Case Studies & Diagnostic Models of the Inter-annual Dynamics of Deforestation in Southeast Asia

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LC LUC Dynamics and Secondary Growth

- Global Carbon Budget: Tropics (Ciais *et al. 1995)*
  - Northern Tropics - source
  - Southern Tropics - small sink
- Explanations:
  - Increase in Tropical NEP offsets deforestation source
  - Reduced rate of deforestation w/increased secondary growth of previously cleared land
- Inconsistent with inter-decadal deforestation data derived from satellite imagery

LC LUC Dynamics and Sec. Growth, Cont.

- Significant Inter-annual Differences in Rates of Deforestation asynchrony in relative contribution of the net flux from clearing and re-growth
  - Inter-annual departures in rates of deforestation from decadal mean
  - Significant abandonment of land to secondary growth

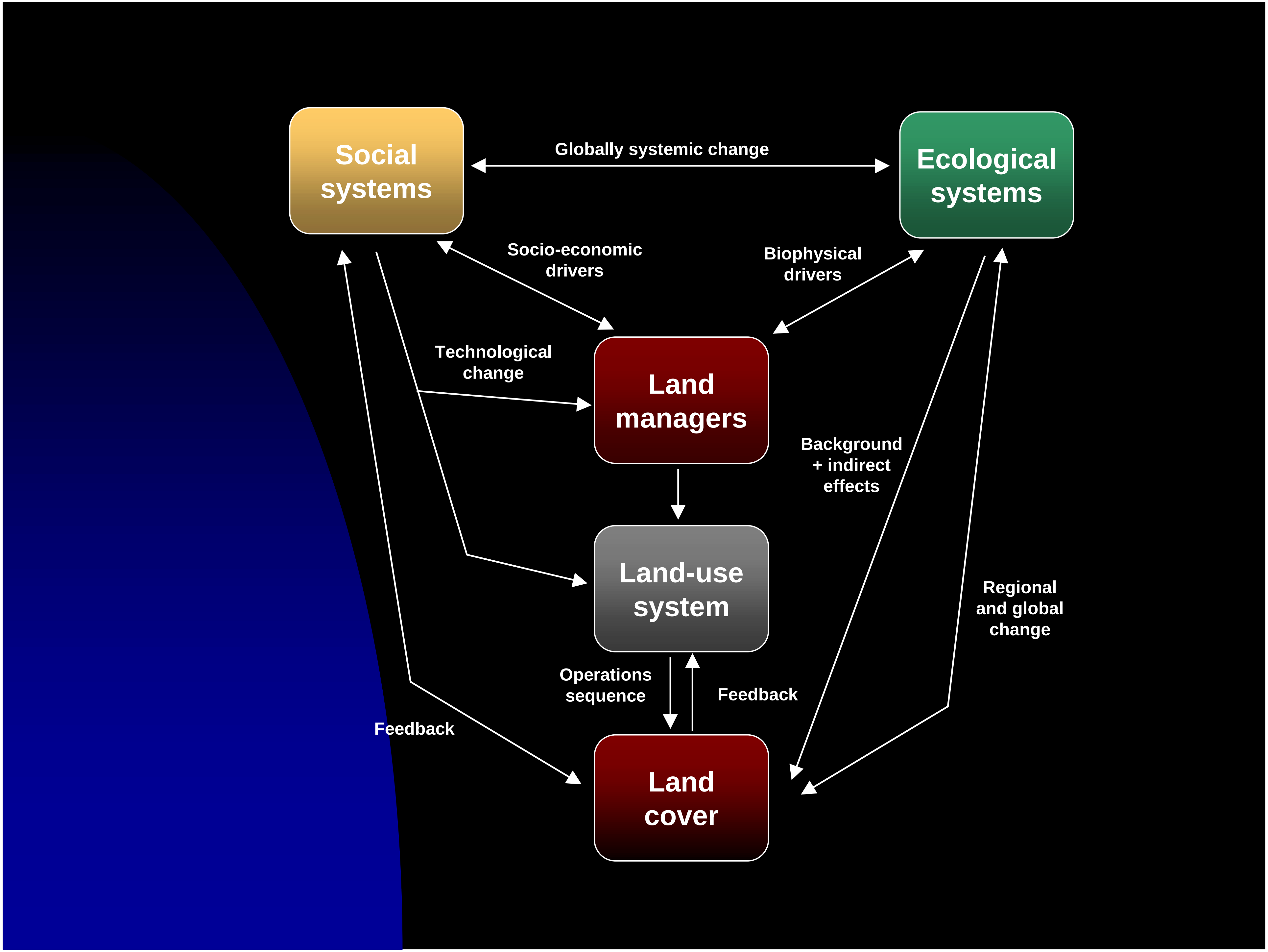
Biophysical & Socio-economic Factors Contributing to LC LUC Dynamics

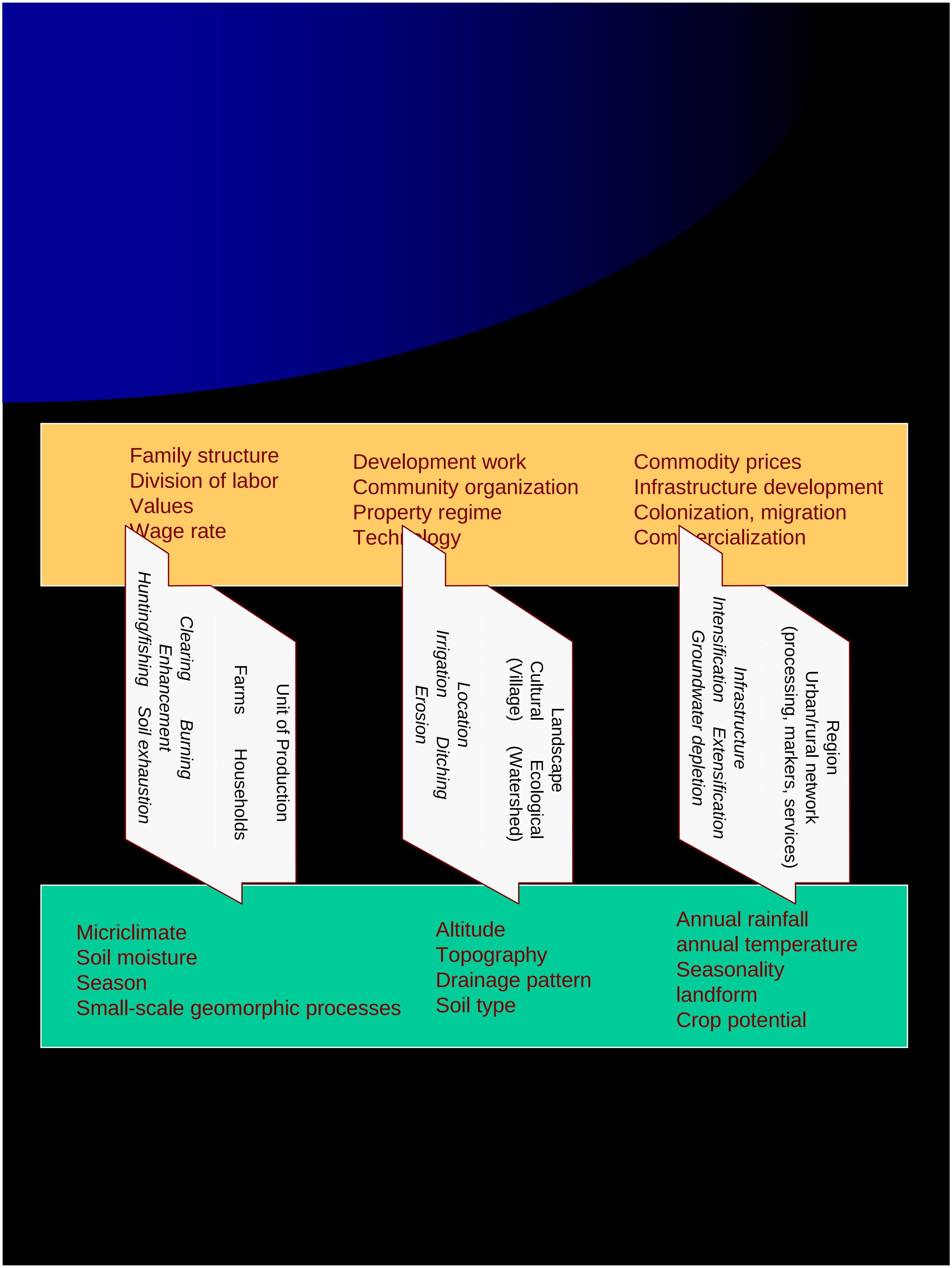
- Dynamic Processes
  - clearing   abandonment   re-clearing

- Active Land Management

- Population Displacement

Land Use Strategies ⇔ Ecological Conditions


Social systems
Globally systemic change
Ecological systems
Socio-economic drivers
Biophysical drivers
Technological change
Land managers
Background + indirect effects
Land-use system
Regional and global change
Operations sequence
Feedback
Feedback
Land cover


Family structure
Division of labor
Values
Wage rate
Development work
Community organization
Property regime
Technology
Commodity prices
Infrastructure development
Colonization, migration
Commercialization
Unit of Production
Farms Households
Clearing Burning
Enhancement
Hunting/fishing Soil exhaustion
Landscape
Cultural Ecological
(Village) (Watershed)
Location
Irrigation Ditching
Erosion
Region
Urban/rural network
(processing, markers, services)
Infrastructure
Intensification Extensification
Groundwater depletion
Micriclimate
Soil moisture
Season
Small-scale geomorphic processes
Altitude
Topography
Drainage pattern
Soil type
Annual rainfall
annual temperature
Seasonality
landform
Crop potential

Research Questions

- Are the inter-annual dynamics and rates of deforestation and abandonment to secondary forest significantly different than the decadal mean in Southeast Asia…
- ...and can this account for a dampening of the biogenic source of carbon apparent in annual observations of atmospheric carbon dioxide and oxygen?

Research Questions, cont...

- Through the integration of socio-economic and satellite data and the development of dynamic deforestation models, can we improve our understanding of the dynamics of deforestation in the tropics…
- ... and the various controls on rates of deforestation and re-growth and land use transition sequences?

Research Activities

- 1. Develop case studies to determine deforestation dynamics: is secondary growth important and does land use change dynamically on an annual basis; what are the land use transition probabilities?
- 2. Determine if the annual rates of deforestation have been significantly different from the decadal mean rate over large areas and the region as a whole
- 3. Develop diagnostic models of the deforestation process to better understand and quantify the different controls on rates of deforestation and abandonment

Southeast Asia Science Network

- Thailand
  - National Resource Council of Thailand
  - Land Development Department
  - Royal Forestry Department of Thailand
  - Kesetsart University
  - Mahidol University
  - Chiang Mai University
- Malaysia
  - University Kebangsaan Malaysia
  - Department of Agriculture Malaysia
  - Forestry Department Malaysia
  - Malaysian Center for Remote Sensing (MACRES)

- Philippines
  - National Mapping and Resource Information Authority (NAMRIA)
  - National Research Council of the Philippines
  - National Economic Development Authority (NEDA)
  - Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA)
- Indonesia
  - Agency for Assessment and Application of Technology (BPPT)
  - National Institute of Aeronautics and Space (LAPAN)
  - National Coordinating Agency for Surveys and Mapping (BAKOSURTANAL)
  - Center for Development Studies, Bogor Agricultural University (BSP-IBP)

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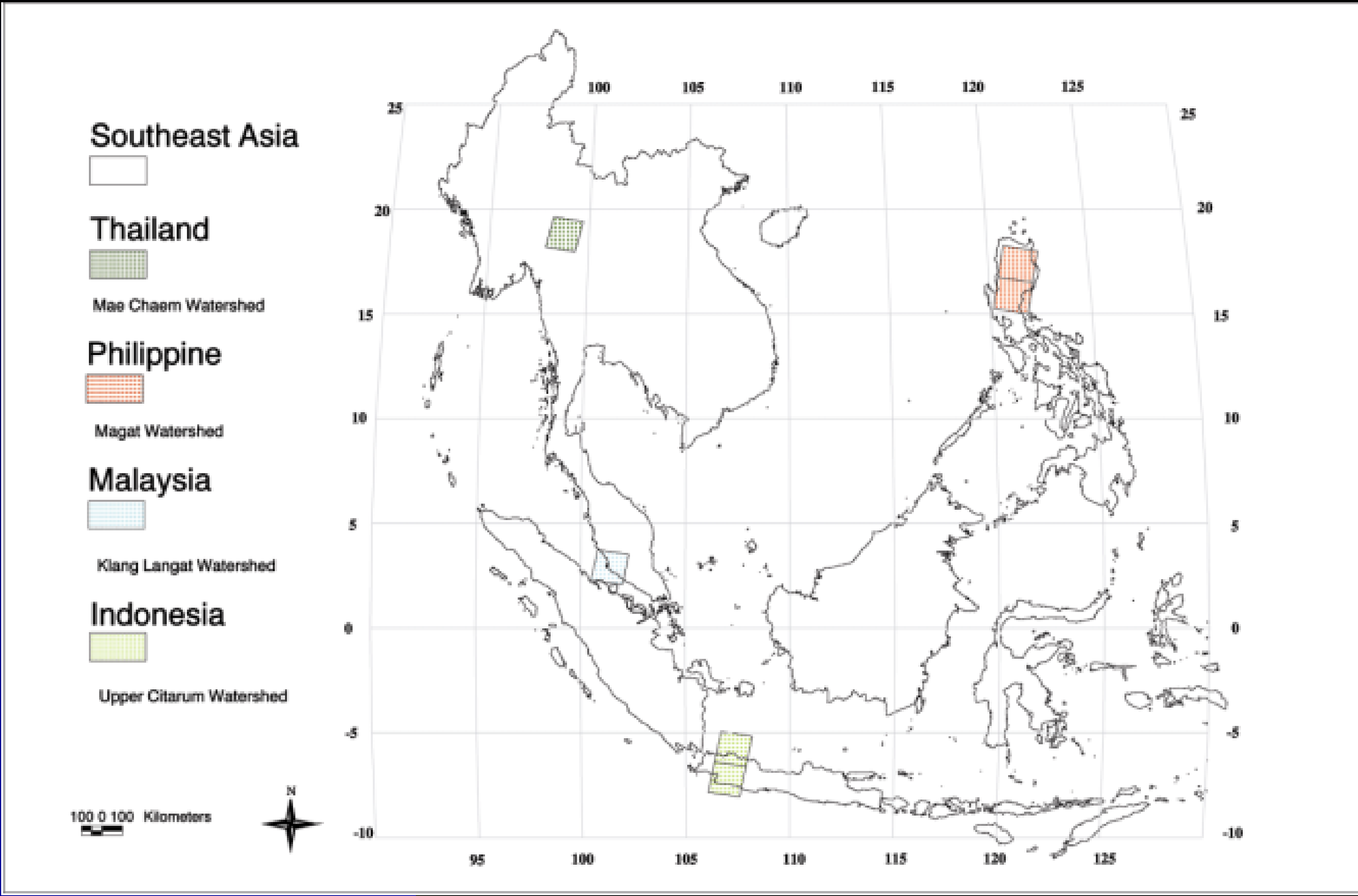
Southeast Asia Case Studies

Building on Phase 1 under IGBP LUCC SARCS

- Multi-date Analysis of Landsat Imagery at 4 study sites
  - Land Cover / Land Use Change Detection
- Sites:
  - Thailand: Mae Chaem Watershed, Chiang Mai
  - Malaysia: Klang Langat Watershed, Selangor
  - Philippines: Magat Watershed, Nueva Viscaya, Luzon
  - Indonesia: Upper Citarum Watershed, Java
- Quantitative analysis of socio-economic factors and LC LUC analysis

Phase 1 Southeast Asia Sites



Land Use and Land Cover Change, sample watersheds in Southeast Asia, SARCS Case Studies: 1974-1996.

Land Use / Land Cover	Indonesia		Malaysia		Philippines		Thailand	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Forest	**-20,994**	**-21.2**	**-37,610**	**-21.8**	**-25,453**	**-35.5**	**-56,894**	**-10.1**
Agriculture	-41,036	-44.0	+14,880	+7.7	-31,694	-62.3	+12,397	+35.6
Urban/Settlement	+51,068	+148.6	+34,664	+161.0	*	*	+3,400	+593.2
Grassland	+8,452	+87.2	-4,509	-56.7	-21,213	-17.9	+1,083	+3.4
Bare/openland	+10,789	+242.0	-7,175	-78.8	*	*	+214	+151.6
Water Body	+3,532	+994.9	+52	+0.5	*	*	+37,800	+110.4
Sample Watershed	Upper Citarum		Klang Langat		Magat		Mae Chaem, Mae Khan and Mae Klang	
Watershed Area, (ha)	259,505		415,409		240,868		669,242	
Time Covered, (yr.)	1984 -1996		1974 -1990		1983 -1993		1985 -1995	

* Remotely-sensed data did not clearly capture these types of land use and land cover.

-, + Denotes decrease or increase in land use and land cover, respectively.

Moving to Phase 2

- Year 1 of NASA LCLUC project is focused on expanding the initial Phase 1 effort: *emphasis on forests and initially Thailand*
- Collaboration between LUCC and START to develop the project with comparable results to other regions,
- Utilizes the IGBP-IHDP framework for linking physical and social science.

Phase 2, continued

- Initial emphasis on LUCC Focus 2, *Direct Observations and Empirical Models*.
- Emphasis now shifting toward integration of LUCC Focus 1, *Land Use Dynamics*, which incorporates socioeconomic data.
- The project takes an interdisciplinary look at the driving forces of land use and cover change in the region.
- To do this, the project has developed a common protocol for methods and datasets, aimed at providing a framework for intercomparison.
- Although isolated studies have been done in specific locales, there are virtually none which provide a region-wide perspective built from case studies with common protocols.

Phase 2, continued

- The project has also aimed at developing a network of practicing scientists in the region.
- This network has been centered on the case studies countries, *with additional participation* from other countries even though they are not currently hosting a case study (e.g. Vietnam).
- This network could and should be expanded over the course of the next phase.

Phase 2, continued

Phase 1 → transition → **Phase 2**

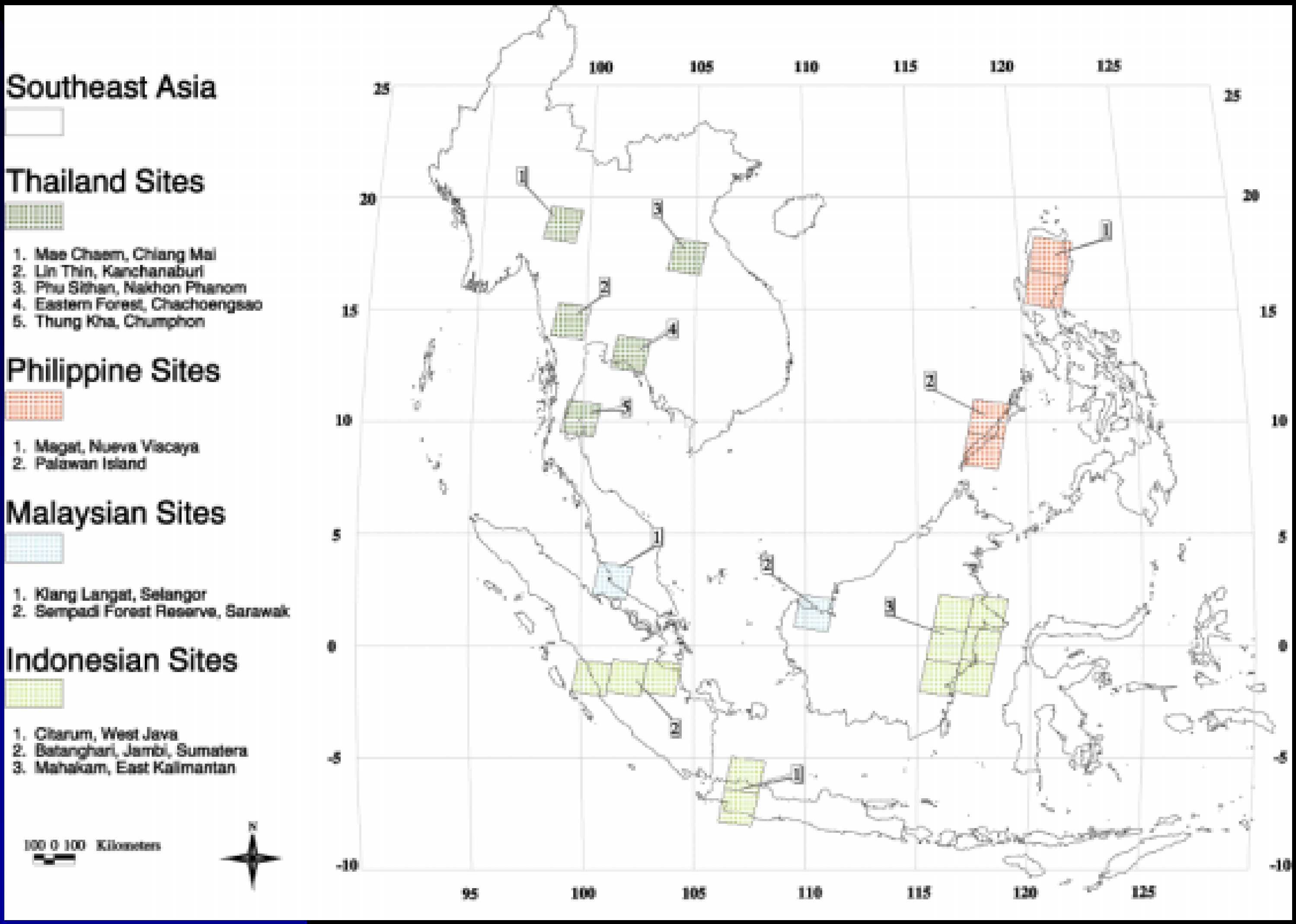
Phase 1

- Case Studies: LUCC Focus 2
- Common methods, Site selection
- Team network
- Field and data analysis
- 2-date change probability model
- initial socio-economic analysis
- Results in Synthesis Workshop

Phase 2

- LUCC Focus 1 - 2 links
- Socio-economic methods
- Expand the network
- Focus on Forests
- Development of models
- Multi-date analysis
- Data set organization
- Regional analysis
- Links to GHG & IGAC

LCLUC phase 2 case studies sites



Phase II Site Description

A Suite of Geographic Gradients

- Geographic: range in latitude & longitude
- Climatic: seasonal dry to persistent wet
- Topographic
  - Inland & Coastal
  - Lowland & Mountainous
- Affected Forest Environments
  - *Dipterocarp* forests
  - Mangrove forests
  - Upland and lowland watersheds
  - Coastal areas (reefs)
- Land Use Characteristics ("drivers")

Land Use Characteristics
(Human“Drivers” of Land Use Land Cover Change)

- Shifting Agriculture
- Temporary Agriculture (annuals)
- Permanent Agriculture (perennials)
- Logging
- Wet Agriculture (paddy rice)
- Wet Agriculture (aqua-culture)
- Urban
- Plantations
- Industry

Variation in Land Use by Case Study

Land Use	Thailand	Indonesia	Malaysia	Philippines
Shifting Agriculture	T1 & T2	I1 & I3		P1 & P2
Temporary Agriculture (annuals)	T1-T5	I1-I3	M1 & M2	P1 & P2
Permanent Ag. (perennials)	T1	I2	M1 & M2	P2
Logging	T1 & T4	I1 & I3	(M1) & M2	P1 & P2
Wet Agriculture (paddy rice)	T1, T4 & T5	I1 & I2	M1 & M2	P1 & P2
Wet Agriculture (aqua-culture)	T5	I1-I3	M1	P2
Urban	T1, T3-T5	I2	M1	P2
Plantation	T1-T5	I1, I3	M1 & M2	P1 & P2
Industry	T5	I2 & I3	M1	

Phase II Case Study Sites

Thailand:

T1 = Mae Chaem
T2 = Lin Thin
T3 = Phu Sithan
T4 = Eastern Forest
T5 = Thung Kha

Indonesia:

I1 = Citarum
I2 = Batanghari
I3 = Mahakam

Malaysia:

M1 = Klang Langat
M2 = Sarawak

Philippines:

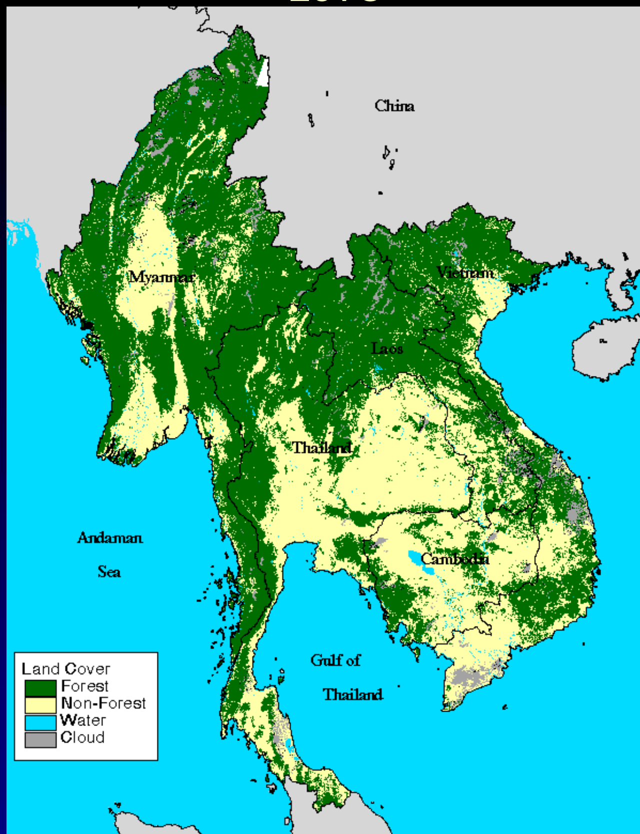
P1 = Magat
P2 = Palawan Island

Expansion of the Network

- Vietnam
- Laos
- Cambodia
- Myanmar

Regional Forest Cover in Southeast Asia

1973

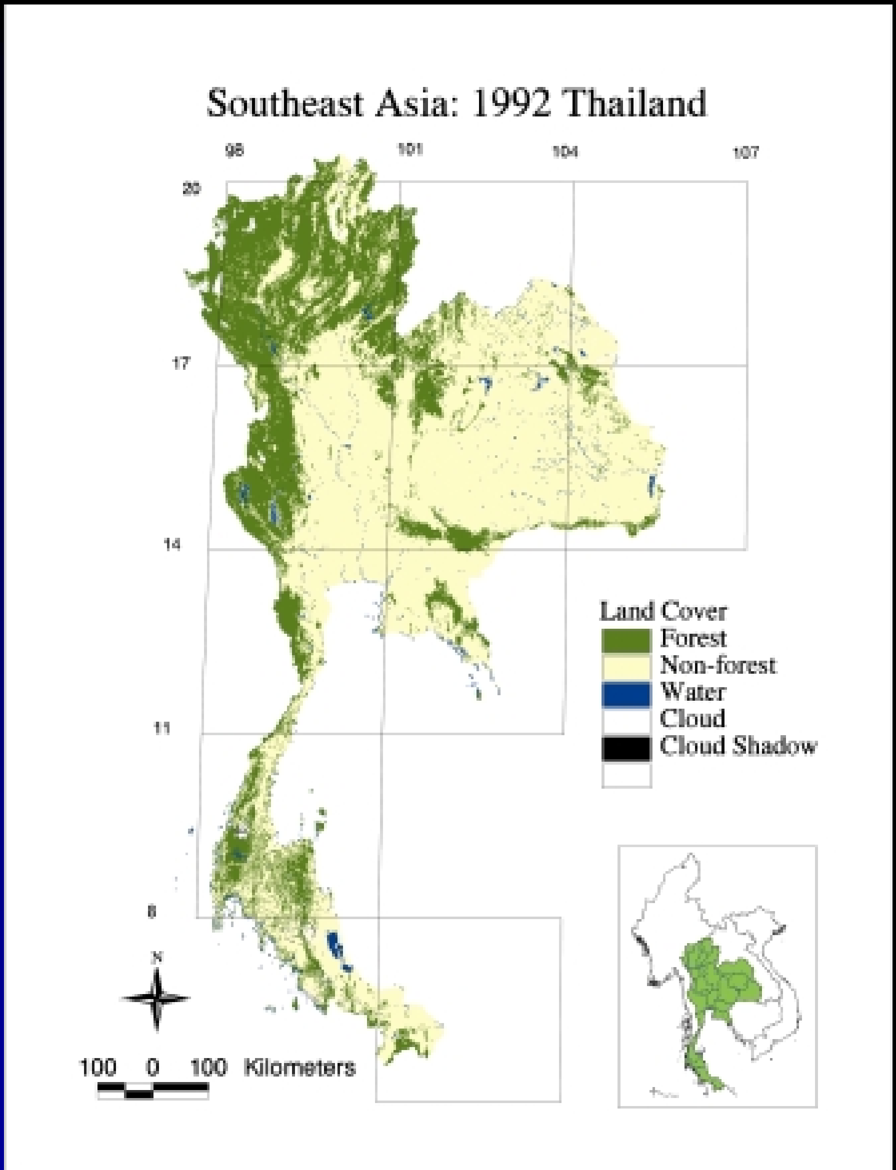


1985

Country	Forest Area in 1973	Forest Area in 1985	Change in Forest	% Change	Defor. Rate/Year
Cambodia	5.25	3.98	1.27	24	0.11
Laos	18.28	16.52	1.76	10	0.15
Thailand	22.56	16.74	5.81	26	0.49
Vietnam	19.92	16.15	3.77	19	0.31
Myanmar	48.71	44.82	3.88	8	0.32
Total	114.70	98.21	16.49	14	1.37

Units: 10^6 ha or 10^6 ha per $year^{-1}$

Recent Updates: 1992 Thailand



Synoptic Forest Cover Change in Thailand

Forest Cover 1973	22.56
Forest Cover 1985	16.74
Forest Cover 1992	16.54
▲1973 – 1985	5.82
▲1985 – 1992	0.20
▲1973 – 1992	6.02
Rate of Deforestation	0.32

Units: 10^6 ha or 10^6 ha per $year^{-1}$

Thailand case study

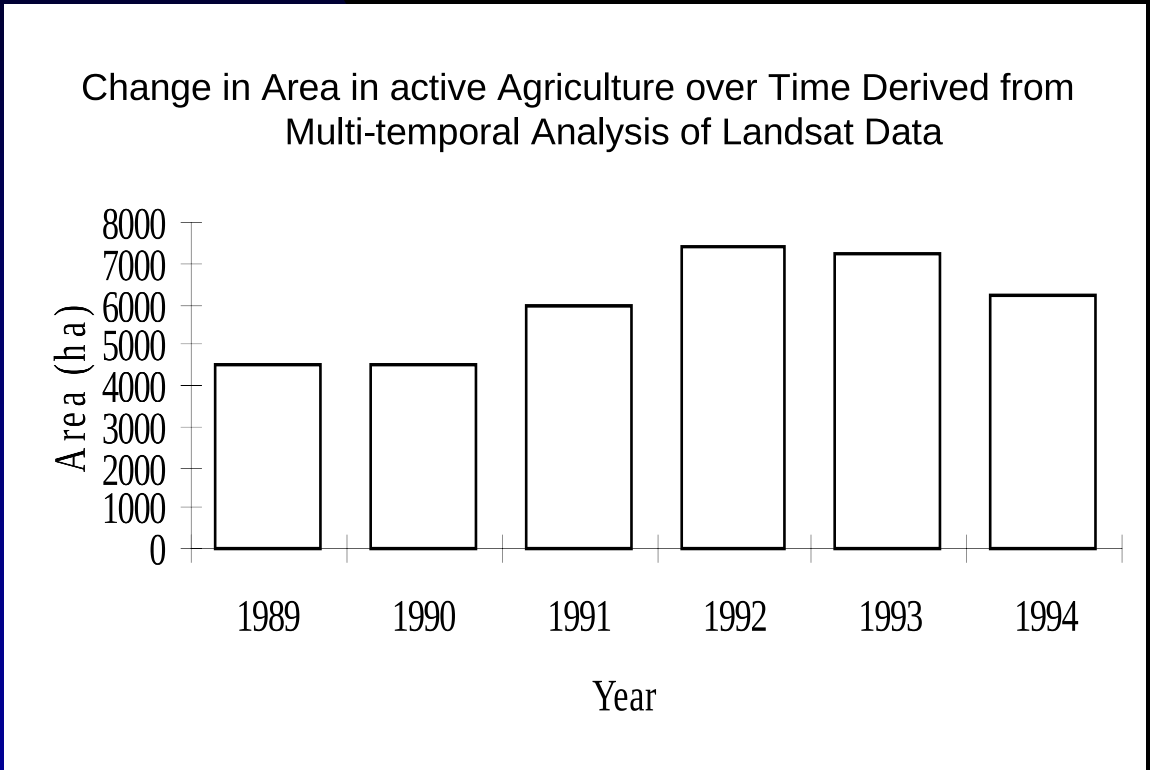
- Importance:
  - Deforested area in Northern Thailand has increased by 36 % between 1980-90.
  - Largest absolute amount of deforestation amongst all regions

Causes of deforestation

- **Logging**
  - Thailand has been a net exporter of wood since the early seventies
  - Contribution to GDP has been negligible
  - Thailand banned logging in 1986
- **Agriculture: Main reason**
  - pushing forward the extensive margin of cultivation (Intensification either not economically possible or is unsustainable)

Multi-temporal Analysis of Co-registered, Annual Data 1989-1994, Chiang Mai, Thailand

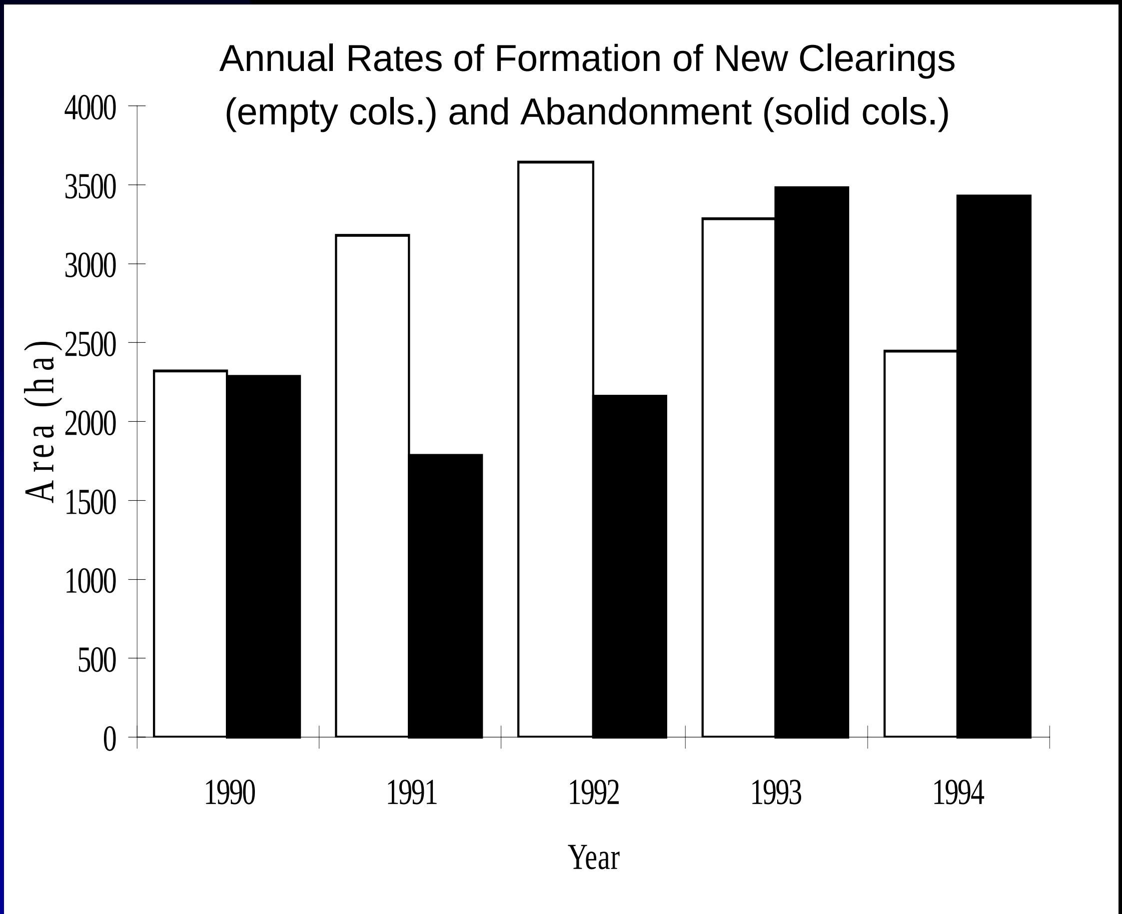
- Change in areas under cultivation



- Area in cultivation increased 38% from 1989 to 1994
- Long cultivation cycles (<6 years) over period from 1989 to 1994 varied from 14% to 23% of total area cultivated
- 81% of area during this period in long fallow, secondary forest or undisturbed primary forest

Inter-annual Analysis Chiang Mai, Thailand

- Annual Extent of New Clearings and Abandonment



- Clearings Varied: low of 2.3 x 10^3 ha in 1990 to peak of 3.7 x 10^3 ha in 1992
- Decline to 2.4 x 10^3 ha in 1994
- In 1990 and 1991 over 50% of cultivated area was on areas just cleared
- Decrease in newly cleared cultivated lands to 38% in 1994
- Smallest amount of abandonment (1991) 1.8 x 10^3 ha
- Largest amount of abandonment 1993 and 1994 3.5 x 10^3 ha and 3.4 x 10^3 ha respectively

Inter-annual Analysis
Chiang Mai,Thailand

- Conclusions
  - Annual deforestation rates highly variable
  - Rate of abandonment highly variable and asynchronous with clearing
  - Carbon-accumulating re-growth a predominant feature of the Chiang Mai landscape
  - Pulse of deforestation in the late 1980s slowing down in the 1990s

New LCLUC Models

- Regional Analysis
  - von Thünen Equilibrium Land Use Model; one date
  - Markov Model of Land Use Change; three dates
  - Fixed Effects Logit Model of Land Use Change; three dates
- Case Study Analysis
  - Markov Model; annual analysis (change matrix)
  - Fixed Effects Model; annual analysis

Approach to modeling

- **Two Types of Models**
  - Explain land use at a point of time
  - Explain change in land use between two points of time
- **Two Levels of Spatial Disaggregation**
  - Landscape (pixel) level
  - District or provincial level

Purpose of Models

- **Understand Patterns of Land Use**
- **Predict Patterns of Land Use**
  - Local level – e.g., for natural resource management
  - Regional level – e.g. to forecast carbon emissions
- **Predict Impacts of Policy Levers**
  - Agricultural policies
  - Employment policies
  - Road building

Types of Land Use Models

- ***Long Run Equilibrium Models***
  - Explain land use at a point of time, ***independently*** of past land use
  - Predict P(Plot i is in use k at time t)
  - Can be estimated using a single cross section of data or multiple cross sections
  - Can be used to predict land use change if future values of explanatory variables can be predicted

Types of Land Use Models, cont.

- ***Markov Models of Land Use Change***
  - Explain probability of land use at *t*+1 given land use at *t*
  - Predict ***P***(Plot ***i*** in use ***k*** at t| Plot ***i*** in use ***j*** at ***t***-1)
  - Allows for state dependence
  - Estimation requires observations on land use at 2 or more points of time
  - Can be used to predict land use change if future values of explanatory variables can be predicted

A Landsat-based deforestation model

- We hypothesize that the farm creation process unfolds in two sequential phases:
  - the initial, ***deforestation*** phase,
  - and the ***regrowth* clearance** phase.
- The timing of these phases depends on the number (m) and interval between deforestation events,
- which in turn is related to the shift time for annual plots (Δt), or the number of years a field producing annuals is used before abandonment (to regrowth) or allocation to pasture or perennials

Deforestation model, cont.

- Consider the three decisions faced by farmers:
  - *(1) deforestation decision,*
  - *(2) field decision,*
  - *(3) regrowth decision.*
- Each of these decisions determines how a particular piece of land will be used, as defined by its groundcover.

- In the deforestation decision, the farmer decides, in the wake of deforesting old forest, the proportions to allocate to annuals production (a), pasture (pa), and perennials (pe).

- With the field decision, the farmer reallocates land used in annuals production to pasture, perennials, or to regrowth (r).

- The regrowth decision involves clearance for annuals, pasture, or perennials.

Deforestation model, cont.

- During the deforestation phase, both deforestation and field decisions are made, although the first field decision occurs with the second deforestation event,
- Thus, the first deforestation event occurs at t= 0, and the first field decision, at $t = \Delta t$. The final deforestation event, with decision, takes place at year, $t = (m-1)\Delta t$.
- After this, regrowth is cleared to annuals, pasture, and perennials in a cycle similar to that of old forest.

Deforestation model, cont.

- Consider the land area cleared in a deforestation event; call this the deforestation event magnitude, or DEM. DEM is a function of the human resources (h), natural resources, i.e. the physical environment (n), and location (l), or

$$DEM_t = DEM\,(h_t, n_t, l).$$

- Similarly, consider the probability of transitions between the land cover classes old forest (o), regrowth (r), annuals (a), pasture (pa), and perennials (pe), or

$$p^t_{i,j} = p^t_{i,j}\,(h_t, n_t, l)., \text{ where}$$

$$I \in (o, a, r),\ j \in (a, pa, pe, r).$$

Deforestation model, cont.

- Stocks of land cover type I at time t are given, in areal terms, as $x^t{}_I$; stock change at time ?t is ?$x^t{}_i$. Hence, the transitions in land cover classes in the deforestation phase are at t = 0, conversion of primary forest, with initial land cover stocks:

$\Delta x^0{}_{o,\,a} = p^0{}_{o,\,a}\ DEM_0$ and $x^0{}_a = \Delta x^0{}_{o,\,a}$ $(= x^1{}_a)$

$\Delta x^0{}_{o,\,pa} = p^0{}_{o,\,pa}\ DEM_0$ and $x^0{}_{pa} = \Delta x^0{}_{o,\,pa}$ $(= x^1{}_{pa})$

$\Delta x^0{}_{o,\,pe} = p^0{}_{o,\,pe}\ DEM_0$ and $x^0{}_{pe} = \Delta x^0{}_{o,\,pe}$ $(= x^1{}_{pe})$

- At t = 2, conversion of plots under annuals production:

$\Delta x^2{}_{a,\,pa} = p^2{}_{a,\,pa}\ x^0{}_a$

$\Delta x^2{}_{a,\,pe} = p^2{}_{a,\,pe}\ x^0{}_a$

$\Delta x^2{}_{a,\,r} = p^2{}_{a,r}\ x^0{}_a$

Deforestation model, cont.

- in addition to the conversion of primary forest:

$$\Delta x^2_{o,a} = p^2_{o,a}\ DEM_2$$

$$\Delta x^2_{o,pa} = p^2_{o,pa}\ DEM_2$$

$$\Delta x^2_{o,pe} = p^2_{o,pe}\ DEM_2$$

- yields the land cover stocks in time period 2:

$$x^2_a = x^0_a + \Delta x^2_{o,a} - S\,\Delta x^2_{a,j}, \quad j \in (pa, pe, r)$$

$$x^2_{pa} = x^0_{pa} + \Delta x^2_{o,pa} + \Delta x^2_{a,pa}$$

$$x^2_{pe} = x^0_{pe} + \Delta x^2_{o,pe} + \Delta x^2_{a,pe}$$

$$x^2_r = \Delta x^2_{a,r}$$