Carbon Flux Assessments in Forest Ecosystems Using Landsat and Terrestrial Sample Based Inventory Data

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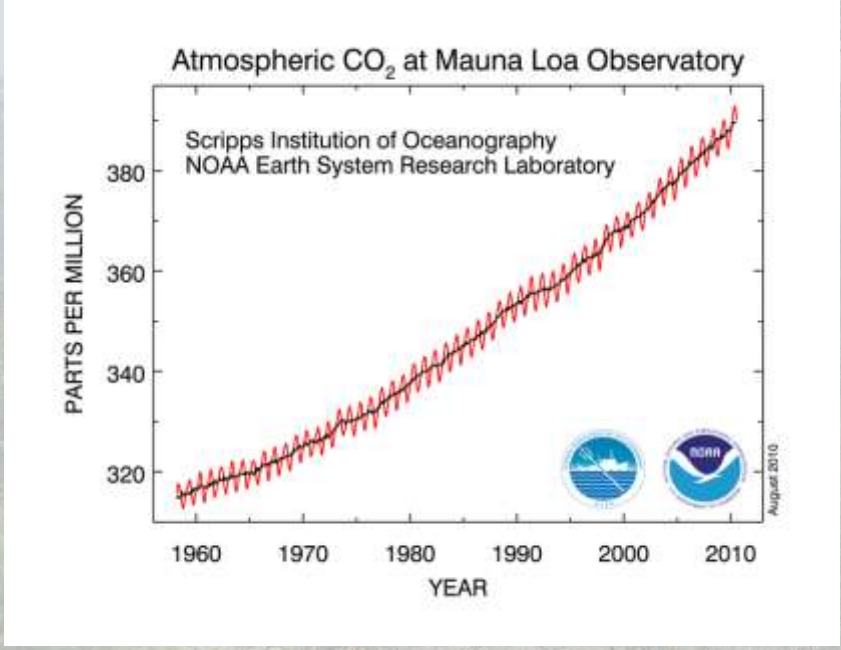
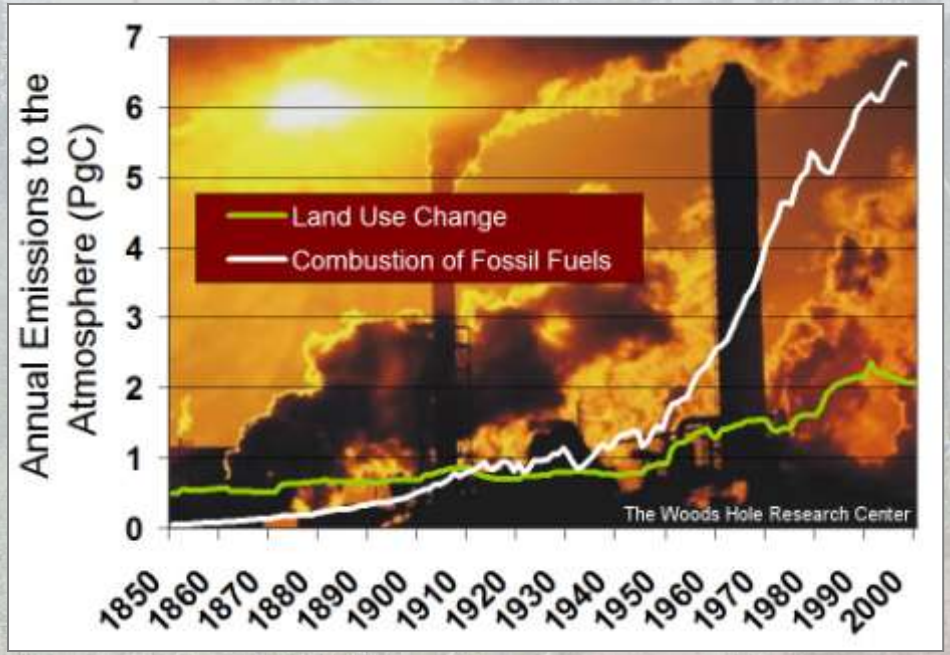
Background

Increase of atmospheric CO_2



(Source: Earth System Research Laboratory: NOAA)

Global annual CO_2 emission



(source: Woods Hole Research Center)

Changes in our climate

At continental, regional and ocean basin scales numerous long-term changes in climate have been observed:

- Changes in arctic temperatures and ice
- Widespread changes in
  - precipitation amounts
  - ocean salinity
  - wind patterns and
  - aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones

(Source: IPCC 2007)

- The area of global forest area is over 4 billion ha, 31% of total land area (FAO 2010)
- The total carbon storage of global forest ecosystem is estimated to 638 Gt for 2005, which is more than the amount of atmospheric carbon (FAO 2005)
- The net change in global forest area in the period of 2001-2010 is estimated to be -5.2 million ha per year, down from -8.3 million ha per year in the period of 1990-2000 (FAO 2010)

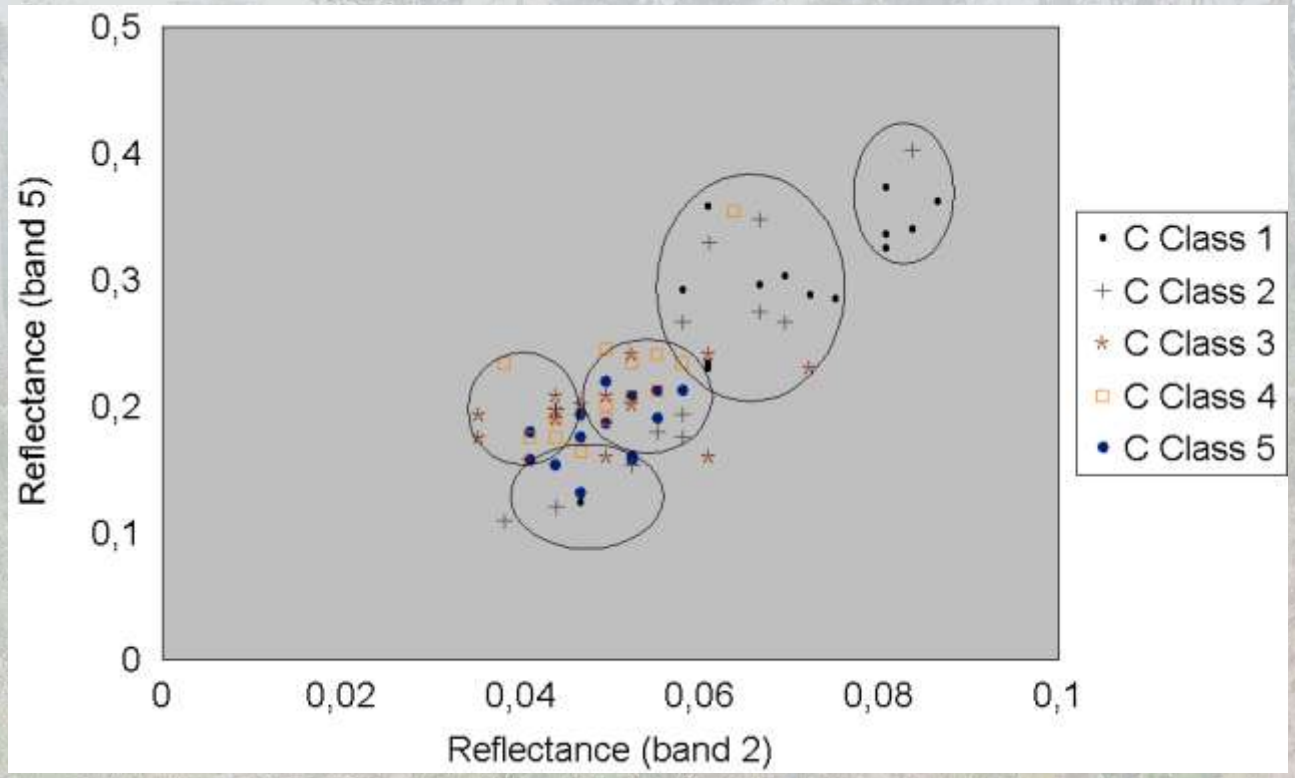
- Global estimation and modeling of above-ground carbon stock are still a challenging task due to unavailability of suitable method that can combine remote sensing and terrestrial sample based inventory data
- Local level studies are useful to understand the terrestrial carbon flux due to deforestation, forest degradation or amelioration activities

Objective

- Estimate forest cover change of a test site over the last decade (2001-2010)
- Quantify the changes in above-ground terrestrial carbon stocks of the ecosystem

Combining remote sensing and terrestrial field-based inventory

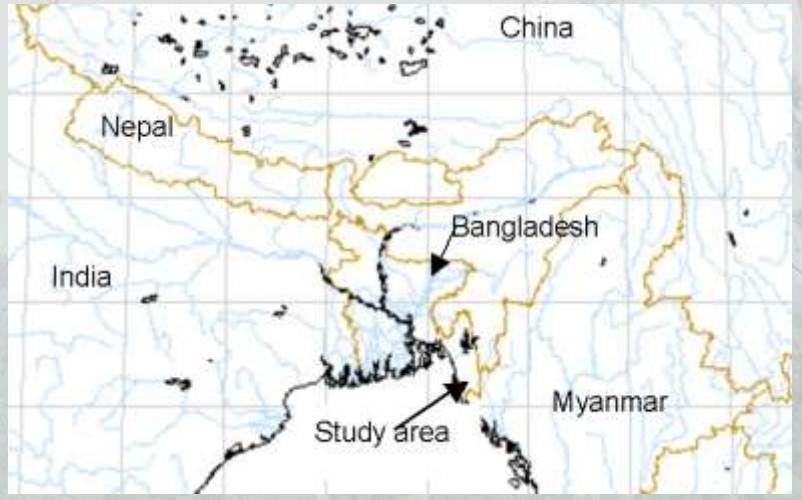
Stratification



Study area and stand information

Location of the study area:

South-eastern Bangladesh



Forest types: *Tropical evergreen and semi-evergreen forests*

Materials

Remote sensing image:

- Recent image: Landsat TM image of 2010
- Historical image: Landsat ETM Plus image of 2001

Field sampling:

- Above-ground carbon estimation: 70 plots (2002-2003)

Methodology

Atmospheric correction

- Atmospheric correction was done by COST method (Chavez 1996), a modified dark object subtraction method
- Digital numbers were converted to at-satellite radiance and surface reflectance

Geometric correction

- Orthorectified Landsat images were re-projected to Lambert Conformal Conic projection
- Landsat images were further rectified with the identifiable objects on the ground (i.e. corner of a pond, bridge etc.)

Multiphase sampling

Phase I	Phase II	Phase III
Reflectance in satellite image	*Dbh* and height of the trees inside the sample plots	Carbon content

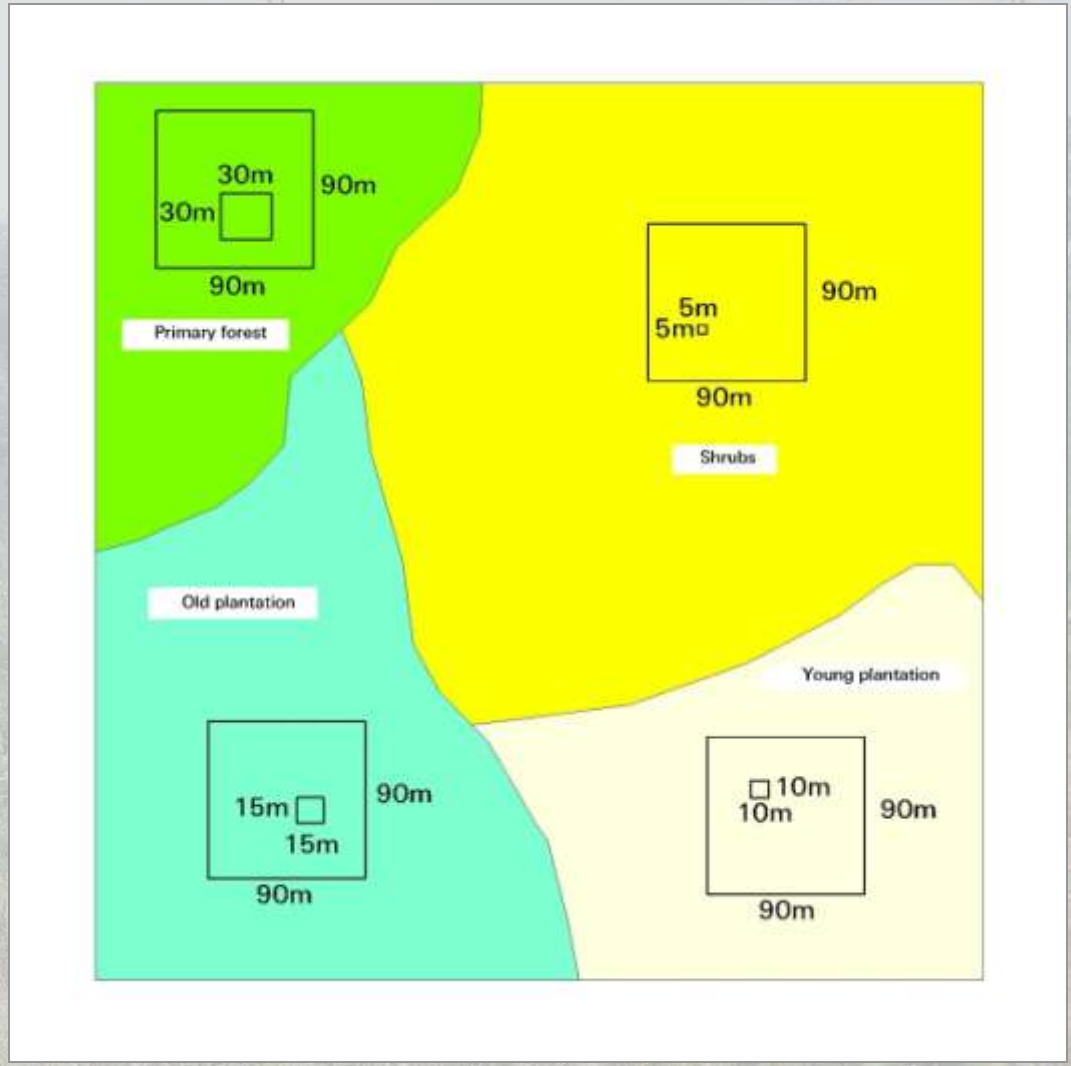
Multistage sampling

Stage I	Stage II	Stage III
Selection of stands	Selection of 90mX90m plots (corresponds of 3X3 pixel window)	Selection of plots in variable size

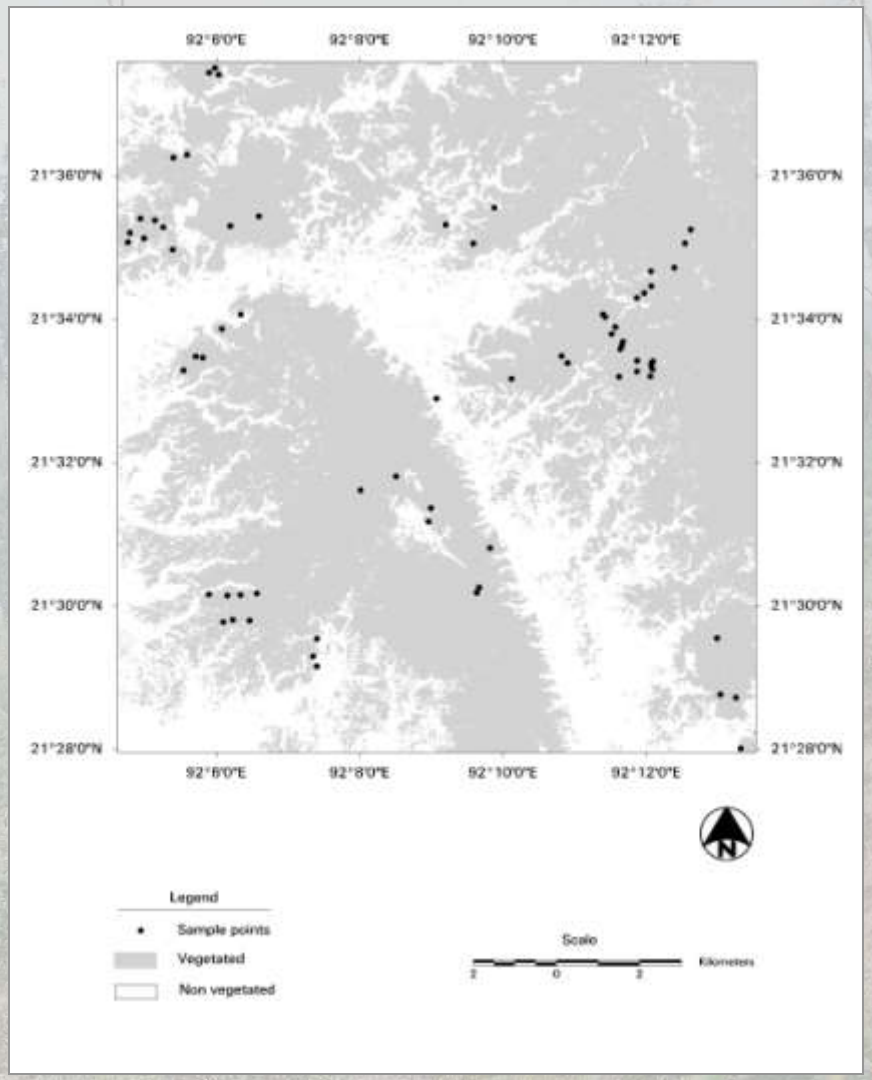
Size of sample plots

- Sample plot size: Variable
- Natural forests: 30m ×30m
- Plantation: 15m x15m or 10m×10m
- Bamboo/shrubs: 5m×5m
- Young regeneration: 2m×2m

Representation of last two-stages in multi-stage sampling



- Distribution of ground samples in the study area (70 sample plots)



Classification procedure

- Study area was visited with the printed raw image
- Vegetation classes were identified
- This knowledge was the basis for training the pixels in supervised classification
- Maximum likelihood algorithm was applied

Stratification

- Forest types identified on the satellite imagery was considered as optimal criteria for stratification

- Idea for stratification is to minimize average variance

$$\bar{V} = \frac{2}{L}\left(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2} + \ldots\ldots\ldots\ldots + \frac{S_L^2}{n_L}\right)$$

Where,

L = number of strata
S_1^2 = y_1 strata variance
S_2^2 = y_2 strata variance etc
n_1 = sample size of strata y_1
n_2 = sample size of strata y_2

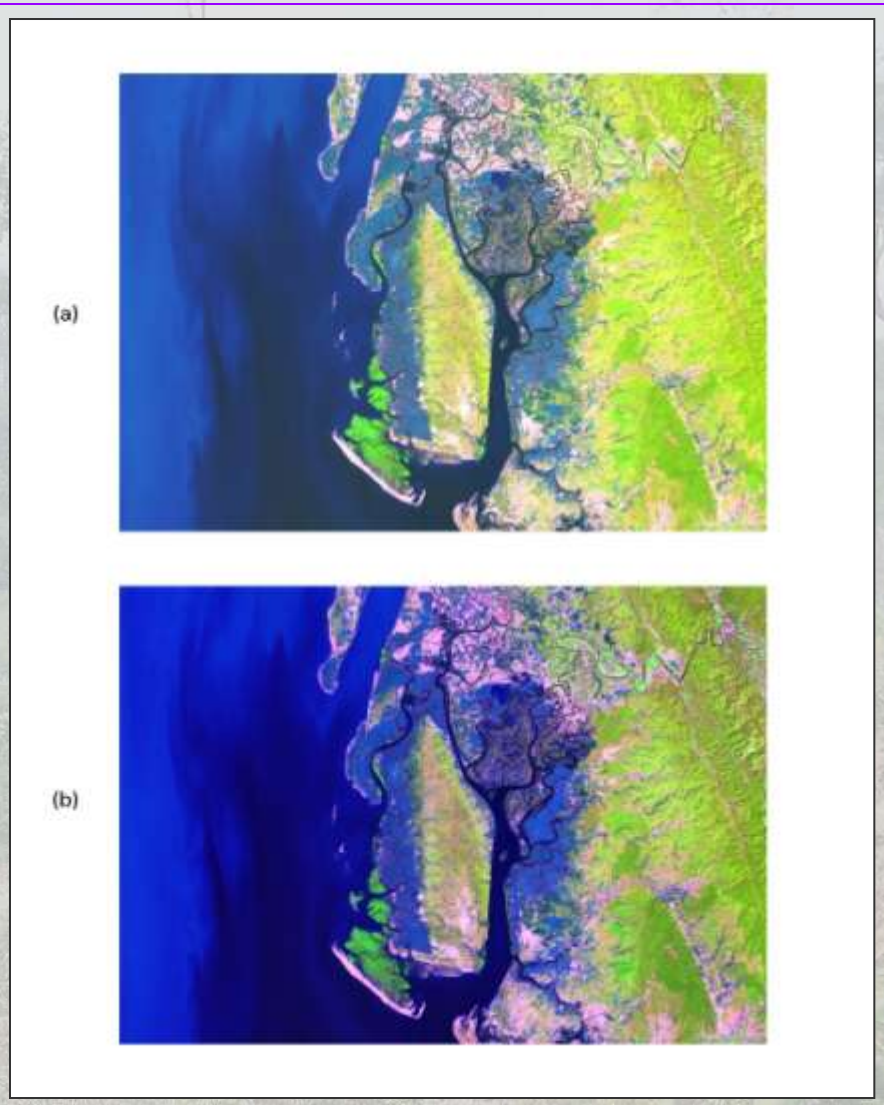
Results

Atmospheric correction

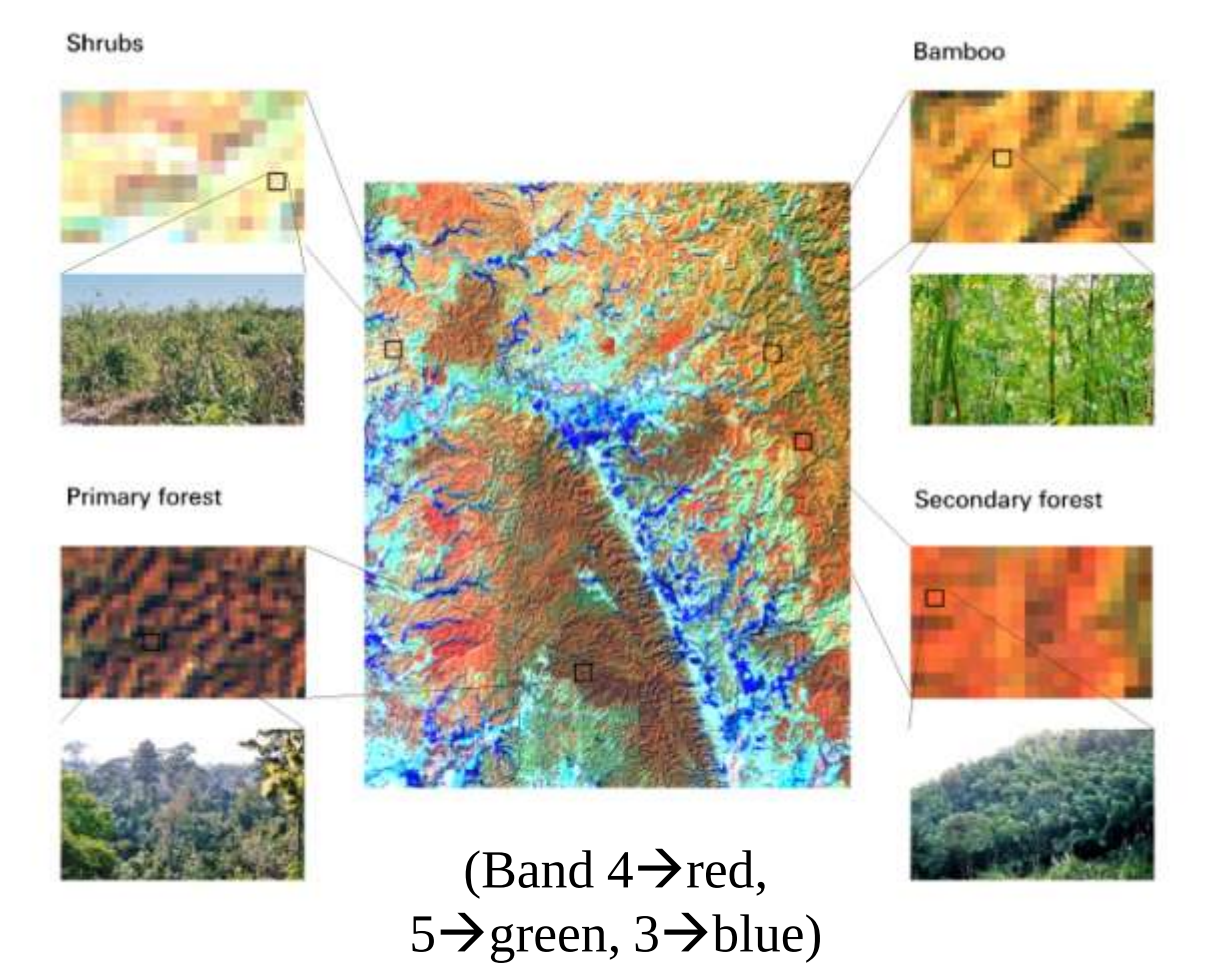
(Example 2001 image)

(a) Raw image

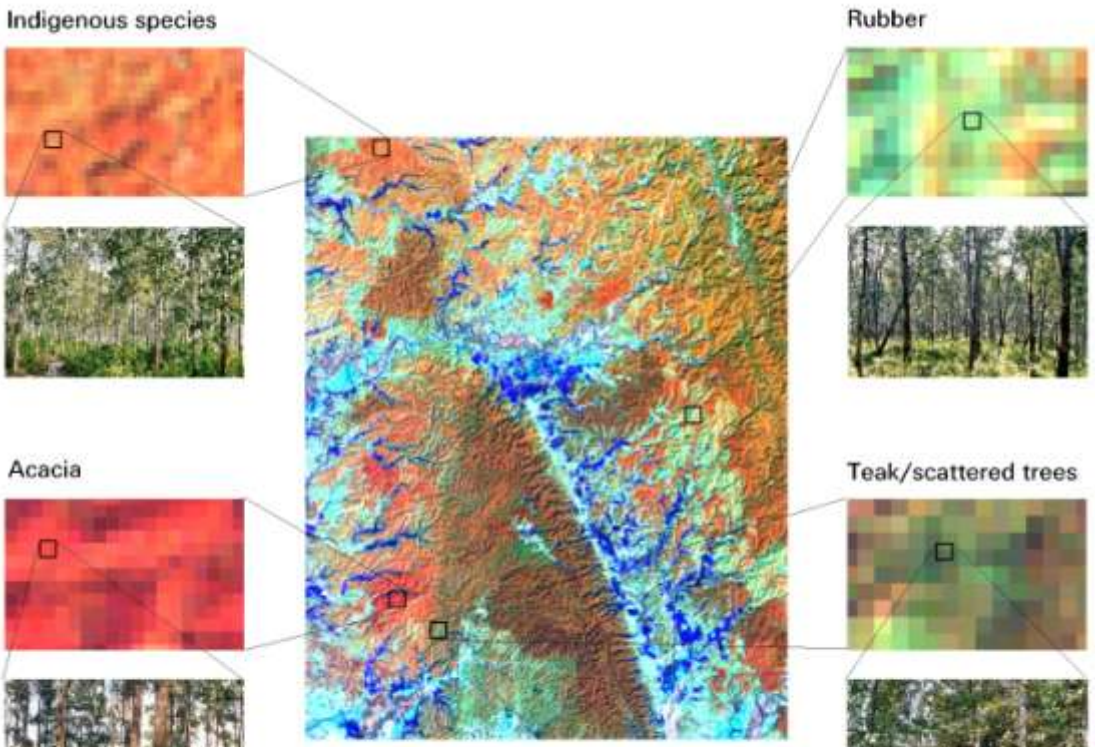
(b) Corrected image



Interpretation of natural vegetation

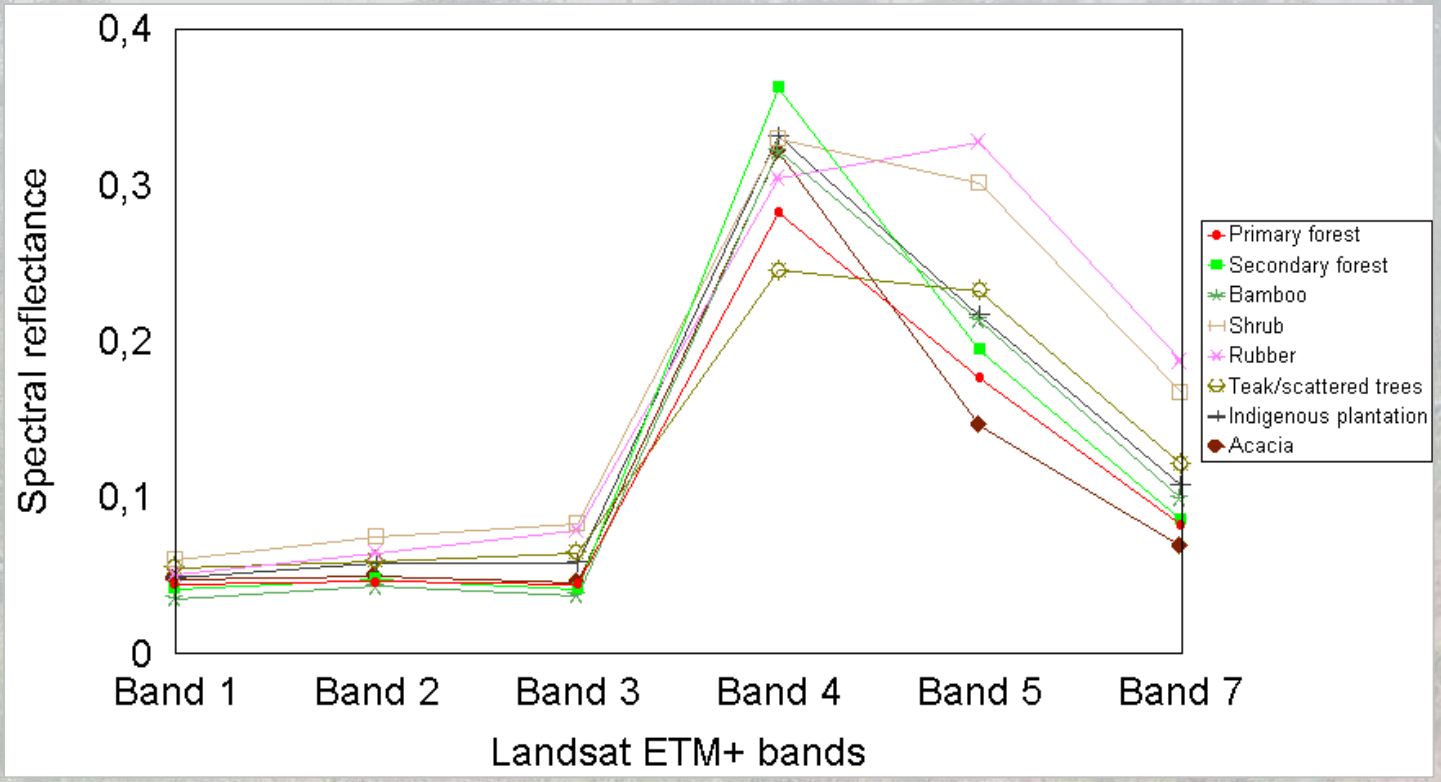


Interpretation of tropical plantation

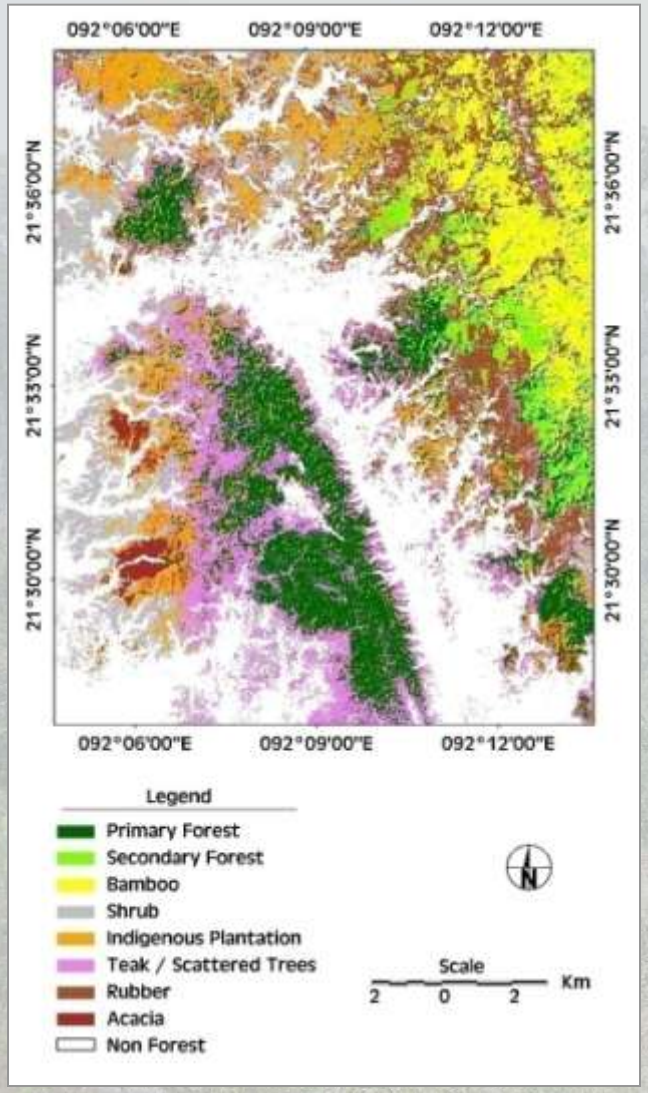


(Band 4→red, 5→green, 3→blue)

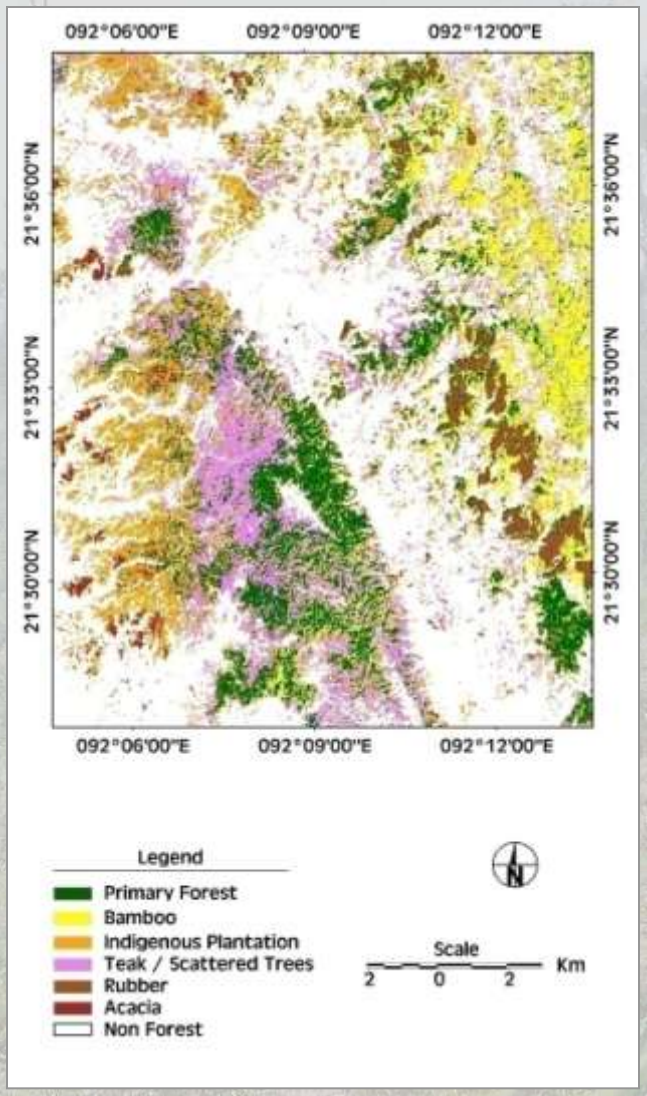
Reflectance pattern of tropical vegetation



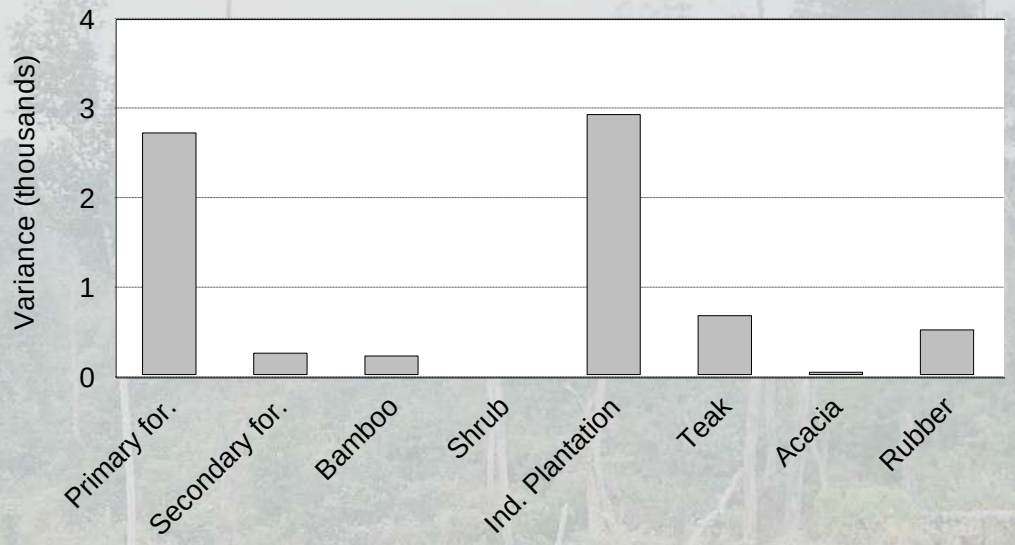
Historical forest cover map (2001)



Recent forest cover map (2010)



Pre-stratification (with terrestrial information)



Forest types

$$\bar{V} = 164$$

Forest cover change matrix 2001-2010 (area in ha)

Landsat 136/045	Year: 2010	Natural forest vegetation		Plantation				Non-forest vegetation		Non-vegetated	Total 2001
Year: 2001		Primary forest	Secondary forest	Indigenous spp.	Teak / S. Trees	Acacia	Rubber	Bamboo	Shrubs		
Natural vegetation	Primary forest	1 441	0	221	1 054	16	5	526	0	687	3 950
	Secondary forest	203	0	48	136	4	2	355	0	286	1 034
Plantation	Indigenous spp.	318	0	800	257	61	12	297	0	810	2 555
	Teak / S. Trees	655	0	360	1 223	28	26	297	0	1 156	3 745
	Acacia	54	0	178	7	32	0	9	0	62	342
	Rubber	241	0	156	388	12	504	484	0	1 221	3 006
Non-forest vegetation	Bamboo	173	0	11	427	0	10	1 135	0	809	2 565
	Shrubs	98	0	553	207	125	33	172	0	1 836	3 024
Non-vegetated		292	0	399	547	137	81	182	0	9 396	11 034
Total 2010		3 475	0	2 726	4 246	415	673	3 457	0	16 263	31 255

Quantifying carbon flux

Type		2001		2010		Change in total C (Mg)
		Area (ha)	Total carbon (Mg)	Area (ha)	Total C (Mg)	
Natural vegetation	Primary forest	3 950	530 762	3 475	466 936	-63 826
	Secondary forest	1 034	89 706	0	0	-89 706
	Bamboo	2 566	160 826	3 456	216 691	55 866
	Shrubs	3 023	2 630	0	0	-2 630
Plantation	Indigenous spp.	2 554	213 930	2 726	228 248	14 318
	Teak / Scattered Trees	3 746	227 733	4 246	258 199	30 466
	Acacia	341	10 472	416	12 738	2 266
	Rubber	3 006	93 036	673	20 829	-72 206
	Non- forest	11 035	-	16 262	-	-
	Total	31 254	1 329 094	31 254	1 203 641	-125 453

Conclusion

- Forest was considerably lost during the last decade (2001-2010); the net loss of primary and secondary forest was 0.48 and 1.03 thousands ha respectively
- 125 Tg of carbon was lost from the study area during the period of investigation (2001-2010) and it was about one-third in compare to the last decade (1992-2001)
- The vast tract of deforested land has also widened the scope of forest plantation. Large-scale forest plantation with fast-growing species will sequestrate a huge amount of carbon

- The success of carbon sequestration and raising forest plantation in the study region still remains a challenging task for Bangladesh Forest Department since forest is highly vulnerable to the extreme human interference

Limitations of the study

Location uncertainty	▪Portable GPS with 15m RMS ▪Accuracy of topographic maps
Sampling design error	▪Sample plots near the accessibility ▪Better stocking in the jurisdiction of local foresters ▪Limited plots from steep slopes
Measurement error	▪Measurement of height in dense forest ▪Lack of training facilities for field crews

Estimation error

- Reliability of allometric relations
- Variability of weight and density inside a single tree

Direction of further research

- Adding height (laser scanning, In-SAR) & below canopy (microwave) information on remote sensing image
- Combine other methods to increase the precision of estimate
- The amount of carbon released to the atmosphere

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Field sampling

- Bangladesh Space Research & Remote Sensing Organization (SPARRSO)
- Bangladesh Forest Department

Staffs of Bangladesh Forest Department & Forest villagers

Further Information

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Thanks for your attention!!!