Integrating Information Technology and Local Knowledge to Detect and Measure Forest Degradation

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Rationale of research

- There is a need to develop methodology for REDD and REDD+
- Results would help overcome one technical problem in REDD & REDD+: The difficulty of detecting and measuring forest degradation

- REDD – Reducing Emissions for Deforestation and Forest Degradation
- REDD+ – REDD *plus* conservation, sustainable management of forests and enhancement of carbon stocks (in developing countries)

Definition of Forest Degradation

In the context of REDD/REDD+

Difficult to quantify:

(1) Changes within the forest which negatively affect the structure or function of the stand or site, and thereby lower the capacity to supply products and/or services **(FAO 2001, 2006)**

Definition of Forest Degradation

Easier to quantify:

(2) A direct human-induced long-term loss (persisting for X years or more) of at least Y % of forest carbon stocks (and forest values) since time T and not qualifying as deforestation **(IPCC, 2003)**

Definition of Forest Degradation

Easier to quantify

(3) Persistent reduction of canopy cover and/or carbon stocks in a forest due to human activities such as animal grazing, fuelwood extraction, timber removal or other such activities, but which does not result in the conversion of forest to non-forest land (which would be classified as deforestation), and falls under the *IPCC 2003 Good Practice Guidance* land category of "forest remaining forest" (**Approved VCS Methodology VM0007**)

Issue: Deforestation (Loss of tree cover below 10% crown closure) or Degradation

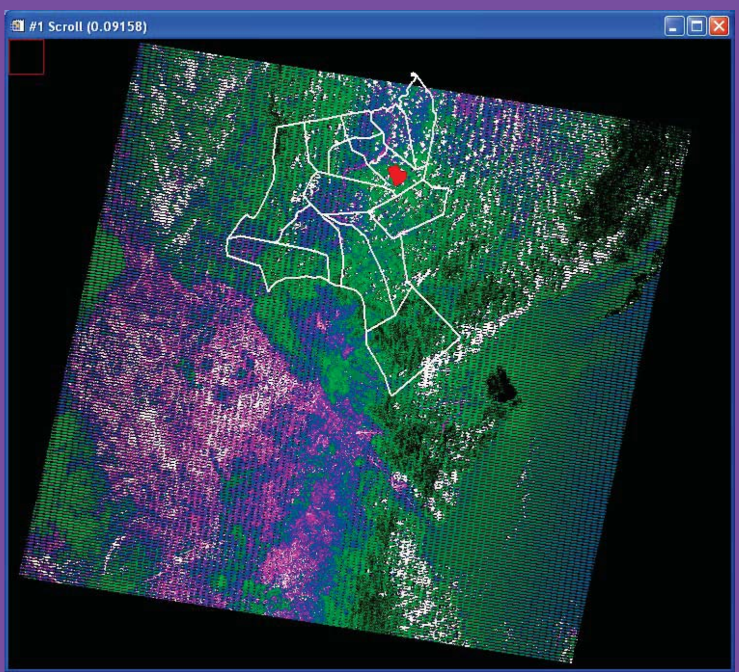
Shown under grid of 0.5 ha, majority of grid cells have more than 10% tree cover

The need for local methodology

- Methodology development focuses on the use of remote sensing data to detect and measure forest degradation
  - Increased spatial resolution
    - Constraint: Very high cost of data
    - Cloud cover problem
  - Multiple data sources (field data, local knowledge, GIS ancillary data) and increased data volume

Why remote sensing data

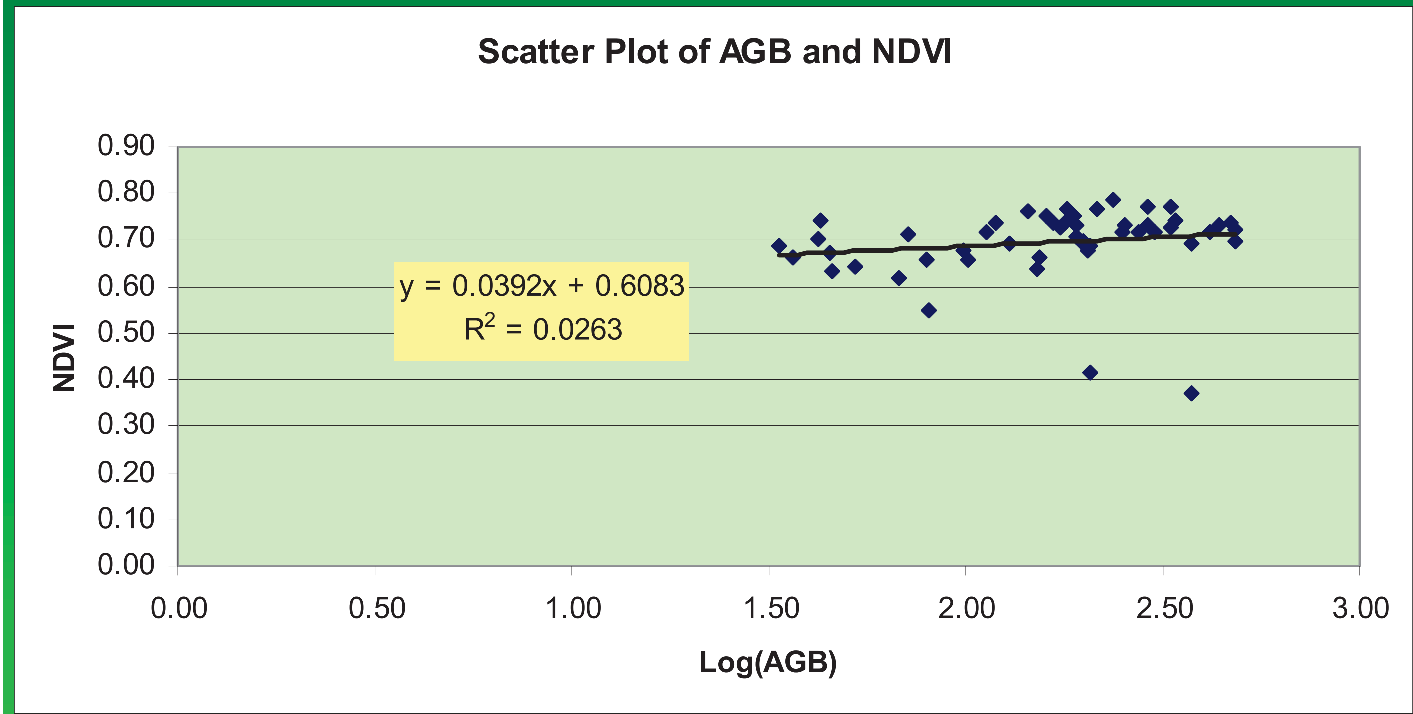
- Covers large tract of land
- Excellent data source for repeated measurements and monitoring
- Can provide historical data
- Best data source for inaccessible areas



But the medium resolution remote sensing data is not so dependable for forest degradation measurement …

- Poor discrimination of crown closure at 30m resolution
- Inconsistency of estimates across time, scene or season
- Weak relationship between AGB/crown closure and spectral response

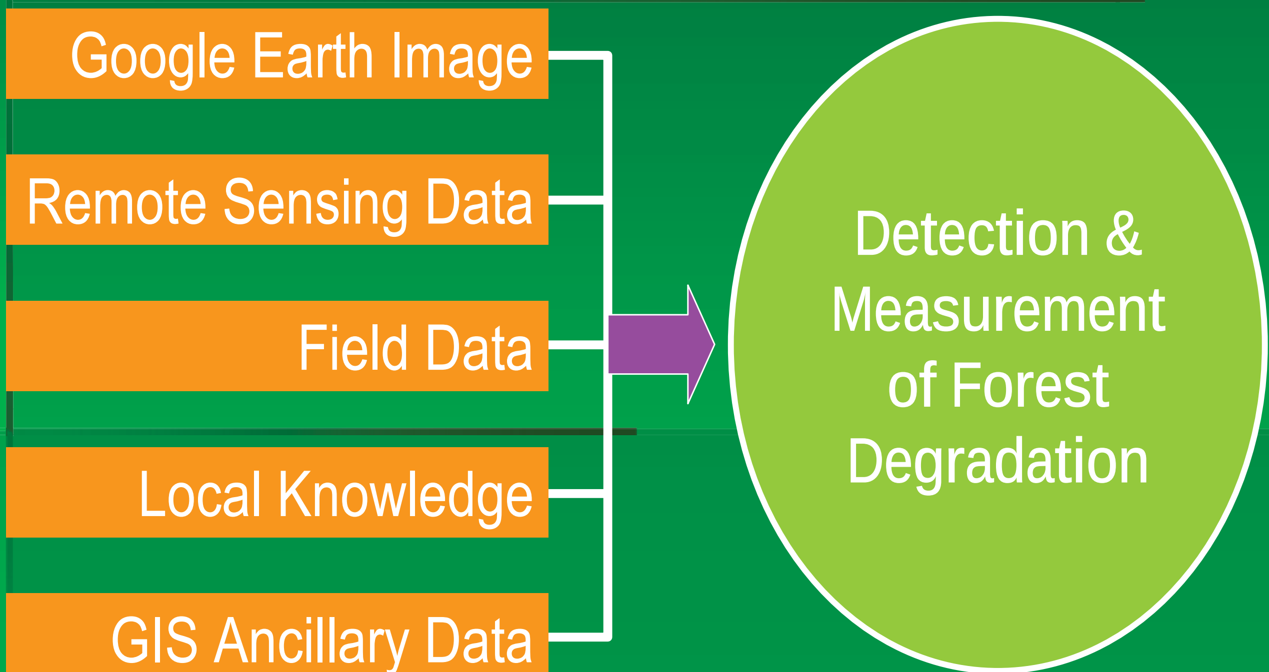
Sample regression between AGB and NDVI



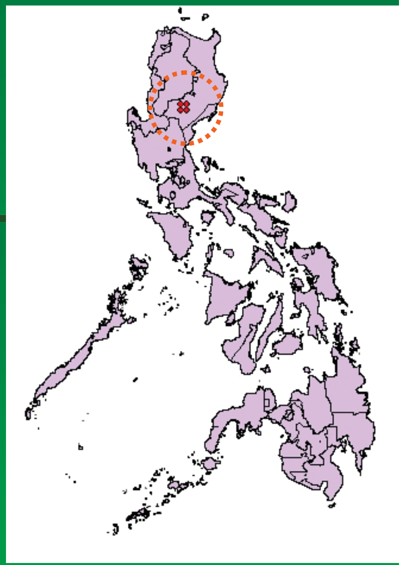
For medium resolution data, we need …

- Increased ground data
- High-quality spatial information from local people
- Integration of GIS ancillary data
- Simplified but reliable methodology not solely dependent on remote sensing data
- Alternative computing technique

Multiple data sources …



The study area



- Barangay Maasin, Quezon, Nueva Vizcaya
- Around 90% of the land is classified as public land
- Agriculture has been transforming thick contiguous forests into thin forest patches
- Community-based forestry program (implemented in 2006) provided land tenure (IPR) to community members; many projects geared towards improving forest cover
- Burning is the main means of clearing land (forest, shrub, grass)

Rice & corn under trees

Maintaining minimal tree cover

Burning along forest edges

Expansion into forest edge

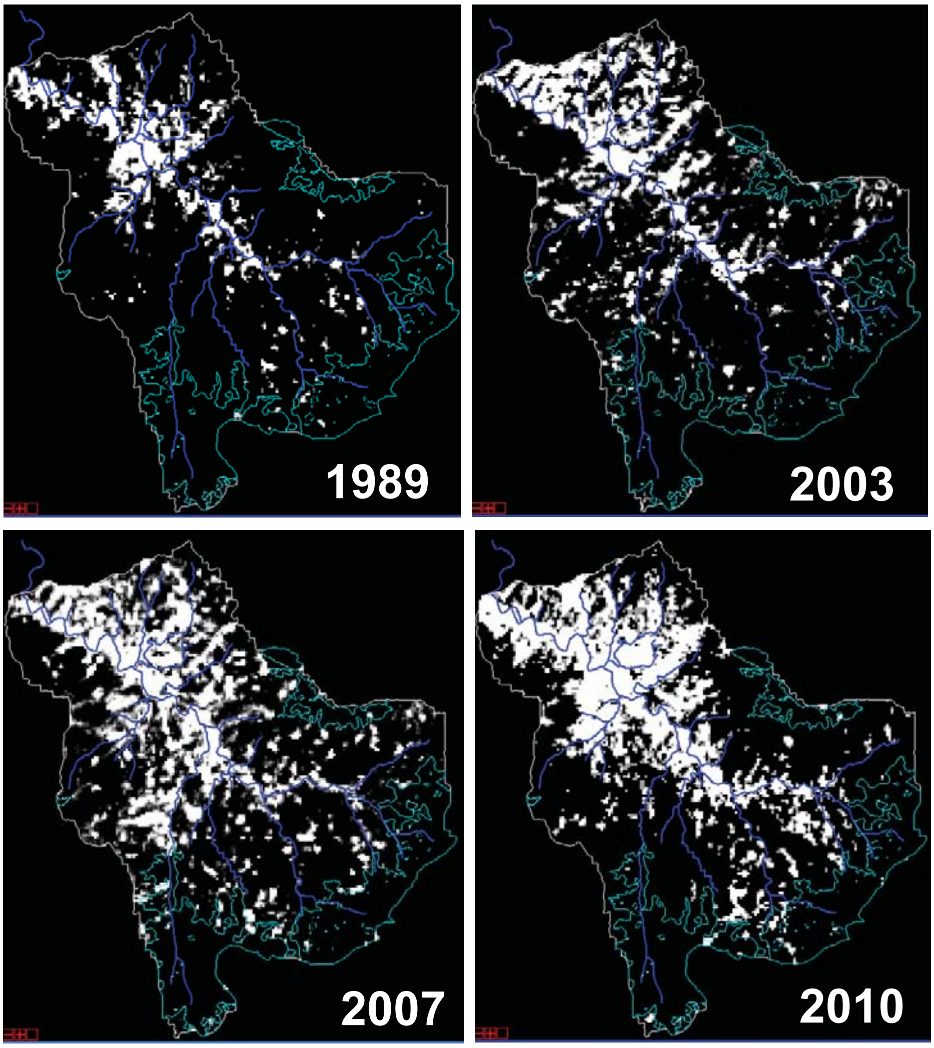
Girdling complements burning

Timber harvesting is not widely practiced as we observed. Cutting for household consumption seems inevitable.

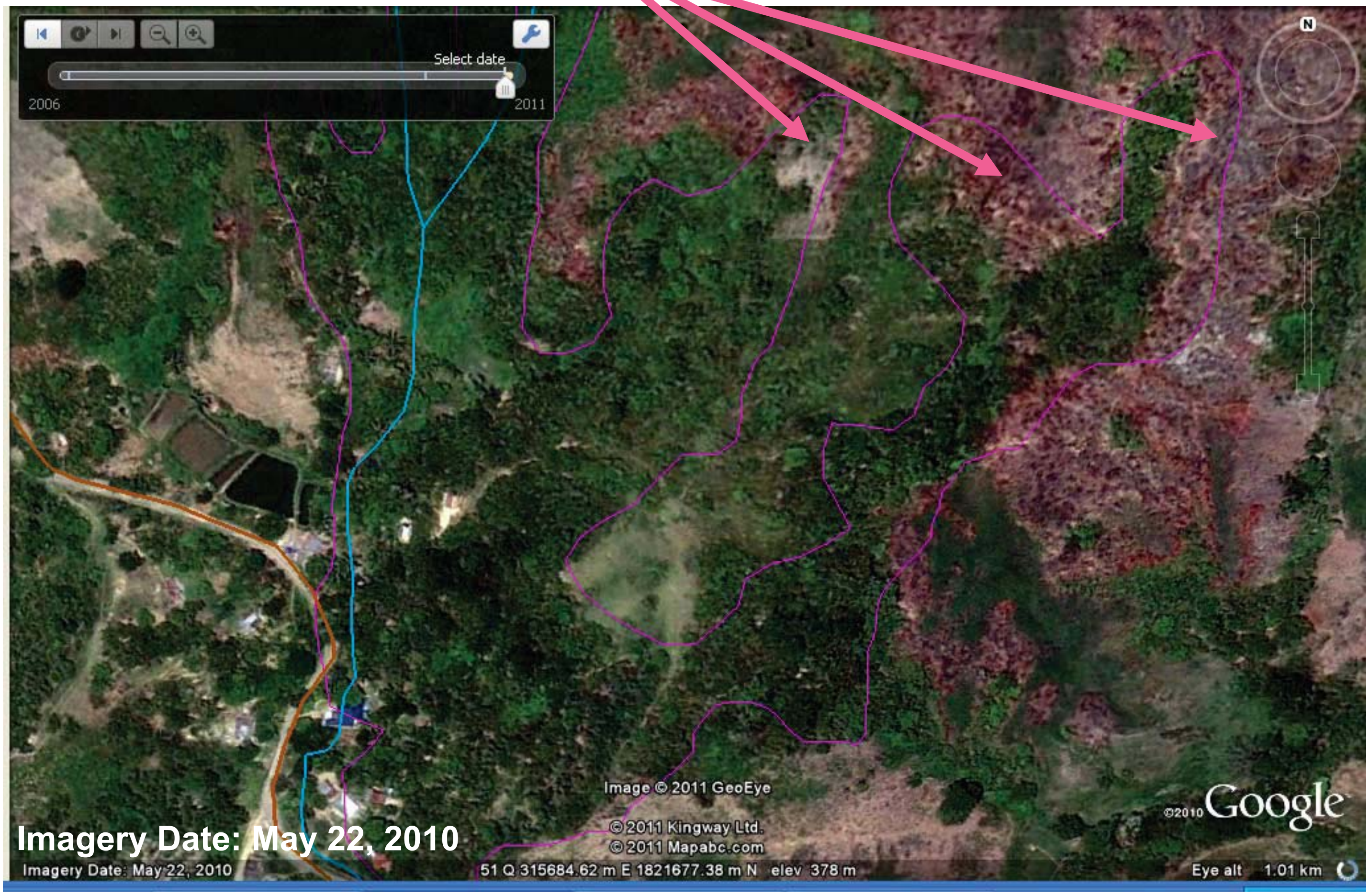
Natural process of re-establishment of forest; long fallow; abandonment of farms

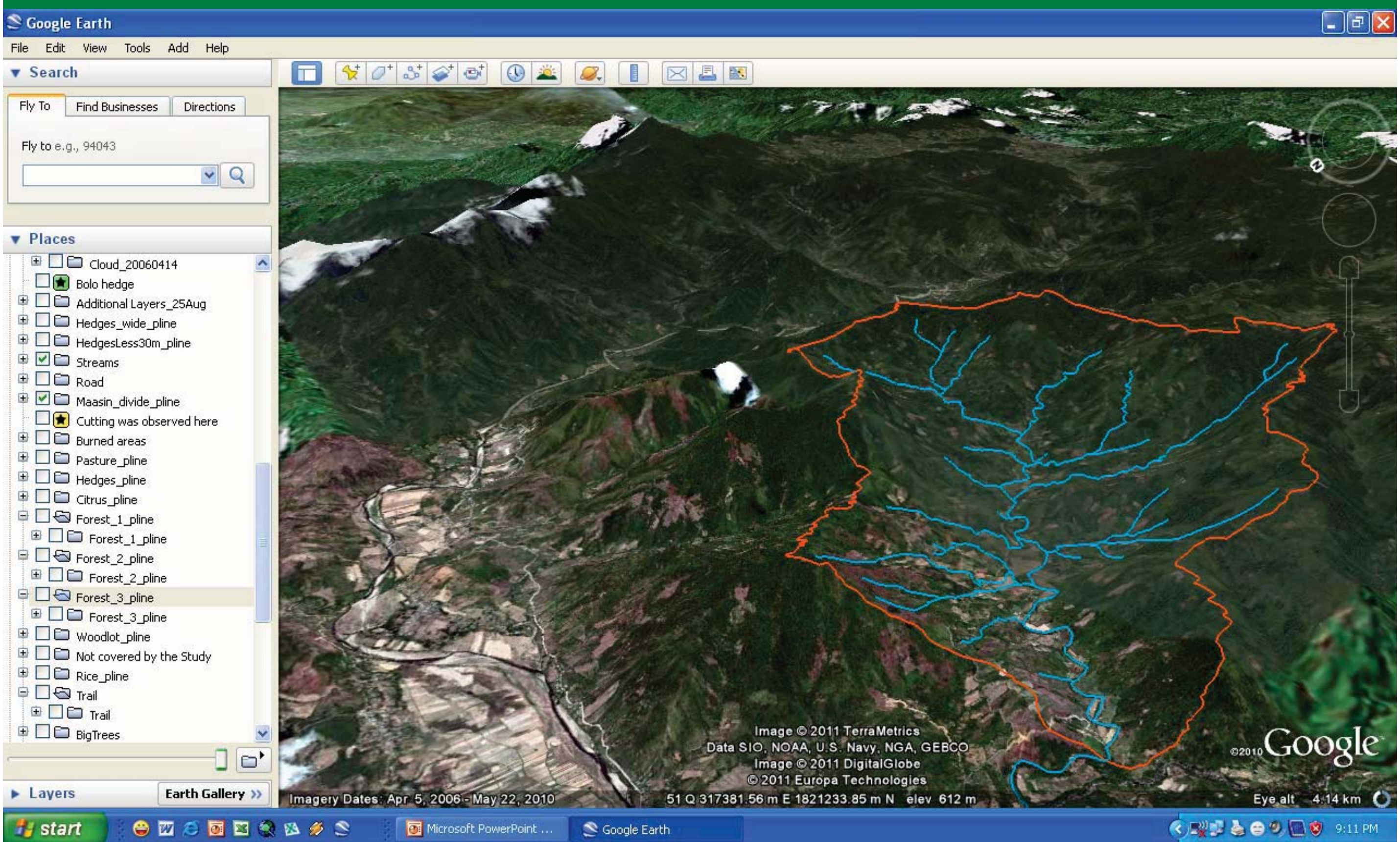
Photographic evidences taken at one point in time may not be enough to establish forest degradation occurrence. A time series data is necessary.

Shown in white are pixels that have high reflectance values (TM3) because of low amount of vegetation. Increasing number of pixels from 1989 to 2010 has been observed



Tree cover disappeared





High-resolution Google Earth image is a very important data source and an excellent visual aid for eliciting information from local people.

Google Earth

- Watershed delineation
- Mapping of streams, roads, points of interest
- Mapping of land cover classes through visual interpretation of the image
- Reference for classification accuracy assessment
- Guide for creating the land cover reference polygons
- Basemap for field data collection

Map derived from GE, a very important base map

Remote sensing data

- Landsat TM (1989) and ETM+ data
  - All available data were evaluated as to usefulness (i.e., cloud cover not too large)
  - DN values converted to reflectance values
- Land cover classification and change analysis employed the Vecter Technique
- Modeling of AGB using individual TM bands, vegetation indices & band ratios, texture measures and principal components

AGB estimation

Approach 1

Classification of land into different land cover/carbon density classes

- e.g., Class Area X AGB factor

Approach 2

Direct estimation of AGB from RS data. Spectral data are the independent variables in regression equations

Back

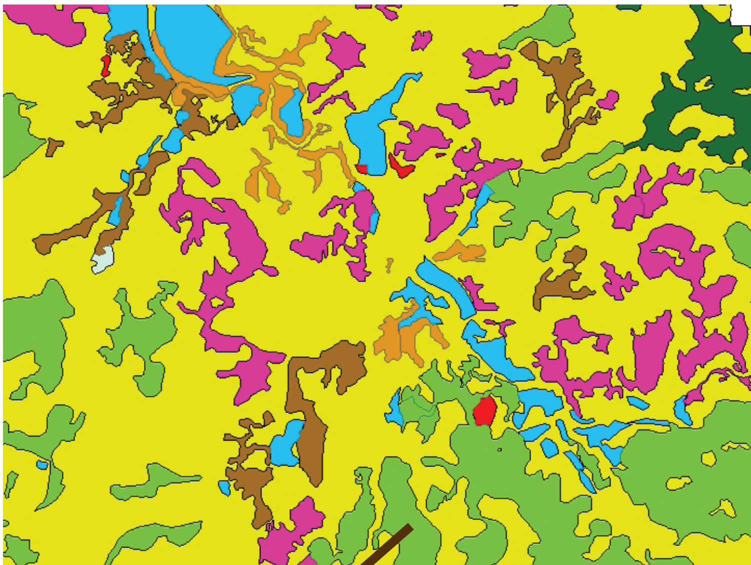
One specific objective of the thesis

1

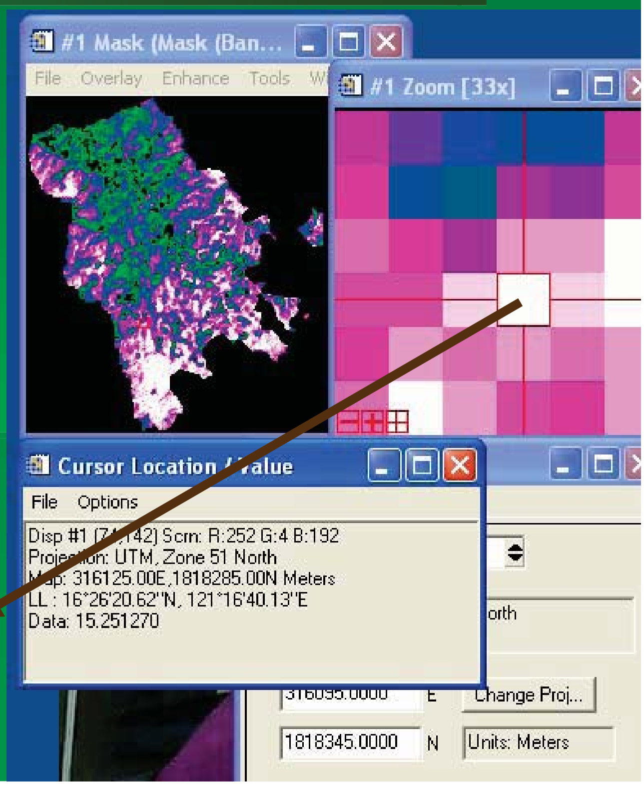
2

Comparison of the two approaches based on accuracy assessment of results

Simple illustration of the 2 basic approaches



Area of this polygon times AGB/ha *or*
Cell area times AGB/cell



This image pixel relates to AGB

Attempt to discriminate as many classes (carbon density strata) as possible (13 classes) in high resolution image by visual interpretation

1. Fc1	8. Grass, coarse
2. Fc2	9. Grass, smooth
3. Fc3	10. Cultivated, regenerating
4. Tree hedges, wide	11. Cultivated, soil exposed
5. Tree hedges, narrow (<30 m)	12. Burned and Landslide
6. Brush, thick	13. Rice paddies and Water
7. Brush, thin	

Separability Analysis
Jeffries-Matusita method

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1)													
(2)	1.8												
(3)	1.9	1.9											
(4)	1.9	1.9	1.7										
(5)	2.0	2.0	1.9	1.8									
(6)	1.9	1.9	1.8	0.8	1.5								
(7)	1.9	1.9	1.8	1.5	1.7	0.6							
(8)	1.9	1.9	1.9	1.7	1.8	1.8	1.8						
(9)	1.9	1.9	1.8	1.1	1.2	0.9	1.2	1.7					
(10)	1.9	1.9	1.9	1.4	1.4	1.5	1.8	1.8	1.5				
(11)	1.9	1.9	1.9	1.3	1.4	1.5	1.8	1.8	1.4	0.3			
(12)	2.0	2.0	2.0	1.7	1.7	1.8	1.9	1.9	1.7	1.2	1.3		
(13)	2.0	2.0	2.0	1.8	1.8	1.9	2.0	1.9	1.7	1.8	1.7	1.8	

Final classification scheme

LC Class/ Carbon Density Strata	Brief Description	
	Visual interpretation of image	Field Observation
Fc1	Thick forest, closed canopy, crown of individual trees are distinct because of the circular pattern of the crown and the difference in crown color; image color is dark green; strips of crown shadow are thinner and shorter; patches are large and contiguous	High proportion of large and old trees are found in this stratum; height of trees of the upper canopy are more or less similar; ground cover is scanty because of low amount of sunlight reaching the forest floor

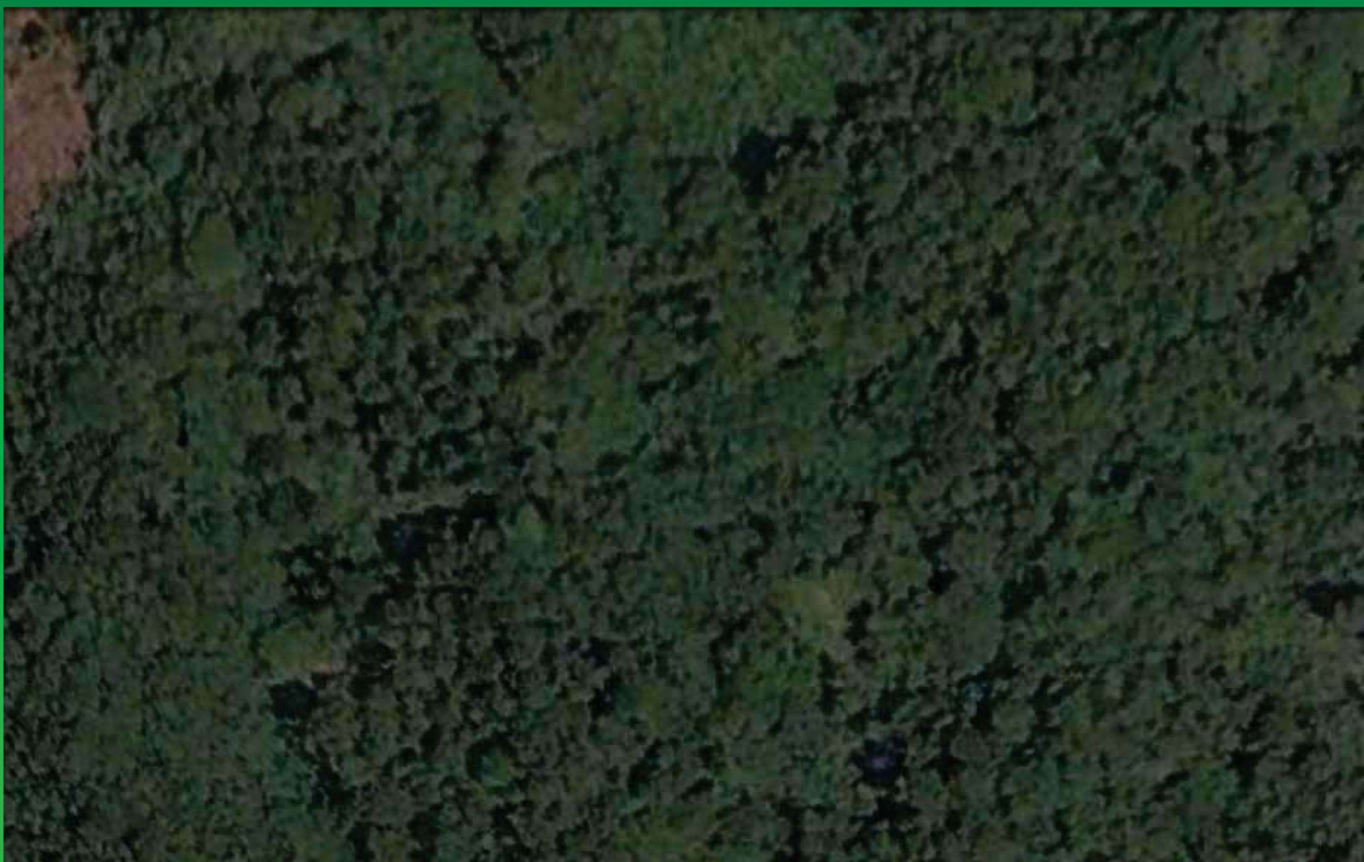
Fc1

A clip from Google Earth image

Final classification scheme

LC Class/ Carbon Density Strata	Brief Description	
	Visual interpretation of image	Field Observation
Fc2	Relatively open to relatively closed canopy forest; strips of crown shadow are thick and longer; patches are large and contiguous; patches are smaller interspersed with patches of grass, shrub or low-density forest (Fc3); tone is lighter than Fc1	Height variation of upper canopy trees more pronounced; in terms of basal area, dominated by white lauan; ground cover usually thick because of high amount of sunlight reaching forest floor; abundant growth of vines, rattans, palms, tree saplings and herbaceous vegetation are found

Fc2



Final classification scheme

LC Class/ Carbon Density Strata	Brief Description	
	Visual interpretation of image	Field Observation
Fc3	Trees are small as indicated by small crown; crown not compact as indicated by lighter shadow; patches are elongated and thin and usually surrounded by land cover which appear to be grass, shrub or non-tree agricultural crops; tone is lighter than Fc2	Dominated by sun-loving trees, usually short trees; appears to be a re-established forest from cultivated areas; include gmelina plantation, dense citrus plantation and mixture of tree, banana, bamboo and runo

Fc3

Fc3 (delineated)

Final classification scheme

LC Class/ Carbon Density Strata	Brief Description	
	Visual interpretation of image	Field Observation
GBC	A mixture of smooth and rough textures, smooth for grass and rough for patches of shrubs, banana, bamboo and trees; lands cleared of vegetation are easy to identify because of exposure of soil, which is light brown to reddish brown	Predominantly non-wooded land; consists of grass, shrubs, farms, home gardens, and hedges of tree-bamboo-banana

GBC

Grass-Brush-Cultivated

Final classification scheme

LC Class/ Carbon Density Strata	Brief Description	
	Visual interpretation of image	Field Observation
RW	Rice paddies and wide streams at lower elevation can easily be identified and delineated in the image; terraced rice paddies at hillside are also easy to identify; rice and corn in dry soil, which appear to be grassland, not included	Tree cover is very minimal and usually found along boundaries; most small streams have strips of tree-bamboo-banana hedges in either side

RW

Cell value of AGB

LC/Strata	AGB/cell (ton/900sq.m)	Source
Fc1	41.71	Inventory data
Fc2	20.95	Inventory data
Fc3	10.85	Inventory data
GBC	2.56	Literature
RW	1.07	Literature

Notes:

Inventory conducted August to September 2010. Used brown's formula for calculation of AGB

Dimension of cell: 30 m x 30 m

RW – usually includes hedges of tree-bamboo-banana

Brown's Formula

For trees 10 to 69 cm dbh:

Y (Kg) = exp {–2.134 + 2.530*ln*D}

For trees 70 and above:

Y (Kg) = 2.69–12.800*D+1.242*D2

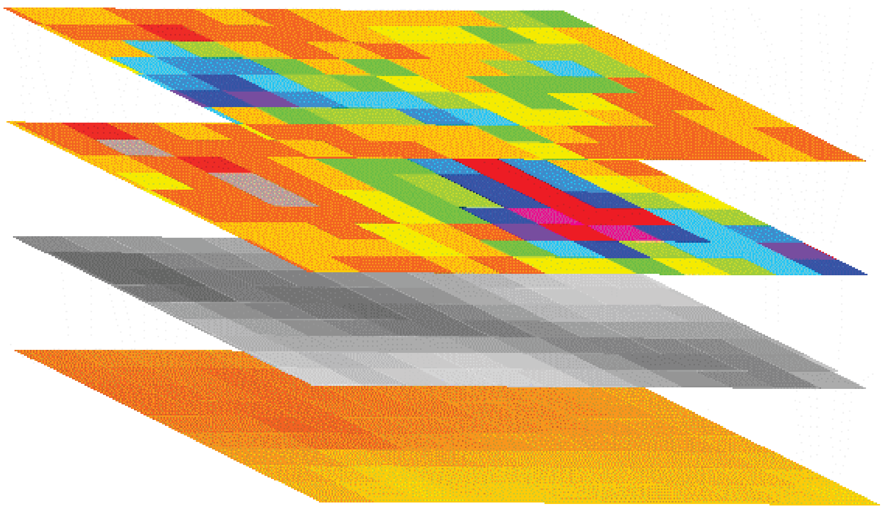
How classes were discriminated in imagery

- We use Vecter Technique, a new technique that is being introduced and demonstrated in this research
- In this technique, *classification is simply by thresholding*
- Enables us to better integrate RS, GIS, inventory data, and local knowledge

What is Vecter?

"Vecter" is coined from vector and raster, the two standard data formats in GIS. Its main advantage over raster format is its attribute table that may store large datasets from various sources. For analysis, queries and some mathematical operations can be performed in vecter (grid cells).

Raster layers



Examples of data sets in raster format: 1989 TM 3 reflectance value, 2010 TM 3 reflectance value, GIS ancillary data such hillshade and slope

Calculation of AGB performed with datasets compiled in vecter attribute table

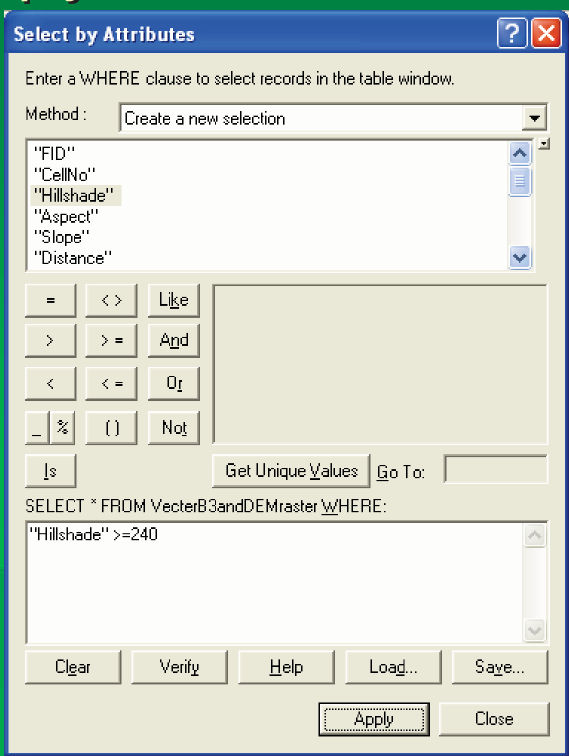
Attributes of VecterB3andDEMraster

FID	Shape *	CellNo	Hillshade	Aspect	Slope	Distance	89b3Ref	Cld201003	1003b3ref	1003LC	8906LcMRc	2010DtSors	2010Data	Change8903	Persistent
6287	Polygon	1711	204	168	92	800	70	Yes	0	0	1	Field survey & LK	1	11	11
6288	Polygon	1721	212	168	95	750	53	Yes	0	0	1	Field survey & LK	1	12	0
6289	Polygon	1732	210	162	97	750	87	Yes	0	0	1	Field survey & LK	1	11	11
6438	Polygon	1721	200	166	95	750	37	Yes	0	0	1	Field survey & LK	1	11	11
6442	Polygon	1752	221	175	83	750	104	Yes	0	0	2	Landsat TM 20100204	4	22	0
9577	Polygon	1907	211	327	16	50	53	Yes	0	0	1	Field survey & LK	2	12	0
9716	Polygon	1889	214	325	23	50	70	Yes	0	0	1	Landsat TM 20100204	2	13	0
9717	Polygon	1898	211	335	28	50	70	Yes	0	0	1	Landsat TM 20100204	2	13	0
9718	Polygon	1907	204	336	31	50	70	Yes	0	0	1	Field survey & LK	4	12	0
9719	Polygon	1916	199	336	34	50	70	Yes	0	0	1	Field survey & LK	4	12	0
9720	Polygon	1925	203	332	34	50	70	Yes	0	0	1	Field survey & LK	4	11	0
10589	Polygon	1897	201	250	20	200	87	Yes	0	0	2	Landsat TM 20100204	4	22	0
10838	Polygon	1830	195	289	24	50	104	Yes	0	0	2	Field survey & LK	2	22	22
10839	Polygon	1830	203	288	20	50	104	Yes	0	0	2	Field survey & LK	2	22	22
10857	Polygon	1850	189	301	25	50	104	Yes	0	0	2	Field survey & LK	2	21	0
10859	Polygon	1850	204	288	15	50	121	Yes	0	0	3	Field survey & LK	2	32	0
10865	Polygon	1860	178	300	28	100	104	Yes	0	0	2	Field survey & LK	4	21	0
10878	Polygon	1879	218	307	17	50	70	Yes	0	0	1	Landsat TM 20100204	2	13	0
11040	Polygon	1915	215	220	21	250	87	Yes	0	0	2	Landsat TM 20100204	1	23	0
11201	Polygon	1915	215	239	17	300	53	Yes	0	0	1	Landsat TM 20100204	1	12	0
11202	Polygon	1924	210	215	15	300	37	Yes	0	0	1	Landsat TM 20100204	1	11	11
11518	Polygon	1897	211	240	17	200	87	Yes	0	0	2	Landsat TM 20100204	1	22	0
11661	Polygon	1949	207	240	20	400	70	Yes	0	0	1	Landsat TM 20100204	1	11	0
12327	Polygon	1940	167	287	44	250	70	Yes	0	0	1	Field survey & LK	1	11	0

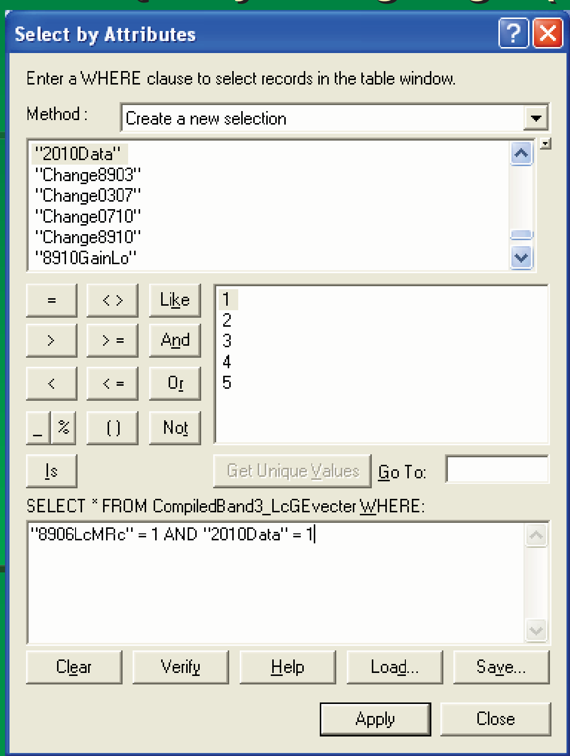
Record: 0 Show: All Selected Records (0 out of 20838 Selected) Options

For calculations and analysis

Simply use ArcGIS' Structured Query Language (SQL)



(a)



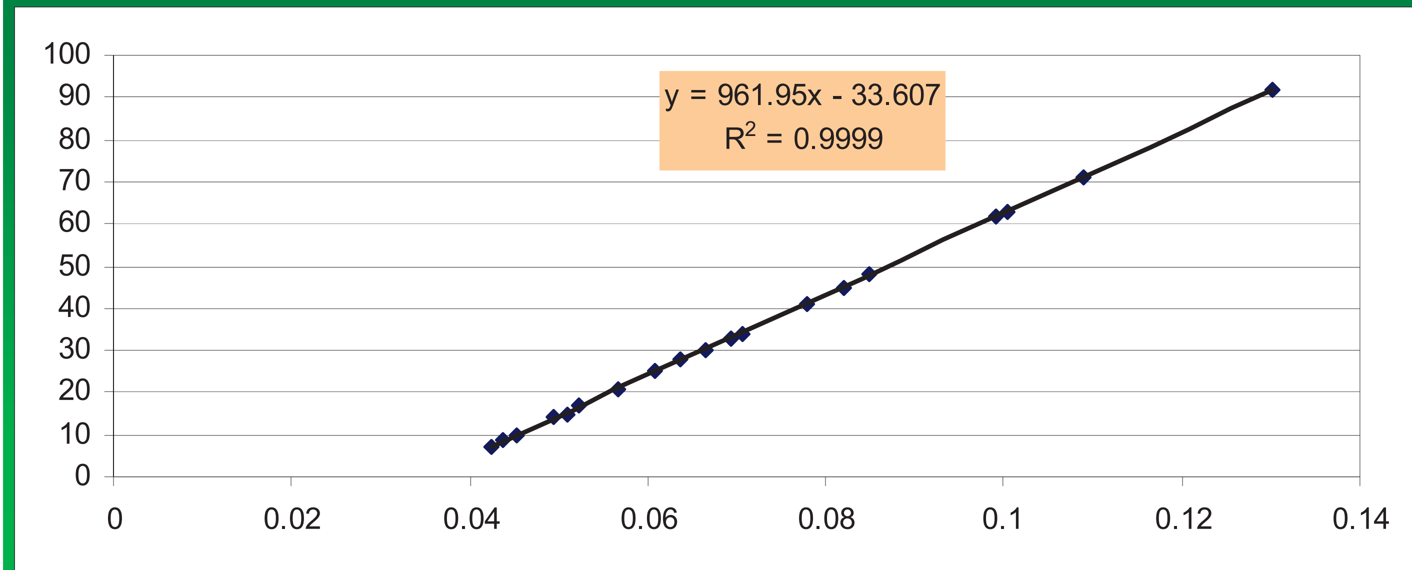
(b)

(a) Selecting heavily hillshaded area (misclassification is likely);
(b) Selecting Fc1 remaining Fc1 between 1989 and 2010

Features

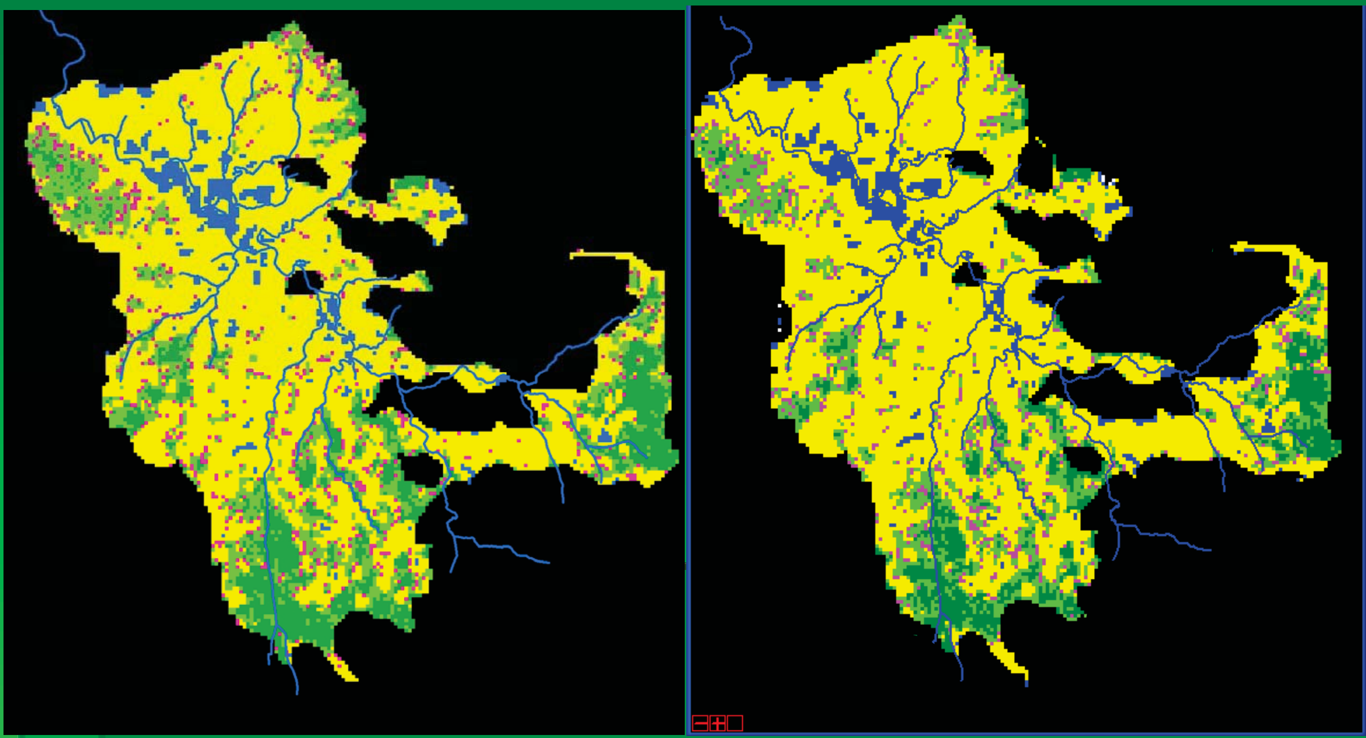
- Large number of datasets can be combined, e.g., time-series landsat data (reflectance values)
- Classification through specifying a threshold for a class
- Analysis carried out in GIS software rather than in RS software
- Main limitation: Neighborhood analysis is not possible

Image pixel values are transformed into vecter cell values



After the transformation, regression between the original pixel value (reflectance, X) and the transformed vecter value (reflectance scaled to 0-255, resampled, Y) was carried out to see if transformation has "preserved" the data.

Visual comparison between pixel & vecter



As expected, practically similar maps

Classification of LC by threshold: Reference Data

- 2006 land cover → mainly Google Earth
- 2010 → mainly field data/inventory data
- 1989 and other years → mainly local knowledge (reference land cover polygons/cells)

- Accuracy assessment result is the basis of the threshold; manual iteration done to get highest accuracy
- Manual reclassification performed over some areas (e.g., due to high hillshade)

Highest overall accuracy obtained with this threshold (77.93)

Fc1	0	14						
Fc2	15	18						
Fc3	19	20						
GBC	21	60						
RW	61	above						
	Fc1	Fc2	Fc3	GBC	Rice	Row Total		
Fc1	48	4	1	5	0	58	82.76	
Fc2	7	48	7	12	0	74	64.86	
Fc3	1	3	57	6	0	67	85.07	
GBC	4	17	9	181	8	219	82.65	
RW	0	0	1	13	12	26	46.15	
Column Total	60	72	75	217	20	444	ok	
	80.00	66.67	76.00	83.41	60.00			
						77.93	Overall Accuracy	
						0.68	K-hat	

Lower accuracy with this threshold (68.02)

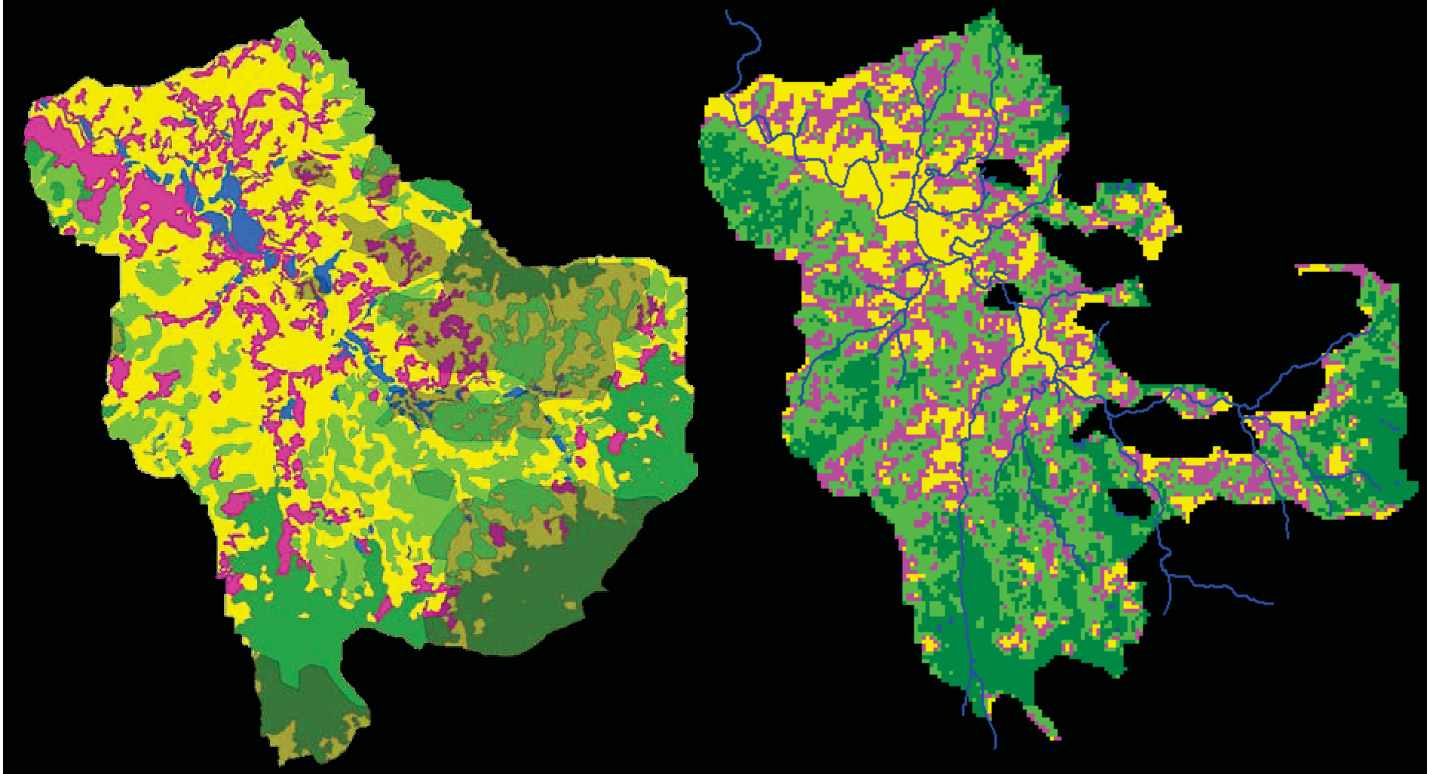
Fc1	0	15						
Fc2	16	18						
Fc3	19	24						
OWL	25	60						
RW	61	above						
	Fc1	Fc2	Fc3	GBC	Rice	Row Total		
Fc1	51	23	3	9	0	86	59.30	
Fc2	4	29	7	8	0	48	60.42	
Fc3	2	9	64	42	0	117	54.70	
GBC	3	11	1	146	5	166	87.95	
RW	0	0	1	14	12	27	44.44	
Column Total	60	72	76	219	17	444	ok	
	85.00	40.28	84.21	66.67	70.59			
						68.02	Overall Accuracy	
						0.56	K-hat	

And this threshold (57.66)
No other combinations will yield overall accuracy of 77.93% or greater

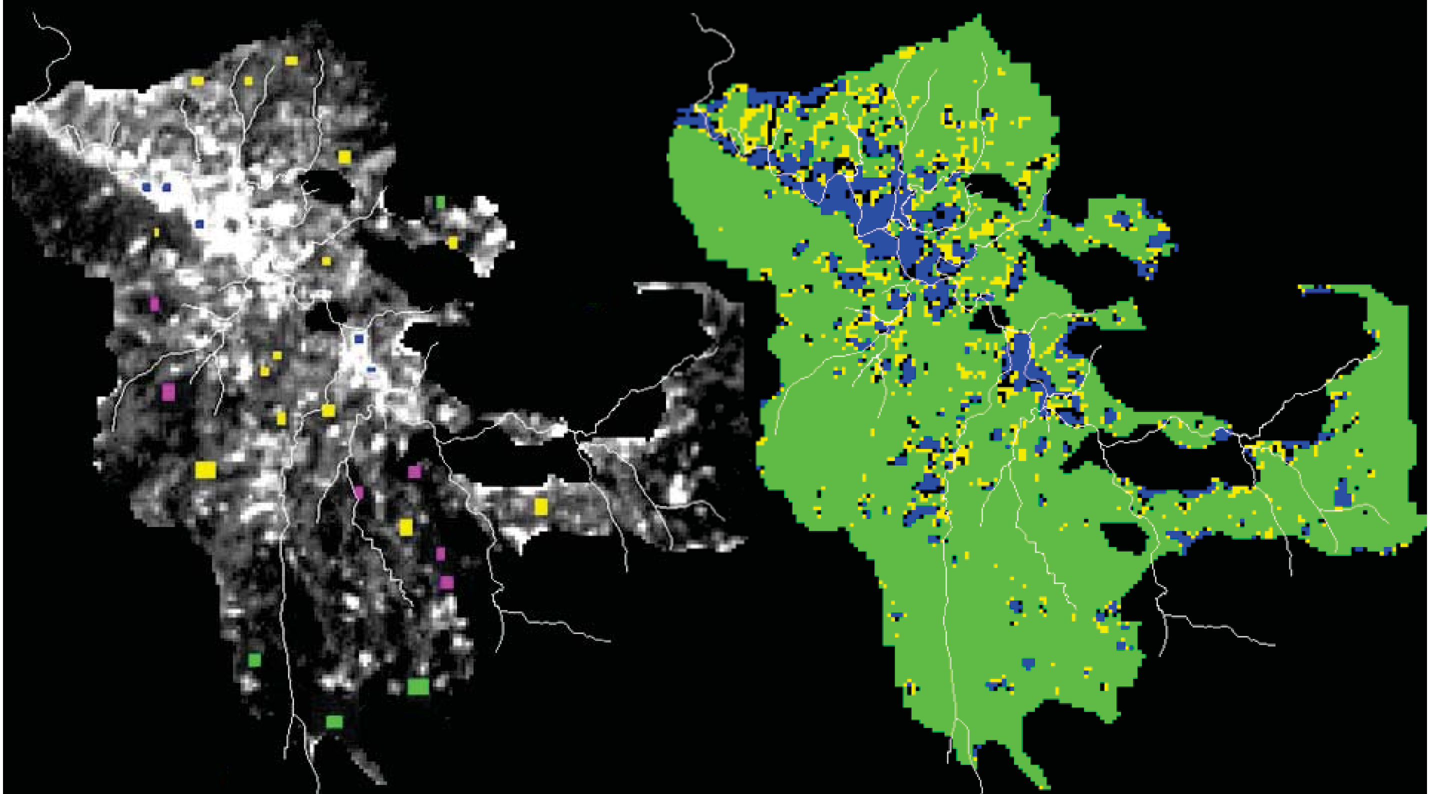
Fc1	0	14						
Fc2	15	18						
Fc3	19	30						
GBC	31	60						
RW	61	above						
	Fc1	Fc2	Fc3	GBC	Rice	Row Total		
Fc1	48	4	1	5	0	58	82.76	
Fc2	7	48	7	12	0	74	64.86	
Fc3	4	16	64	103	0	187	34.22	
GBC	1	4	1	84	8	98	85.71	
RW	0	0	1	14	12	27	44.44	
Column Total	60	72	74	218	20	444	ok	
	80.00	66.67	86.49	38.53	60.00			
						57.66	Overall Accuracy	
						0.45	K-hat	

What prompted us to use Vecter Technique?

- Compared to Vecter Technique, lower overall accuracy were obtained for several unsupervised and supervised classification results.



Reference Map (Google Earth-Field) vs. Landsat Unsupervised-IsoData Classification



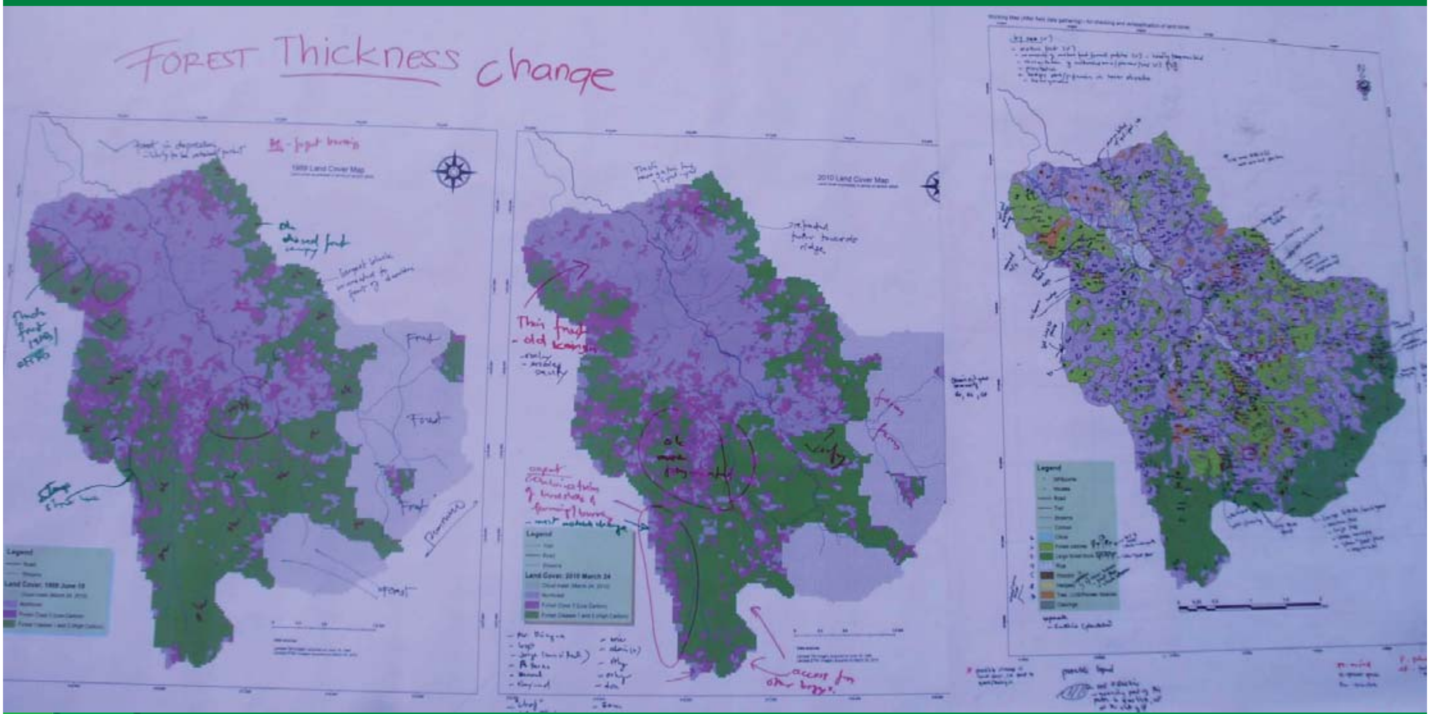
Sample result of a supervised classification (right) using carefully selected ROIs based from GE image and field data (left)

Threshold for other data

Class	1989	2003	2007	2010
Fc1	0 - 85	0 – 60	0 - 40	0 - 24
Fc2	86 - 108	60 -90	41 - 64	25 - 38
Fc3	109 - 130	91 - 110	65 - 96	39 - 48
GBC	131 - 230	111 - 220	97 - 220	49 - 95
RW	>230	>220	>220	>95

We built a methodology where local knowledge is a necessary data source?

- Threshold specification requires assessment of accuracy. In turn, accuracy assessment requires reference data, for which local knowledge is a necessary input. LK is particularly important for datasets where field data/inventory data is not available, e.g., datasets other than 2006 and 2010

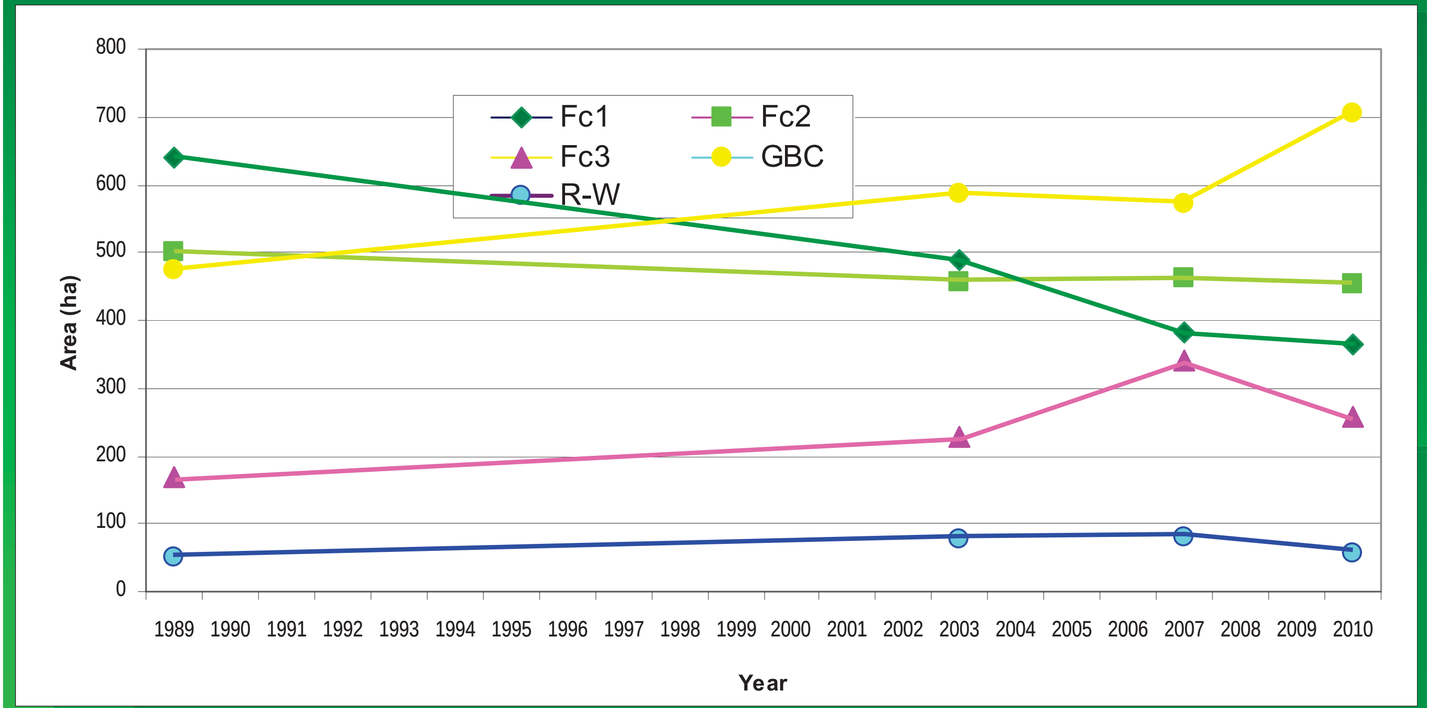


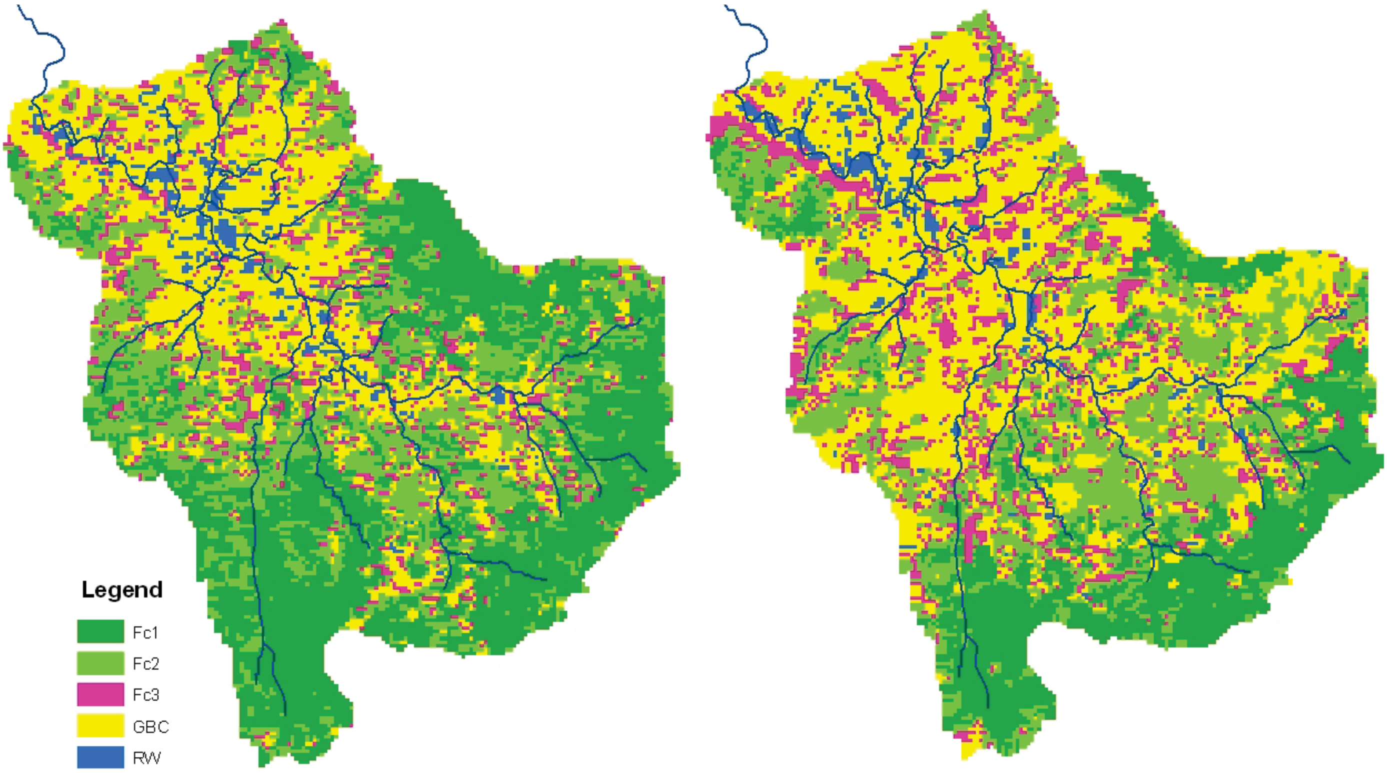
Information collection requires visual aids such as these maps printed on tarpaulin and …

…photos of the landscape and the landscape itself via viewsheds

Apparent decline in AGB, 1989 to 2010

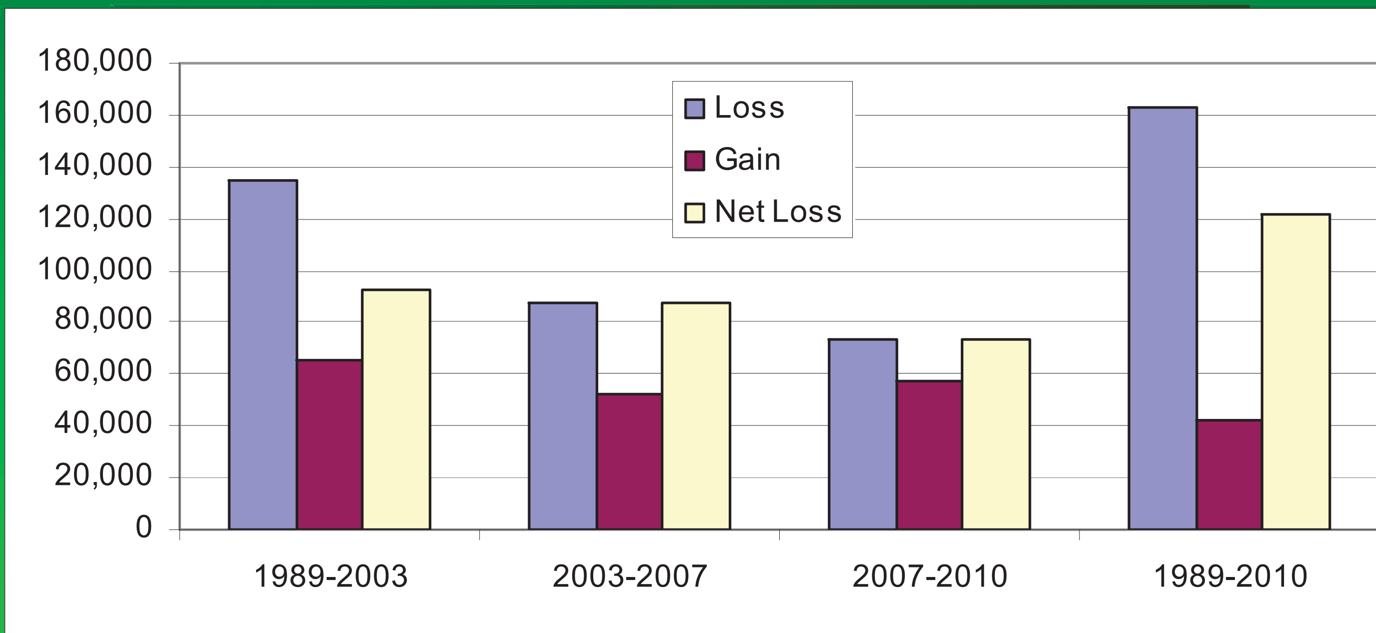
(Change in extent of each LC class)





1989 and 2010 land cover class maps

Net loss in AGB in four periods



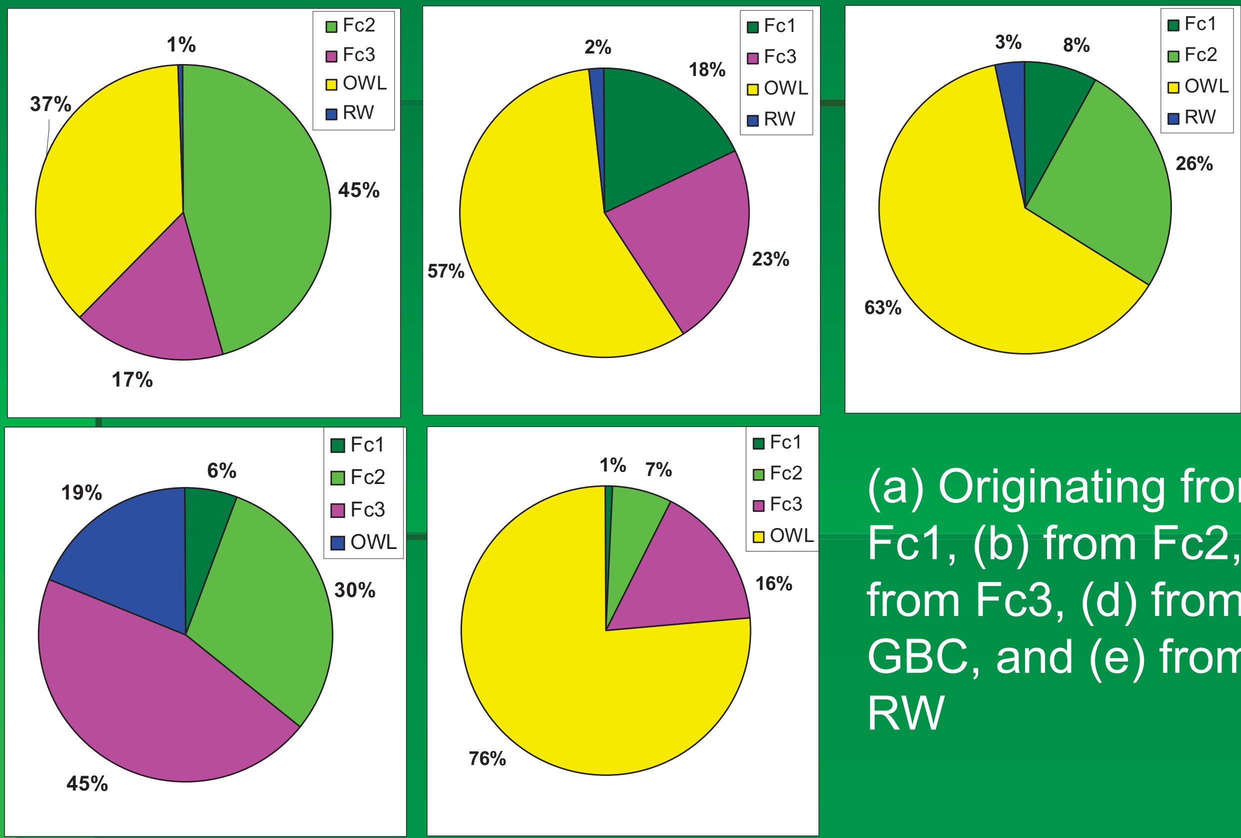
Class movement

- Closed canopy forest declined steadily from 1989 to 2010.
- Fc2 also declined but grew (abandonment of kaingin or long fallow) as well hence net loss was small.
- Fc3 had increased during the period; many gmelina plantations were established
- GBC increased because forests were cleared for cultivation.

High carbon forest to steadily decrease?

- People prefer to encroach into large and contiguous forest blocks (Fc1) than into smaller patches of relatively open-canopy forests
  - Soil fertility
  - Fewer claimants to compete with (early 1990s)
  - Patches at lower elevation have claimants
  - Less worry that fire he set would damage other's "property"; unclaimed areas as buffer

Composition of change from a land cover class to another, 20-year period



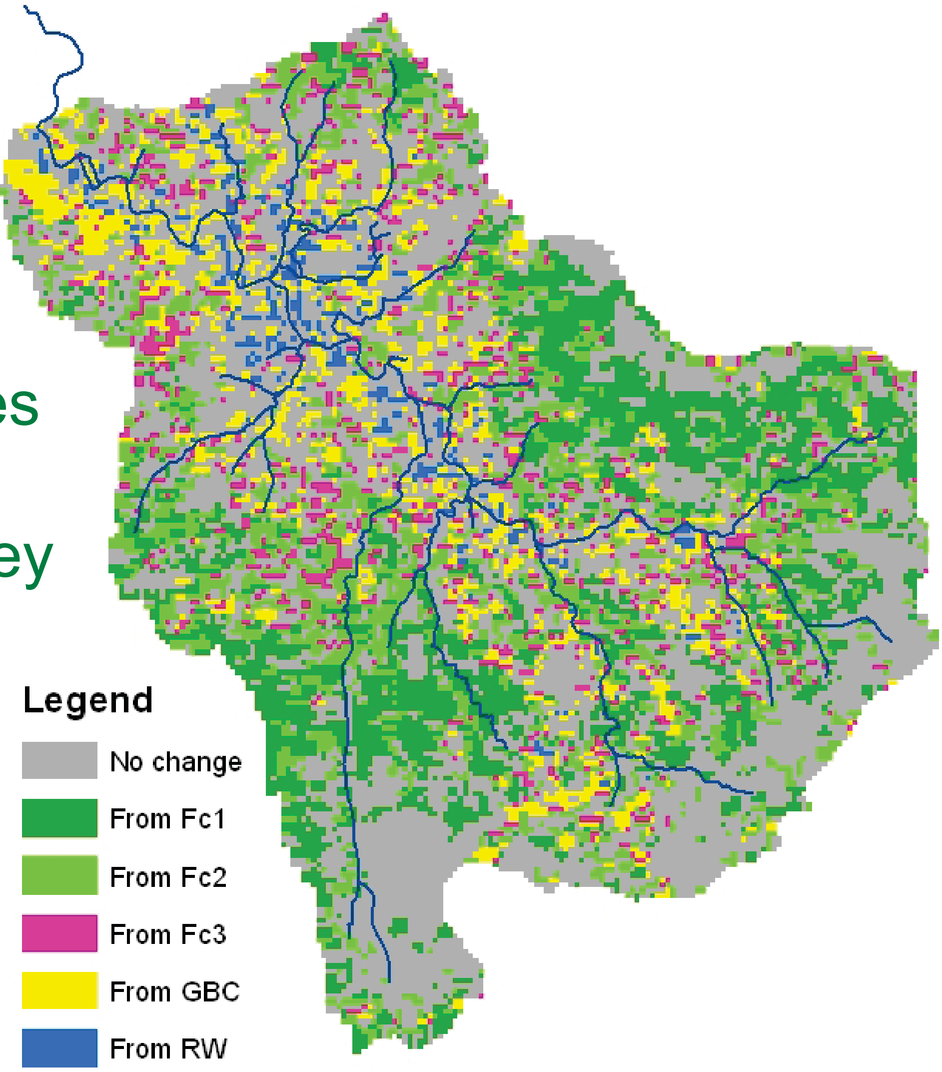
(a) Originating from Fc1, (b) from Fc2, (c) from Fc3, (d) from GBC, and (e) from RW

Composition of change …

- Expansion of GBC is most notable. Fc1 and Fc2 likely to transform to GBC directly.
- Large tract of land covered by grass, shrub and/or crops (GBC) reverted back to forest; at 20-year period more becoming Fc3 than Fc2
- Though less expected, GBC may revert back to closed canopy forest (Fc1)

Pattern of fragmentation

Pixels that changed classes and those that remained as they are in 1989



AGB estimation approaches

Approach 2:

Direct estimation of AGB from RS data

- Linear regression: Y is AGB (AGB/pixel); Xs are spectral data
  - Individual TM bands
  - Vegetation indices & band ratios
  - Principal component
  - Tasseled Caps
  - Texture measures
- Y estimated using Brown's Formula
- n = 50 plots (20 x 20m) for model building; n = 20 plots for model evaluation (RMSE)
- Used the Landsat data acquired on March 24, 2010

Individual TM bands

- Band 1 (blue-green)
- Band 2 (green)
- Band 3 (red)
- Band 4 (near infrared)
- Band 5 (mid-infrared)
- Band 7 (mid-infrared)

Vegetation indices and band ratios

NDVI	(B4-B3)/(B4+B3)
EVI	2.5*(B4-B3)/(B4+6*B3-7.5*B1+1)
ARVI	(B4-2*B3+B1)/(B4+2*B3-B1)
ASVI	B4+0.5-0.5*SQRT(((2*B4+1)^2)-8*(B4-2*B3+B1))
MSAVI	B4+0.5-0.5*SQRT(((2*B4+1)^2)-8*(B4-2*B3))
SAVI	((B4-B3)*1.5)/(B4+B3+0.5)
ND53	(B5-B3)/(B5+B3)
ND54	(B5-B4)/(B5+B4)

Vegetation indices and band ratios

ND57	(B5-B7)/(B5+B7)
ND32	(B3-B2)/(B2+B2)
VIS123	B1+B2+B3
MID57	B5+B7
Albedo	B1+B2+B3+B4+B5+B7
TM 4/3	B4/B3
TM 5/3	B5/B3
TM 5/4	B5/B4
TM 5/7	B5/B7

Tasseled Cap (vegetation index) and Principal Components

- Brightness
- Greenness
- Wetness
- Fourth
- Fifth
- Sixth

- Band 1
- Band 2
- Band 3
- Band 4
- Band 5
- Band 7

Texture Measures

- Window 7 x 7 was selected
  - Data range
  - Mean
  - Variance
  - Entropy

Method

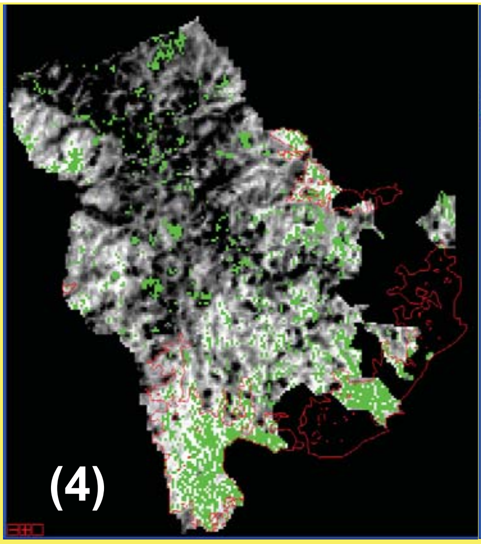
- Stepwise Regression was used to select best model for each group and combinations of groups
- Model results were evaluated based on R^2, Adjusted R^2 , RMSE and visual comparison with reference map
- For this presentation, I will only present 4 models

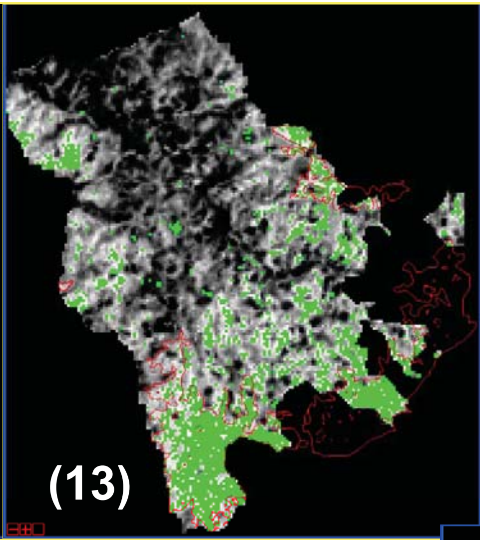
Regression models

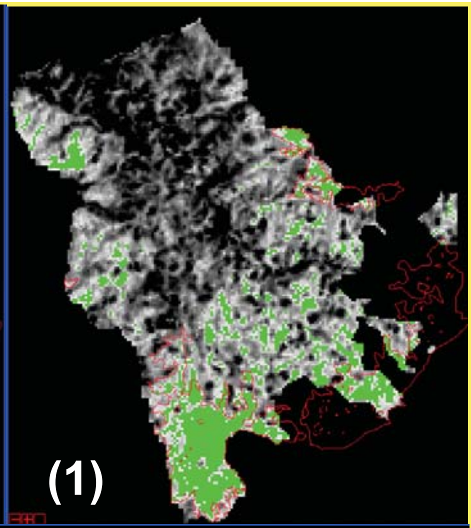
No.	Model
1	Log(AGB) = 3.005 - 16.177*TM3
4	Log(AGB) = 2.696 - 40.769*Fourth
8	Log(AGB) = 2.172 - 35.581*PC_b4 - 6.387*PC_b3
13	Log(AGB) = 3.050 - 28.351*Fourth - 10.217*TM3

Model performance

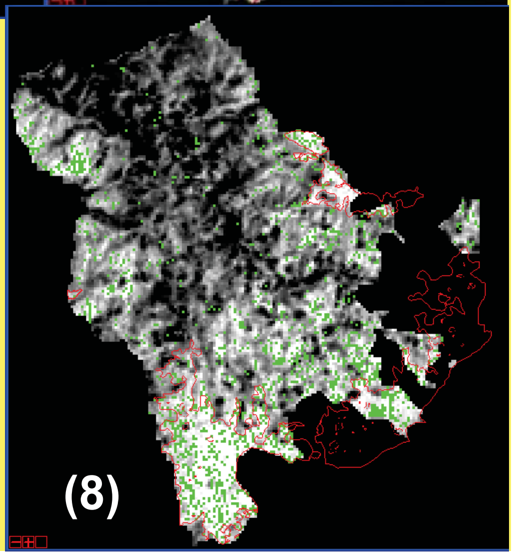
No.	R^2	Adjusted R^2	Significance	RMSE
4	0.339	0.325	0	44.93
13	0.431	0.407	0	45.45
1	0.309	0.294	0	46.00
8	0.339	0.311	0	49.90







AGB map produced by the models



AGB estimates (approach 1 vs. approach 2)

Model	AGB (tons)	Difference from Vecter
Vecter	239,435.86	--
Model 4	234,102.24	5,333.62
Model 13	206,481.71	32,954.15
Model 1	196,408.58	43,027.28
Model 8	228,117.10	11,318.76

201003 data, cloud masked

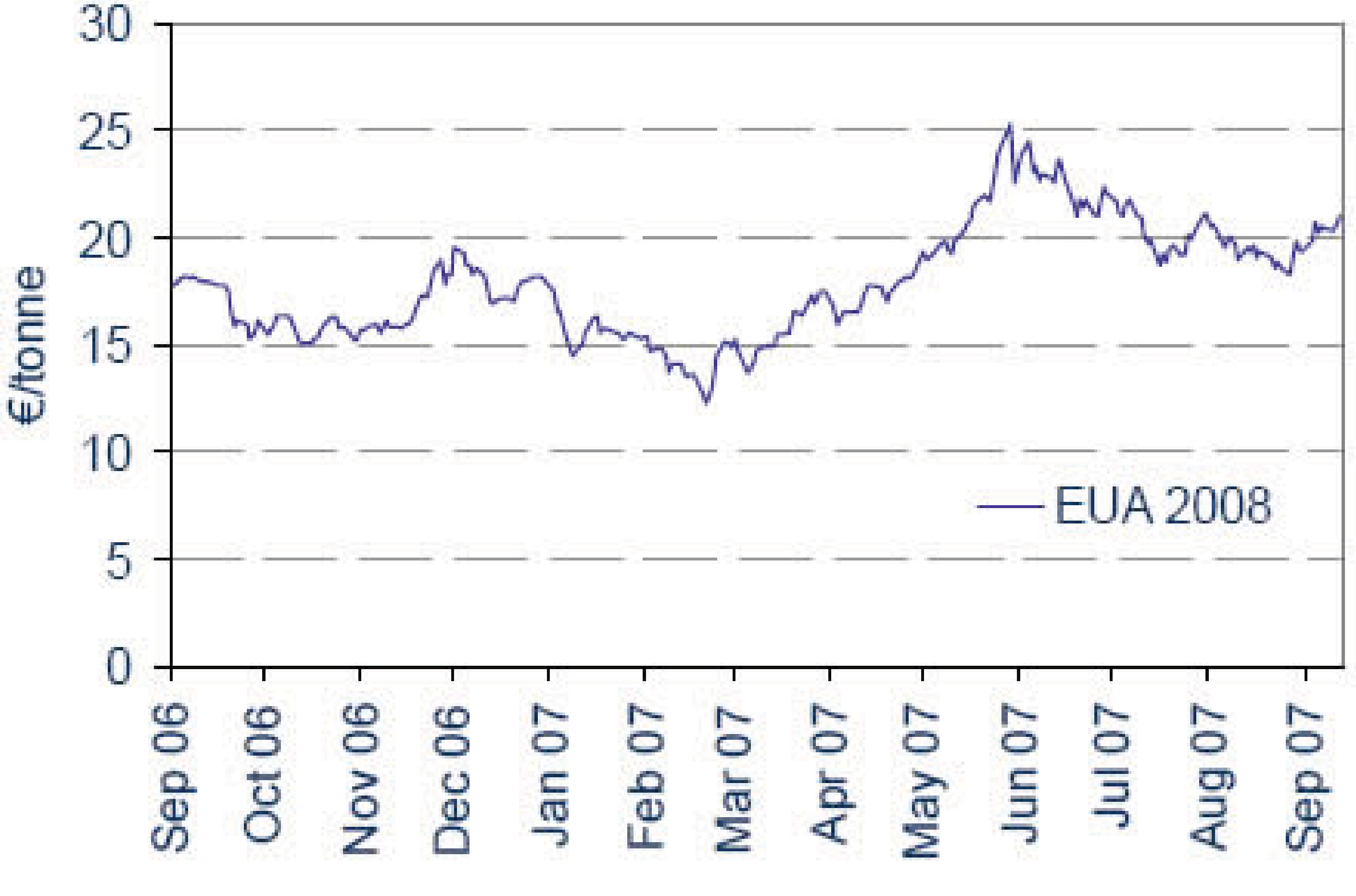
Findings

- Different models give different AGB estimates; variations might be large
- Use of different measures of model performance may result to identifying different best models
- The two approaches may give comparable estimates in terms of total AGB of a landscape

Forest

Forest - land with an area of more than **0.5 hectare** and tree crown (or equivalent stocking level) of **more than 10 percent**. The trees should be able to reach a minimum height of **5 meters** at maturity in situ. It consists either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground or open forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 percent. Young natural stands and all plantations established for forestry purposes, which have yet to reach a crown density of more than 10 percent or tree height of 5 meters are included under forest.

Basis for Carbon Price



Vegetation indices

- NDVI – Normalized Difference Vegetation Index
- EVI – Enhanced Vegetation Index
- ARVI – Atmospherically Resistant Vegetation Index
- ASVI – Atmospheric and Soil Vegetation Index
- SAVI – Soil Adjusted Vegetation Index
- MSAVI – Modified Soil Adjusted Vegetation Index