- change 1993-95
- change 1990-93
- change 1986-90
- urban, pasture, other

5 0 5 km

# **Project Development**

- ***Land Cover / Land Use History Database***
  - ***develop and test methods to create a 7-date change detection database which identifies forest conversion pathways over a 20yr span;***
  - ***use satellite image change detection techniques to generate spatial data on forest clearing and regrowth, facilitate technology transfer to local agencies, and provide a baseline for future monitoring.***

# **Project Development**

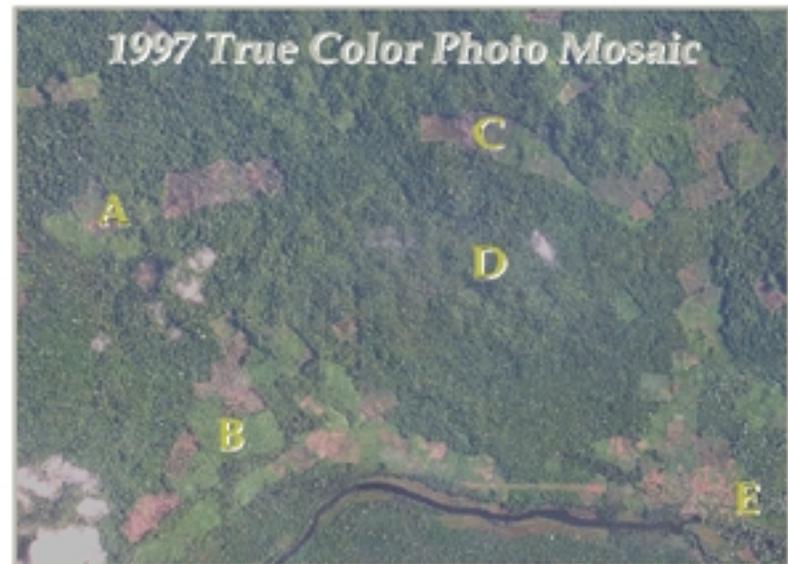
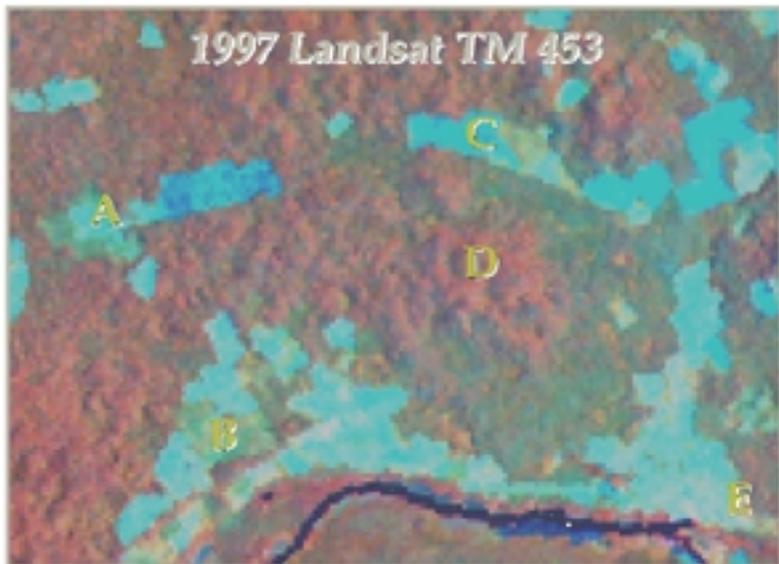
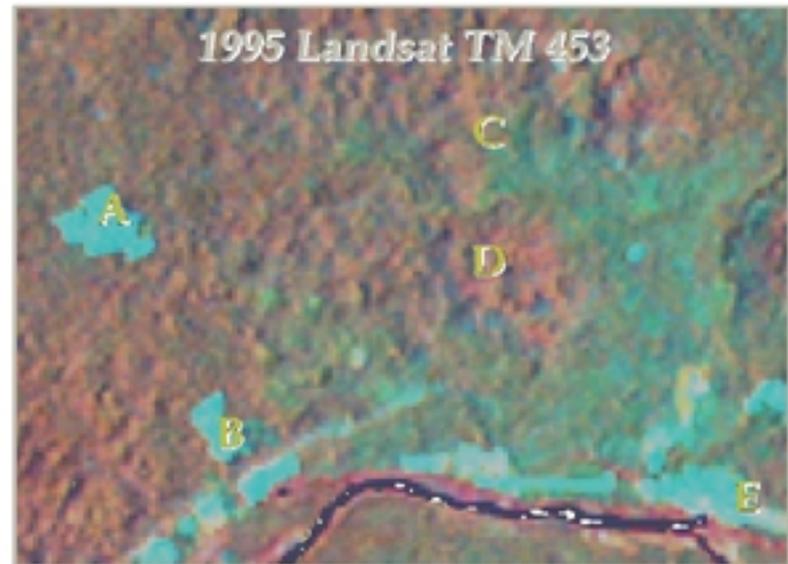
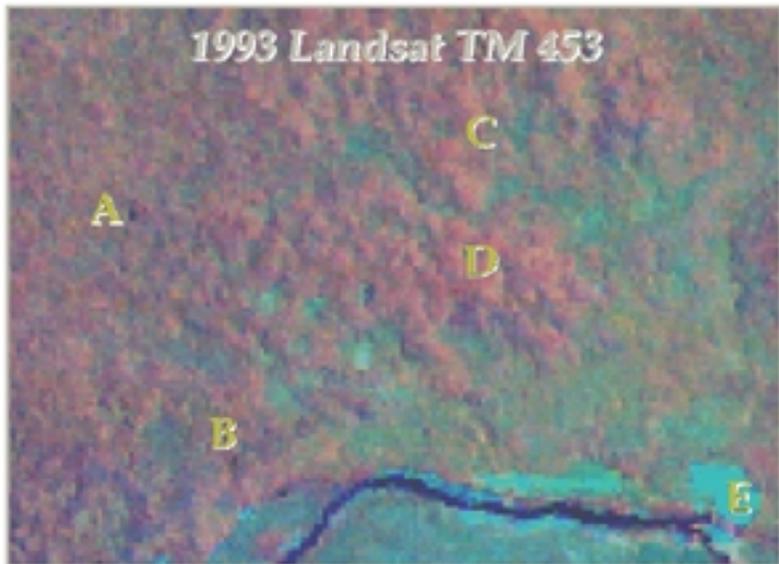
- ***Image Processing / Change Detection***
  - ***Radiometric calibration***
  - ***Image Differencing of Normalized Difference Vegetation Index (NDVI)***
  - ***Principal Components Analysis (PCA)***
  - ***3-Date RGB-NDVI Color Composites***
  - ***Threshold / Classify results of each method***
  - ***Assess the accuracy of and statistically compare the resulting error matrices***

# Image Processing / Change Detection Methods

- ***Relative radiometric “normalization” (Eckhardt et al. 1990, Hall et al. 1991)***
  - ***reference image: 1997 TM bands 3,4,5***
  - ***subject images: 1995 TM 3,4,5 and 1993 TM bands 3,4,5***
  - ***select “radiometric control sets”, compute bright and dark control set means for each image***
  - ***correct each subject image by regression against the reference image:***  $Y' = m_i x + b_i$

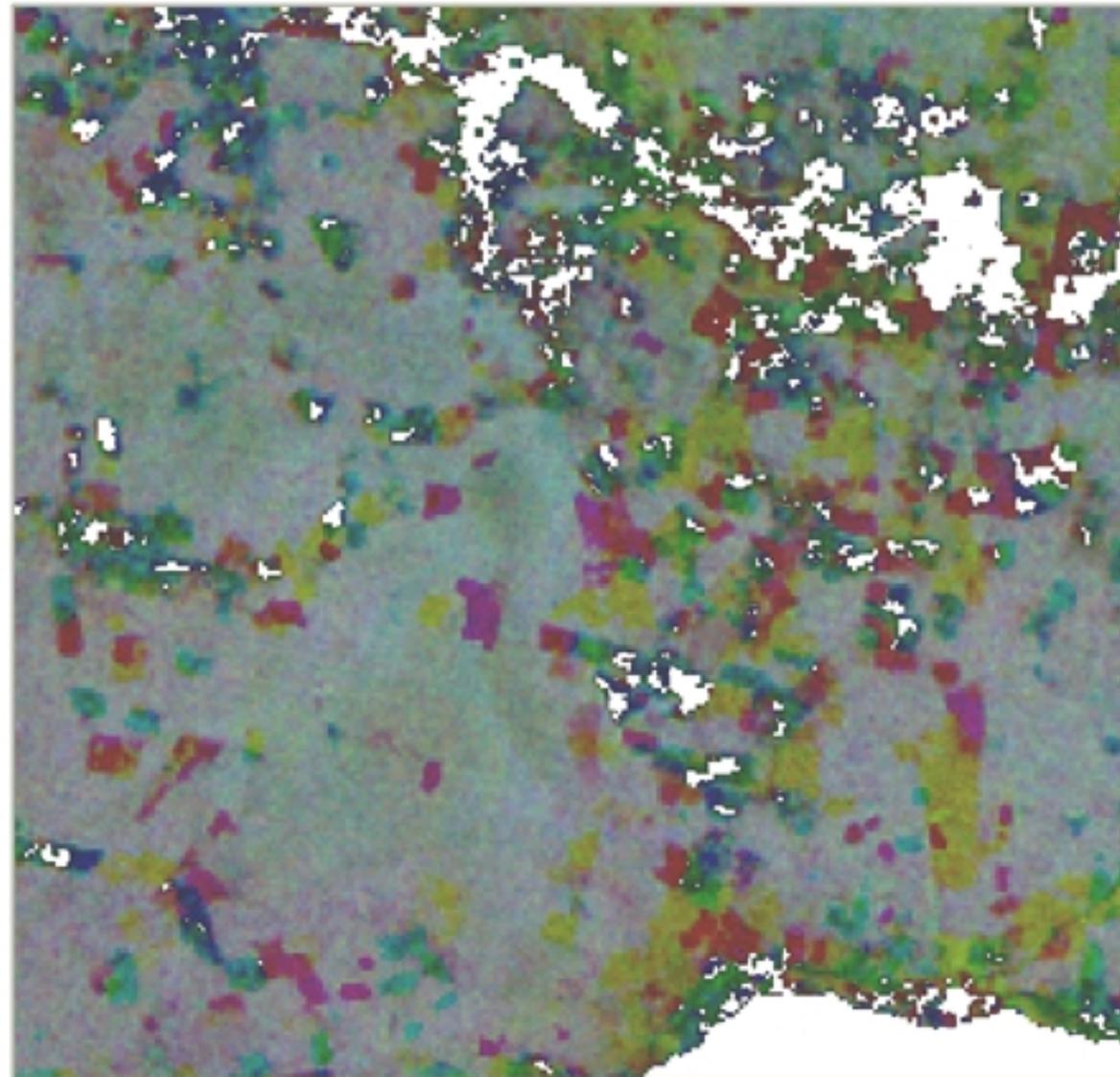
$$m_i = (B_{ri} - D_{ri}) / (B_{si} - D_{si})$$

$$b_i = (D_{ri} B_{si} - D_{si} B_{ri}) / (B_{si} - D_{si})$$



# Image Processing / Change Detection Methods

- ***3-date RGB-NDVI (Sader and Winne 1992)***
  - *calculate NDVI for each date and stack them into a 3 layer image with the following color scheme:*  
**1993 - RED                      1995 - GREEN                      1997 - BLUE**
  - *run unsupervised clustering on the 3 layer image (preserve color scheme in output clusters)*
  - *interpret clusters based on signature statistics, color additive theory, TM RGB color composites, and comparison with visually interpreted sample points*
  - *recode into 3-date time series change detection image*

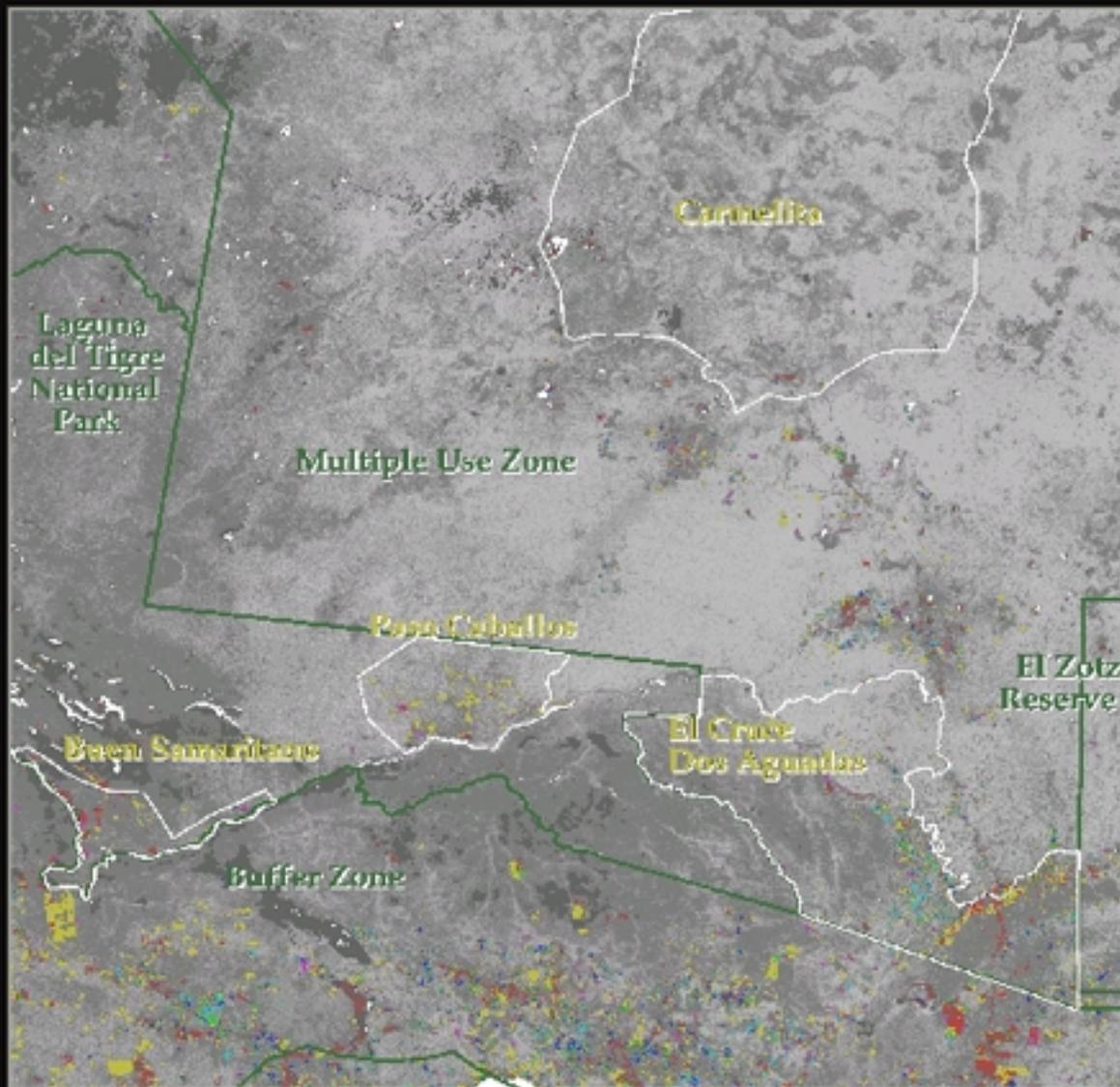


### 3-Date RGB-NDVI Image Interpretation

-  cleared before 93,  
regrow 95-97
-  cleared before 93,  
regrow 93-97
-  cleared before 93,  
regrow 93-95, cleared 95-97
-  cleared 93-95,  
no regrow
-  cleared 1993-95,  
regrow 95-97
-  cleared 95-97
-  no change, high NDVI  
(forest)
-  no change, low NDVI  
urban, pasture, other

# **Image Processing / Change Detection Methods**

- ***Accuracy Assessment***
  - *visually interpret a new set of reference points*
  - *create error matrices for the results of each method against the reference points*
  - *calculate user's and producer's accuracy, overall accuracy, and KAPPA statistic (Congalton and Green 1999) for each error matrix*
  - *compare the independent error matrices with a Z-test*



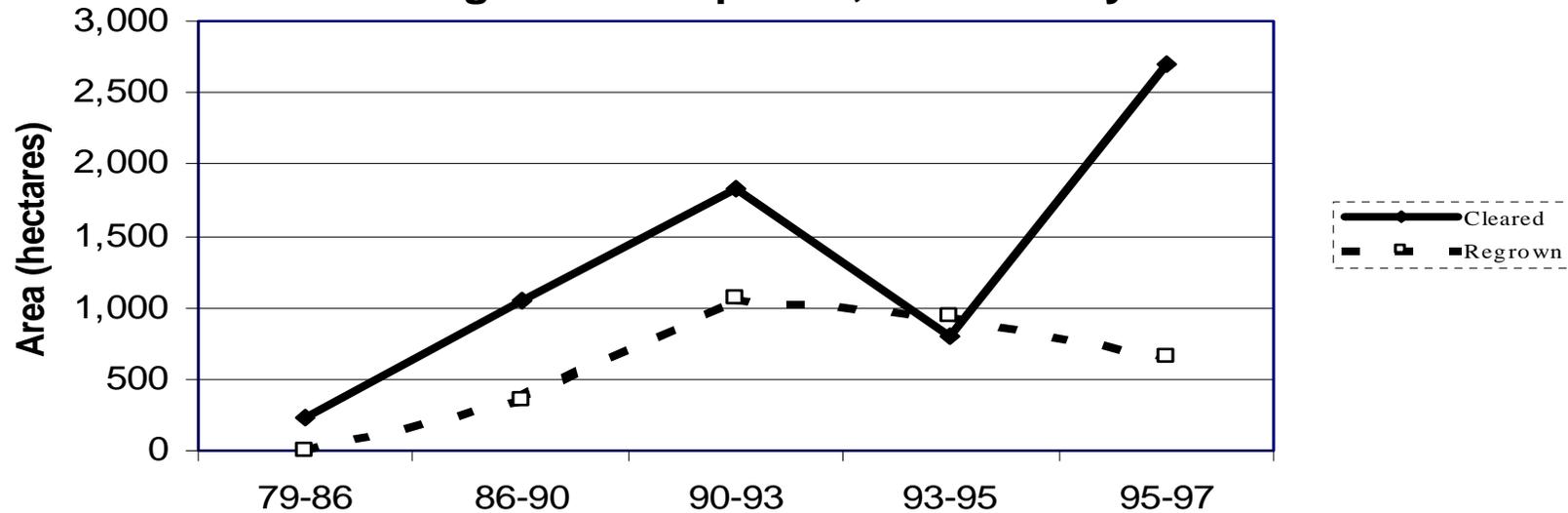
## Change Detection Image for a portion of the MBR: 93, 95, 97

### RGB-NDVI Method



# Analysis and Early Results

**Total area cleared vs. regrown *per year* during each time period, entire study area**



**Total area cleared vs. regrown during each time period, study area**

	79-86	86-90	90-93	93-95	95-97	Total
Cleared	1,631.46	4,198.26	5,484.95	1,611.31	5,385.46	18,306.44
Regrown	-----	1,418.80	3,188.35	1,880.82	1,297.72	7,785.69

**Average patch size cleared vs. regrown during each time period, study area**

	79-86	86-90	90-93	93-95	95-97	Avg
Cleared	5.10	5.61	5.29	3.43	4.71	4.83
Regrown	-----	3.06	3.92	3.03	2.61	3.16

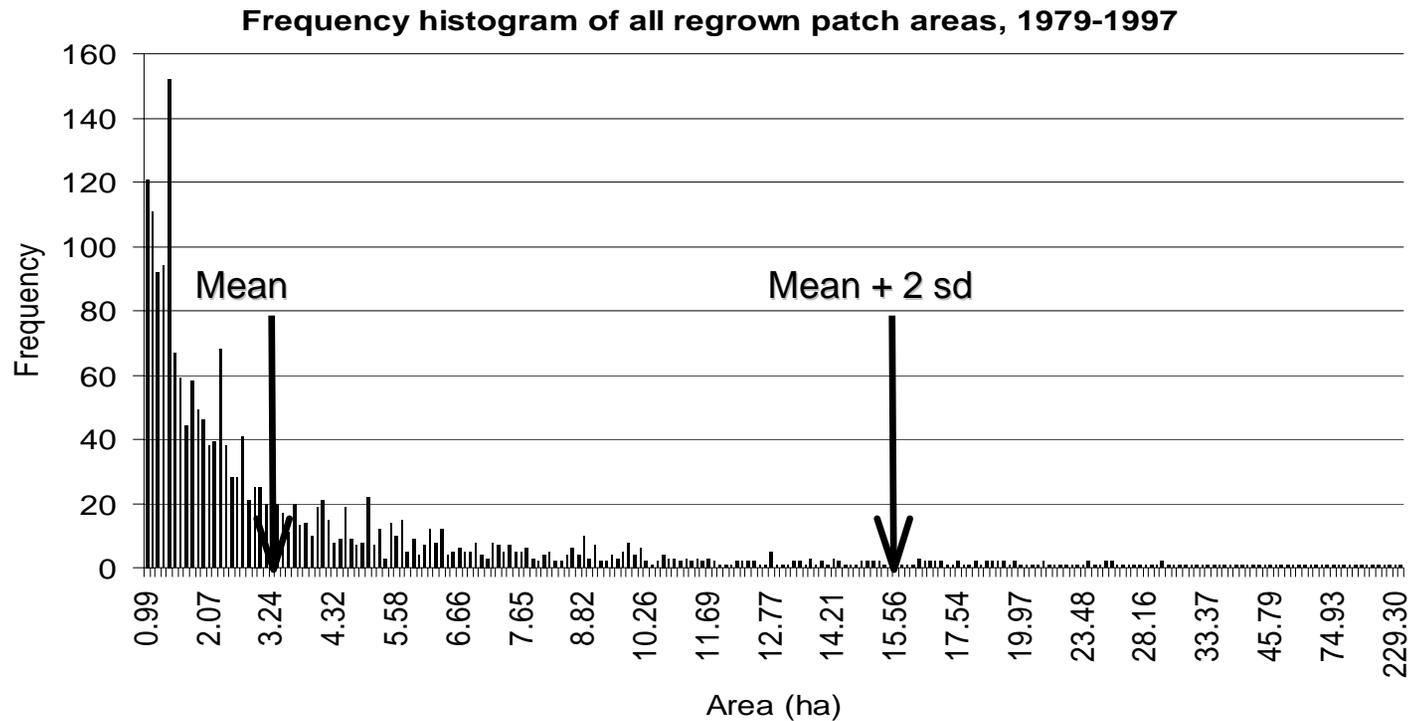
# Land Cover / Land Use History Database

## Percent of area cleared from fallow for each time period

Unit	90-93	93-95	95-97
Buen Samaritano	0.00	0.00	0.25
Carmelita	0.00	45.00	22.37
Cruce Dos Aguadas	0.88	18.79	12.49
Paso Caballos	0.00	0.00	0.00
Other: Buffer Zone	0.24	14.87	6.62
Other: Multi-use	0.68	27.34	8.57
Other: National Park	0.00	0.00	0.00
Other: Biotope	0.00	13.62	12.19
<b>Entire Study Area</b>	<b>0.07</b>	<b>15.66</b>	<b>6.93</b>

## Area regrown to area cleared ratio during each time period

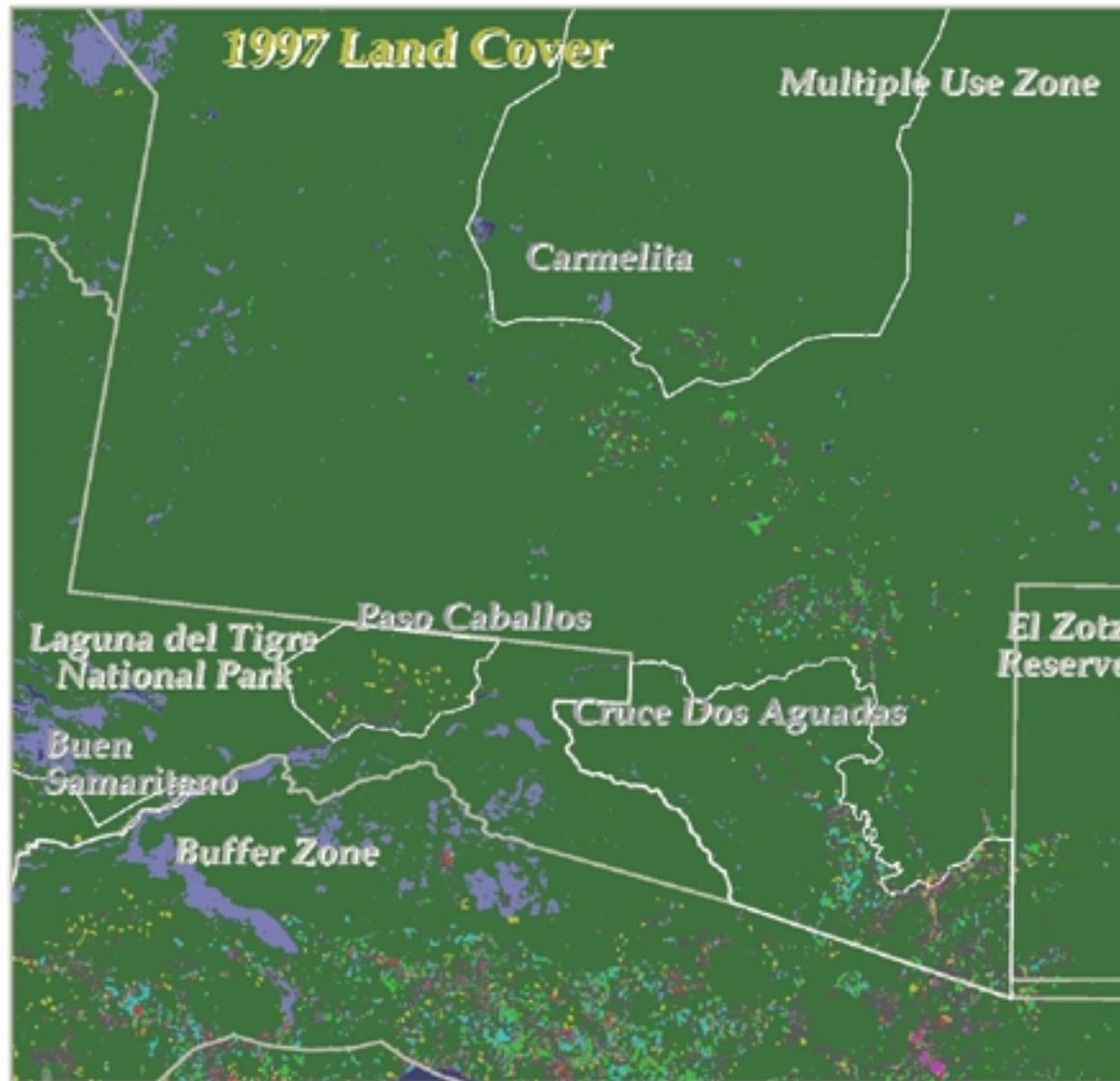
Unit	86-90	90-93	93-95	95-97	Avg.
Buen Samaritano	0.07	0.00	0.04	0.67	0.15
Carmelita	4.82	3.06	0.46	0.31	1.16
Cruce Dos Aguadas	0.85	0.67	1.35	0.16	0.54
Paso Caballos	3.08	0.00	0.00	0.10	0.09
Other: Buffer Zone	0.20	0.51	1.27	0.25	0.38
Other: Multi-use	0.76	1.00	1.24	0.27	0.59
Other: National Park	5.33	0.53	0.00	0.12	0.19
Other: Biotope	0.98	1.58	0.81	0.43	0.88
<b>Entire Study Area</b>	<b>0.34</b>	<b>0.58</b>	<b>1.17</b>	<b>0.24</b>	<b>0.43</b>



### Cleared patches not regrown and >15 ha in size

Unit	Count	Total Area	Mean Size
Buen Samaritano	4	112.90	28.23
Carmelita	1	33.19	33.19
Cruce Dos Aguadas	10	386.19	36.82
Paso Caballos	5	108.49	21.70
Other: Buffer Zone	82	3,685.90	44.95
Other: Multi-use	8	210.41	26.30
Other: National Park	2	36.16	18.08
Other: Biotope	0	0.00	0.00
<b>Entire Study Area</b>	<b>112</b>	<b>4,555.24</b>	<b>40.67</b>

## 1997 Land Cover



# **Discussion / Future Research**

- ***Change Detection Methodology***
  - ***3-date RGB NDVI method preferred for its high accuracy, ability to process three dates at a time, ease in interpretation, and utility for future monitoring and technology transfer***
- ***Land Use / Land Cover History Database***
  - ***facilitates description of land cover change pathways, spatial analysis of forest clearing and regrowth, and development and testing of hypotheses related to socio-economic factors***

# **Discussion / Future Research**

- ***Socio-economic drivers of LCLUC***
  - ***develop and test hypothesis related to the socio-economic factors that result in the spatial patterns of land use change observed in the satellite imagery and LCLUC database***
  - ***develop spatially explicit models to explain the trends in land cover conversion using socio-economic data, and use those models to predict LCLUC behavior in the region under different possible and relevant scenarios***

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