Different Methods To Estimate Above Ground Biomass: A Comparative Study From Nepal

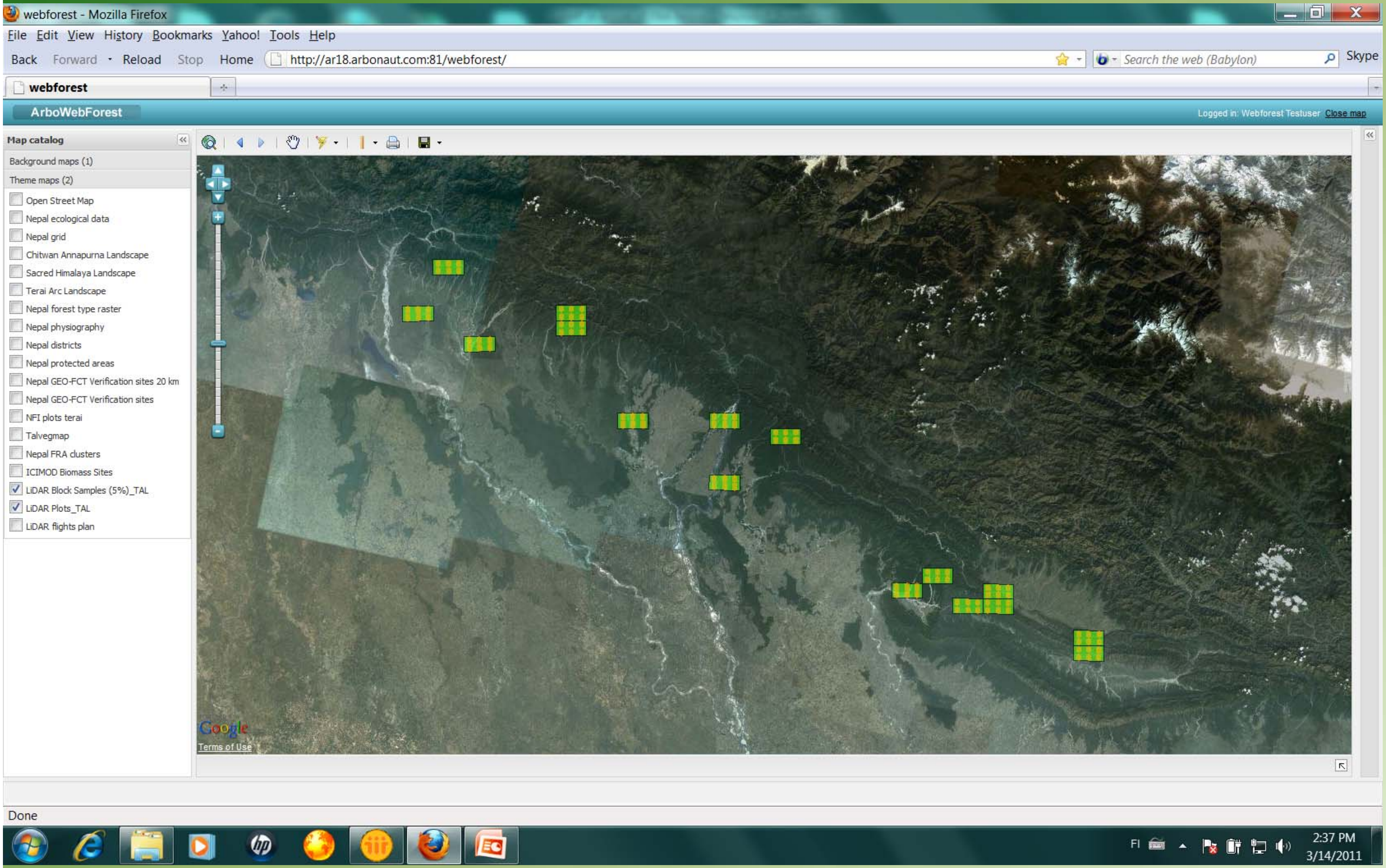
A Comparative Study from Nepal Data

- Comparing 4 different methods to extrapolate LiDAR estimated carbon to landscape
  - Tradition forest classification, supervised &/or unsupervised and ground verification
  - Forest Canopy Density (FCD) Mapper based on proportion of canopy cover
  - Automated classification based on proportions of photosynthetic, non-photosynthetic vegetation and bare soil (CLASlite)
  - LiDAR Assisted Multisource Program (LAMP) based on satellite features & Rapid Eye satellite data

Field Vegetation Plots

- For LiDAR campaign in TAL of Nepal
- 20 random LiDAR sampling blocks were chosen weighted by
  – Importance of vegetation type and
  – Inverse to the amount of area available
- Random plots were set up in each of 20 blocks
  – Each bock has 6 clusters
  – Each cluster has 8 circular plots
  – Each plot is 12.61 m in radius (500 m^2)

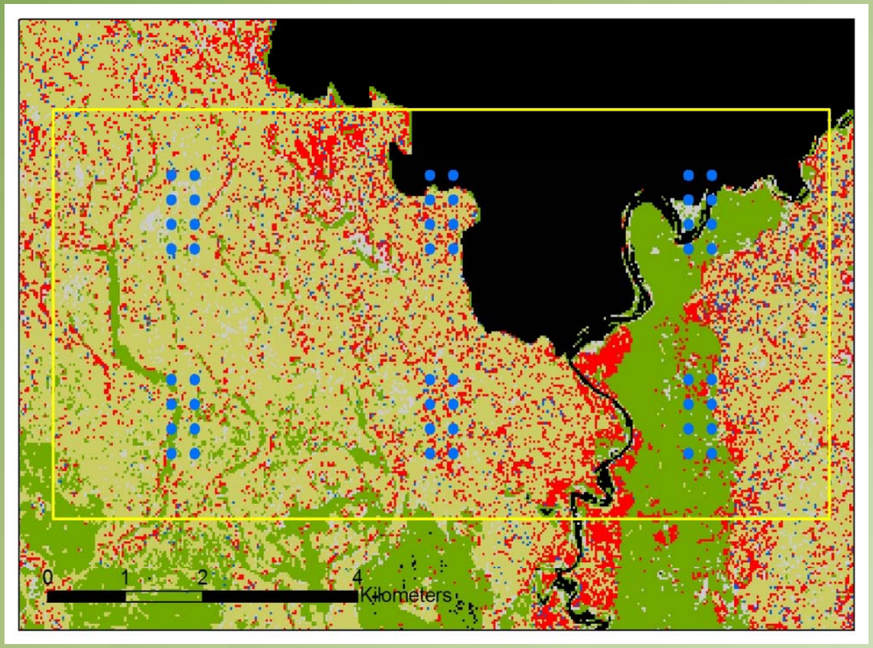
Distribution of Field Plots



Field Data Collection

- All trees > 5 cm DBH measured
- Every 5th tree measured for height
- Volume Equations from Sharma & Pukkla (1990) used to estimate biomass

Vegetation Plots Layout



Above Ground Biomass (t/ha) in Different Forest Types of TAL Using only Field Plots

Forest Type	Mean	STD	N
Chir Pine	174.1	109.0	55
Hill Sal	223.1	146.1	143
Sal	271.0	156.3	225
Mixed	229.0	141.2	67

Field Based Plots Only

Benefits:

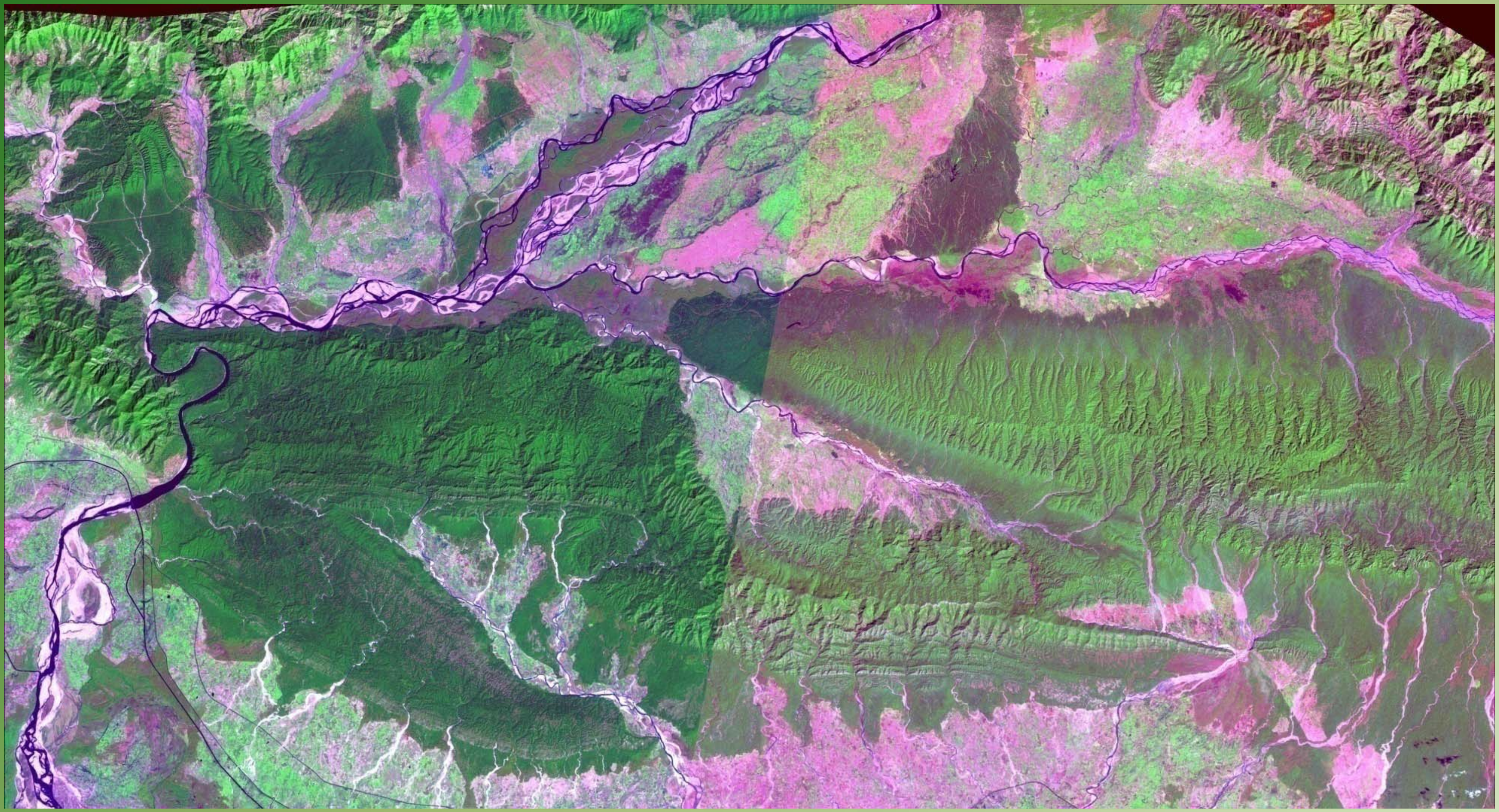
- Low-tech method widely understood & used
- Opportunity to involve local communities to establish a participatory process
- Still needed to calibrate remote sensing measurements

Limitations:

- Challenging to produce globally consistent results
- Covers small geographical area
- Time consuming
- Becomes expensive as data needs to collected routinely

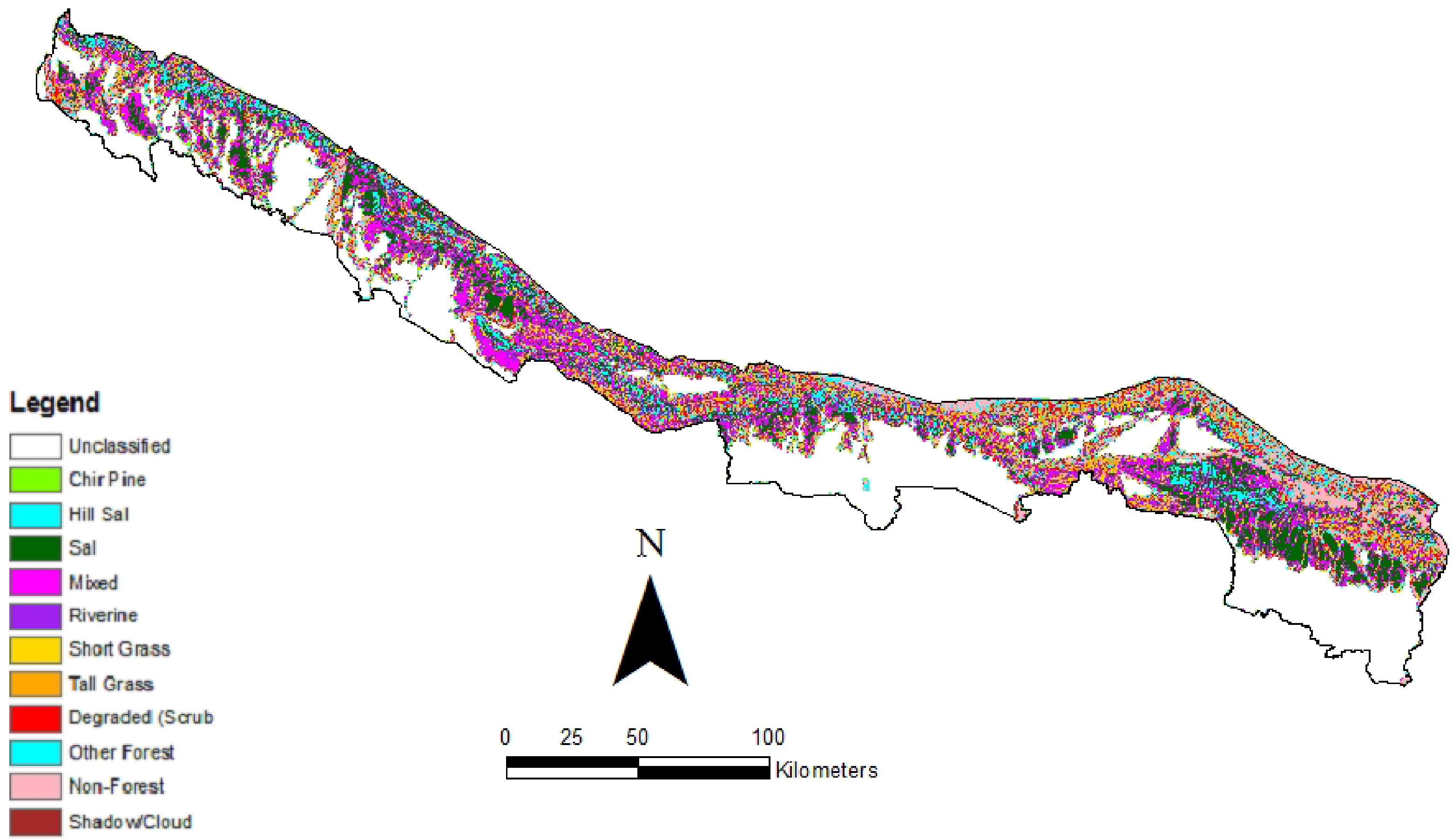
How to Extrapolate data to Landscape?

Satellite-based Biomass Estimation



Landsat Scene of Chitwan, Nepal, 2010

Forest types of Terai Arc Landscape (TAL)



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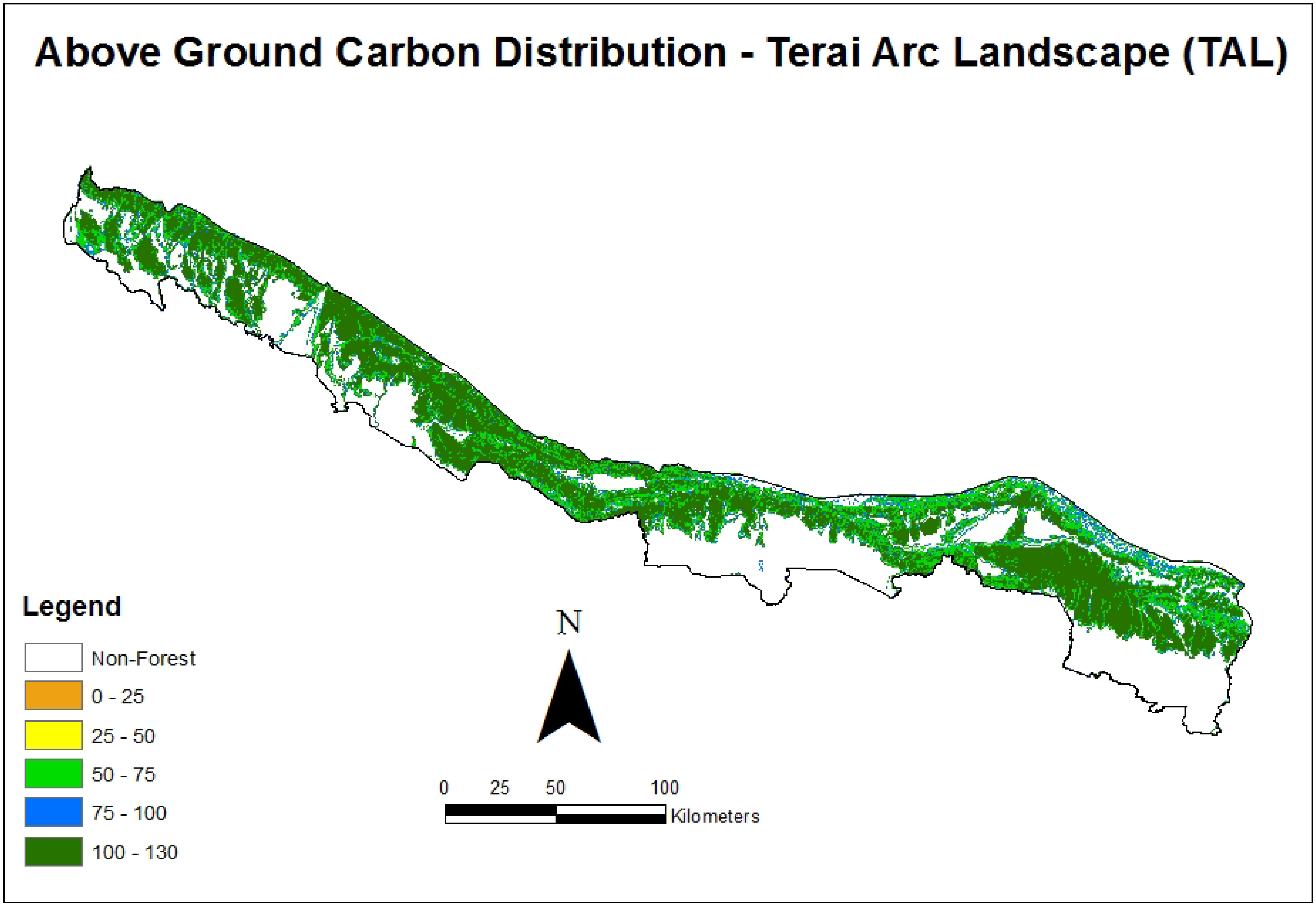
Above Ground Biomass Using Veg Plots & Classified Satellite Map

Forest Type	Area in ha	Above Ground Biomass (t/ha)	Above Ground Carbon (t/ha)
Chir Pine	39,320	6,846,752	3,286,441
Hill Sal	392,584	87,582,515	42,039,607
Sal	365,200	106,376,712	51,060,822
Mixed	171,526	39,278,092	18,853,484
Total	968,630	240,084,071	115,240,354

Field Plots + Satellite Data



Field Plots + Satellite Data

Benefits:

– Landsat satellite data routinely collected and freely available
– Deforestation can be identified easily
– Images from 2 time period can be compared to monitor change in forest conditions

Limitations:

– Spectral indices saturated at relatively low carbon stock
– Provides single value for each forest type
– Change detection possible only at a pixel level
– Not possible to measure forest degradation
– Doesn't provide region variation for the forest conditions

How to account for variation in carbon due to bio-physical conditions?

Tools to measure variation in forest carbon

- Forest Canopy Density Model (FCD) – ITTO
- ArboLiDAR – Arbonaut Ltd., Finland
- Fractional Covers - Carnegie Institute, USA (CLASlite)
- Fractional Index – IMAZON, Brazil (Imgtools)

Forest Canopy Density Mapping Model (FCD)

- **Rikimaru (1996) introduced a biophysical spectral response modeling**
- **An alternative deductive approach to map forest canopy density using 4 indices derived from Landsat TM imagery**
  - **Advance Vegetation Index (AVI)**
  - **Bare Soil Index (BI)**
  - **Shadow Index or Scaled Shadow Index (SI, SSI)**
  - **Thermal Index (TI)**
- **Provides 10 canopy density classes at 10 % intervals, 0-10, 10-20, 20-30 ……90-100**

FCD Method - Carbon Analysis For TAL

Landsat TM Satellite image was stratified using FCD method into 4 Classes (Strata):

- Strata 1: 1 – 10% Shrub land (Non Forest)
- Strata 2: 11 – 40% Degraded Forest
- Strata 3: 41 – 70% Moderately Dense Forest
- Strata 4: 71 – 100% Dense Forest

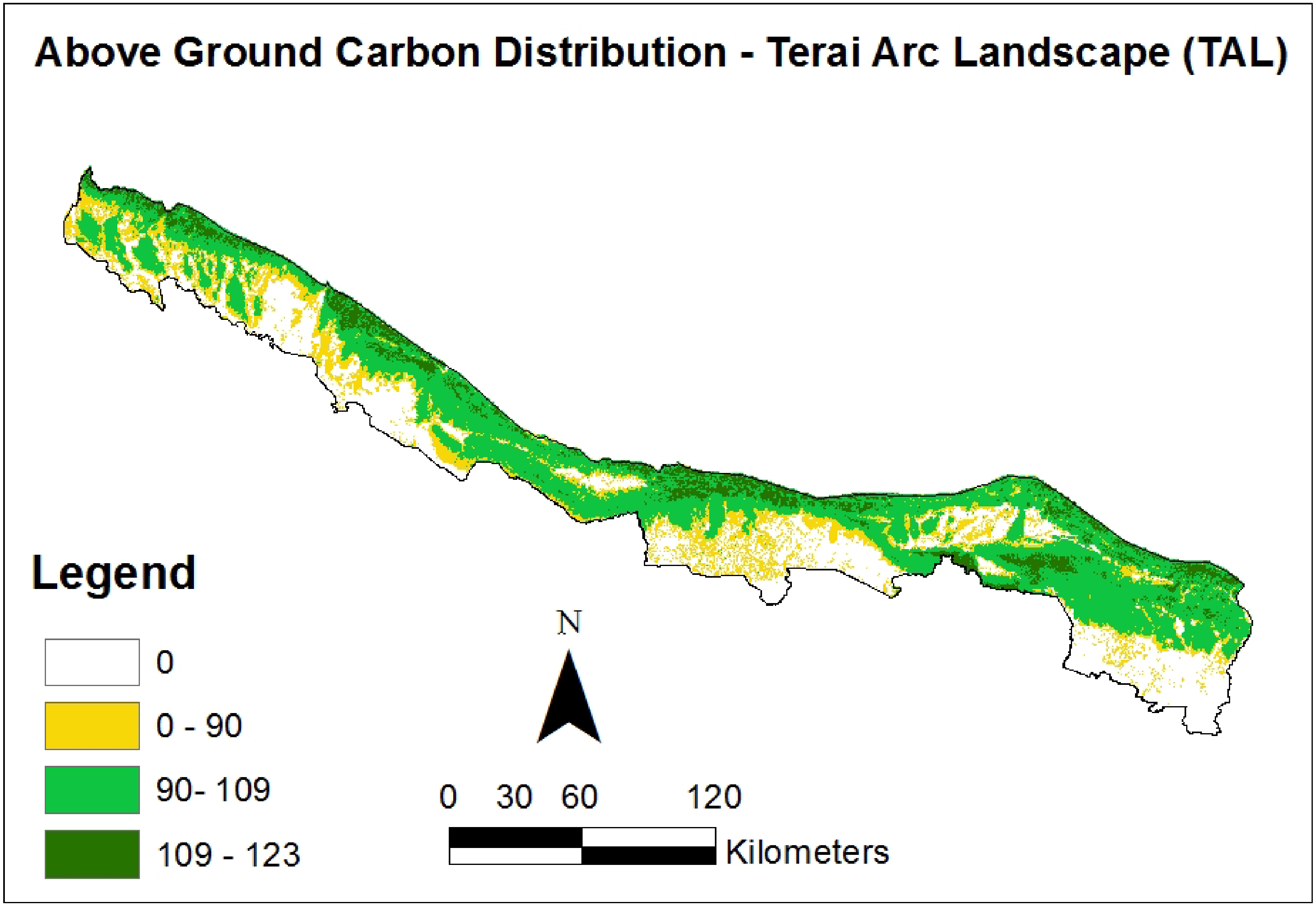
AGB Prediction using FCD & Field Plots

	Mean AGB (ton /ha)	Mean Carbon (tC/ha)	Standard Deviation	N
Strata 2	187	89.9	149.7	91
Strata 3	228	109.2	149.6	414
Strata 4	257	123.5	151.8	53

Carbon Distribution using FCD + Field Plots for TAL

Strata	Area in ha	Carbon in tons
Strata 2	226,272	20,337,779
Strata 3	762,001	83,234,410
Strata 4	116,482	14,385,640
Total	**1,104,755**	**117,957,829**

FCD – Carbon Distribution – ton C/ha



FCD Method

Benefits:

- Uses freely available software & Landsat data
- Accounts for variation in Carbon distribution due to biophysical conditions

Limitations:

- Requires user input of threshold for all 4 indices
- Thus may introduce human bias/error
- Can’t measure degradation
- Pixel to pixel change detection is not supported within the software

How can LiDAR help in AGB estimate at the Landscape Level?

Sampling: Field Plots Vs. LiDAR

- LiDAR sampling covers a much larger area (10-50 Km^2) compared to field plots (20 -50 m^2), in less time
- Wall-to-wall LiDAR scanning captures variability in biomass, both within and between vegetation types
- Accurately measures tree canopy height and vertical forest structure, critical for estimating biomass
- 1% - 5% sampling of forest is enough to built reliable models to develop LiDAR to biomass relationships called Lidar metrics
- Once models have been tested, repeated field measurements or LiDAR sampling is not needed
- Above-ground Carbon can be estimated using Lidar metrics.

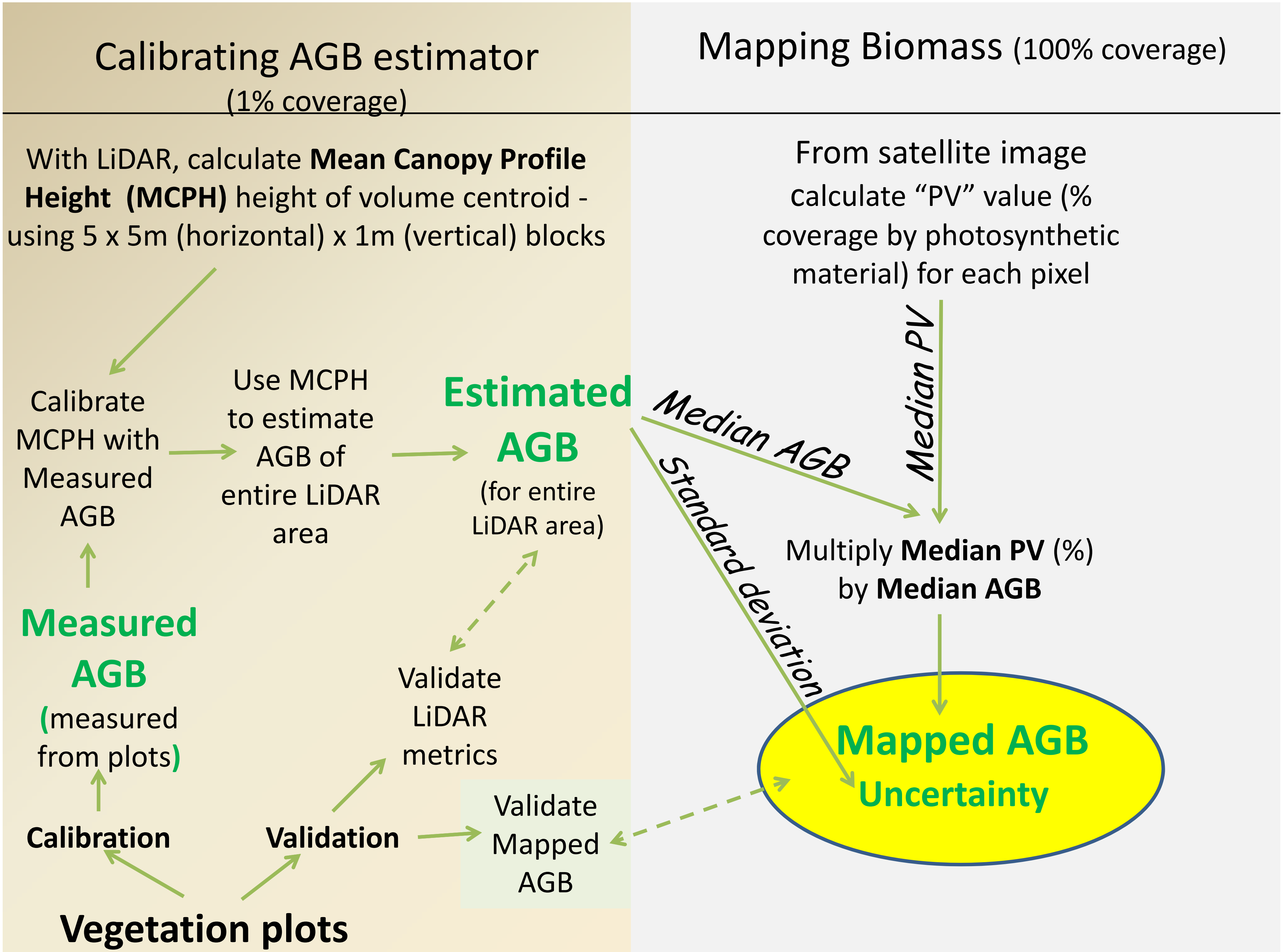
Lidar-carbon Approach

1. **REDDlite method developed by Carnegie Institute, USA**

2. **LAMP (**LiDAR Assisted Multisource Program) **method developed by Arbonaut Ltd., Finland**

REDDlite Method

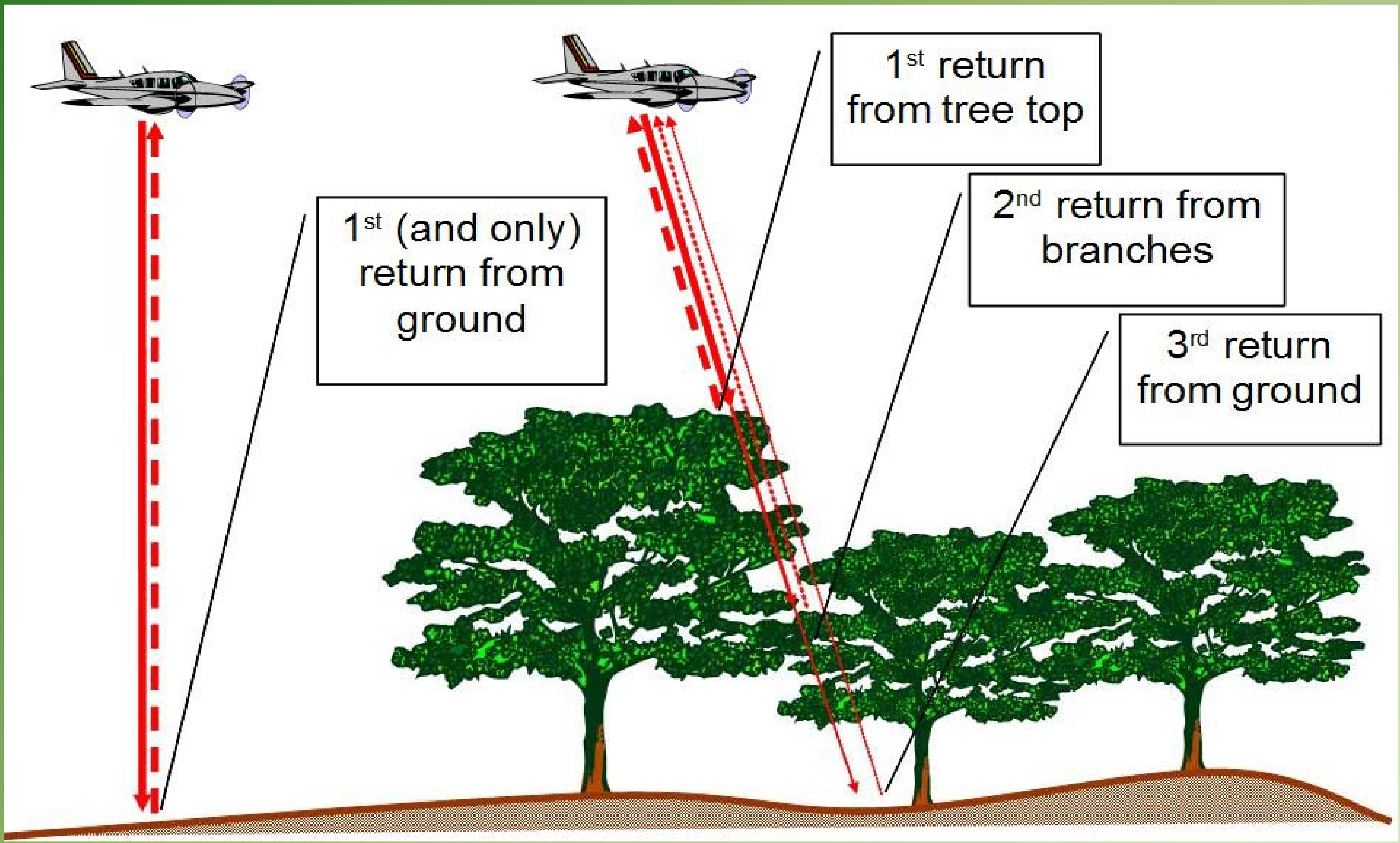
a. Stratify sampling area with available vegetation map to select sampling areas
b. Use Lidar to sample 1-5% of the project area
c. Develops Lidar-Carbon relationship (Lidar metrics) using Mean Canopy Profile Height (MCPH) to fit Non-linear Regression Model
d. Estimates carbon distribution in entire Lidar coverage area
e. Uses CLASlite software & TM Satellite imagery to extrapolate Carbon to the entire Landscape (project area)



Calibrating AGB estimator
(1% coverage)
Mapping Biomass (100% coverage)
With LiDAR, calculate **Mean Canopy Profile Height (MCPH)** height of volume centroid - using 5 x 5m (horizontal) x 1m (vertical) blocks
From satellite image calculate "PV" value (% coverage by photosynthetic material) for each pixel
Calibrate MCPH with Measured AGB
Use MCPH to estimate AGB of entire LiDAR area
Estimated AGB
(for entire LiDAR area)
Median AGB
Median PV
Standard deviation
Multiply **Median PV** (%) by **Median AGB**
Measured AGB
(measured from plots)
Validate LiDAR metrics
Mapped AGB
Uncertainty
Validate Mapped AGB
Calibration
Validation
Vegetation plots

Field Data Collection

LiDAR Scanning



Best Fit Models for Different Forest Types

Type (n)	Model No.	RSS	AIC_C	ΔAIC_C	ω_i	Adj. R^2	RMSE
Chir Pine (71)	7	19.4	-78.4	0.000	0.653	0.64	0.54
Hill Sal (172)	13	32.7	-279.1	0.000	0.998	0.68	0.44
Sal (193)	13	35.7	-319.5	0.000	0.949	0.55	0.43
Mixed (96)	13	15.1	-171.2	0.000	0.992	0.71	0.54

Model Parameter Estimates for "Best" Model(s) Selected

Veg.	Model No.	Pred. CV (%)[1]	Model (parameter estimate SE in "()" below parameters)
Hill Sal	13	8.2	2.597 + 1.51(LQMCH) (0.136) (0.061)
Sal	13	7.8	2.213 + 1.308(LQMCH) (0.209) (0.085)
Mixed	13	7.4	2.068 + 1.381(LQMCH) (0.207) (0.091)
Chir Pine	7	10.7	6.74 + 0.211(X2) + 0.168(X4) + 0.078(X6) + 0.161(X8) (0.231) (0.063) (0.061) (0.053) (0.045)
All	13	10.1	2.041 + 1.373(LQMCH) (0.087) (0.039)

[1]Predicted CV ≈ (RMSE/((log($\bar{Y}$+1.0)))×100 where $\bar{Y}$=mean AGB from field plots

AGB Estimate for LiDAR Blocks

Vegetation Type	Mean AGB ton/ha	Std. Error ton/ha	N
Chir Pine	232.45	24.9	61,163
Hill Sal	207.24	17.0	283,454
Sal	243.16	18.0	255,132
Mixed	201.08	14.9	64,853

How To Scale Up To The Landscape Level?

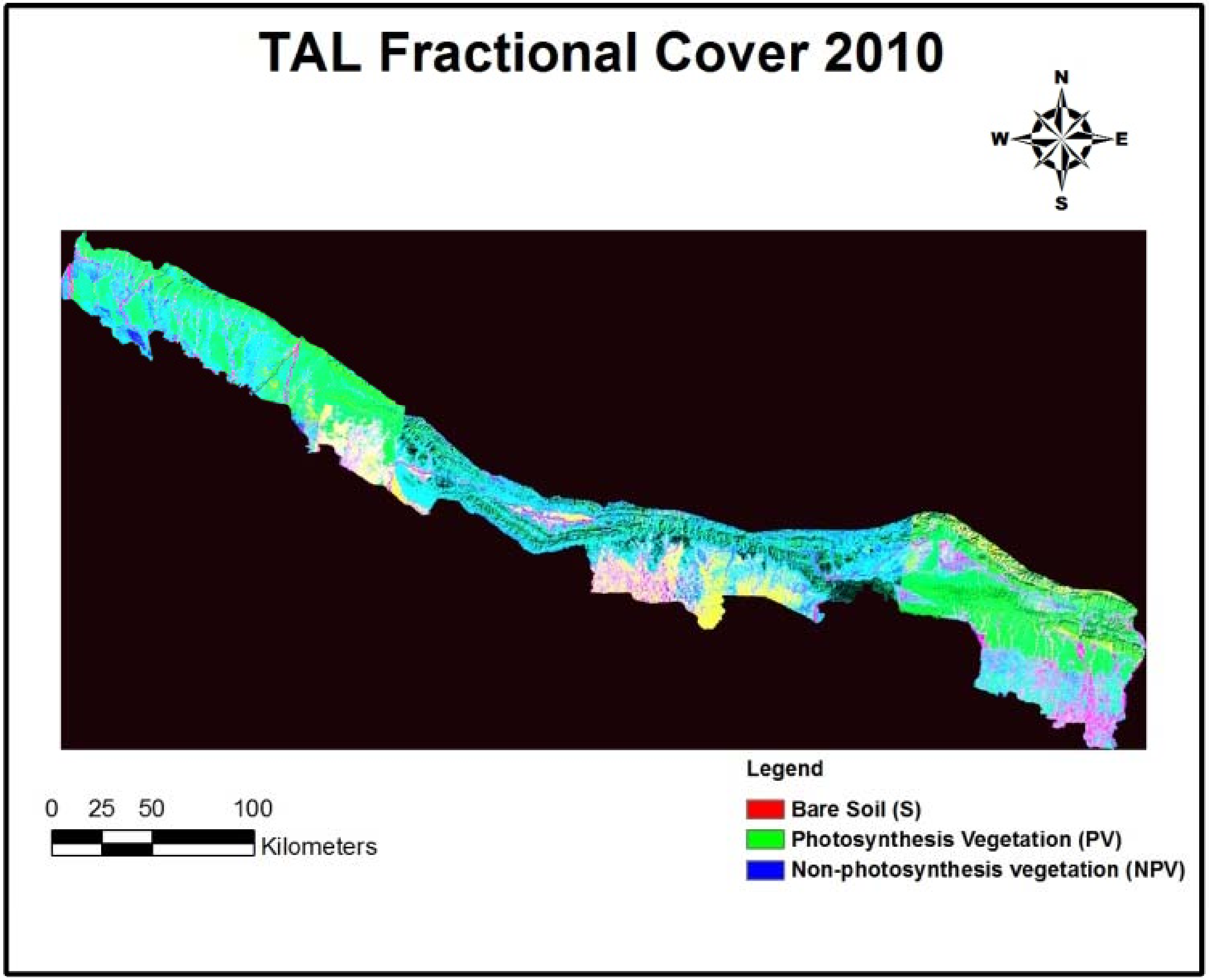
Fractional Methods

Two methods currently available

- IMGTools – IMAZON, Brazil – in refining and debugging stage.
- CLASSlite – Carnegie Institution, USA

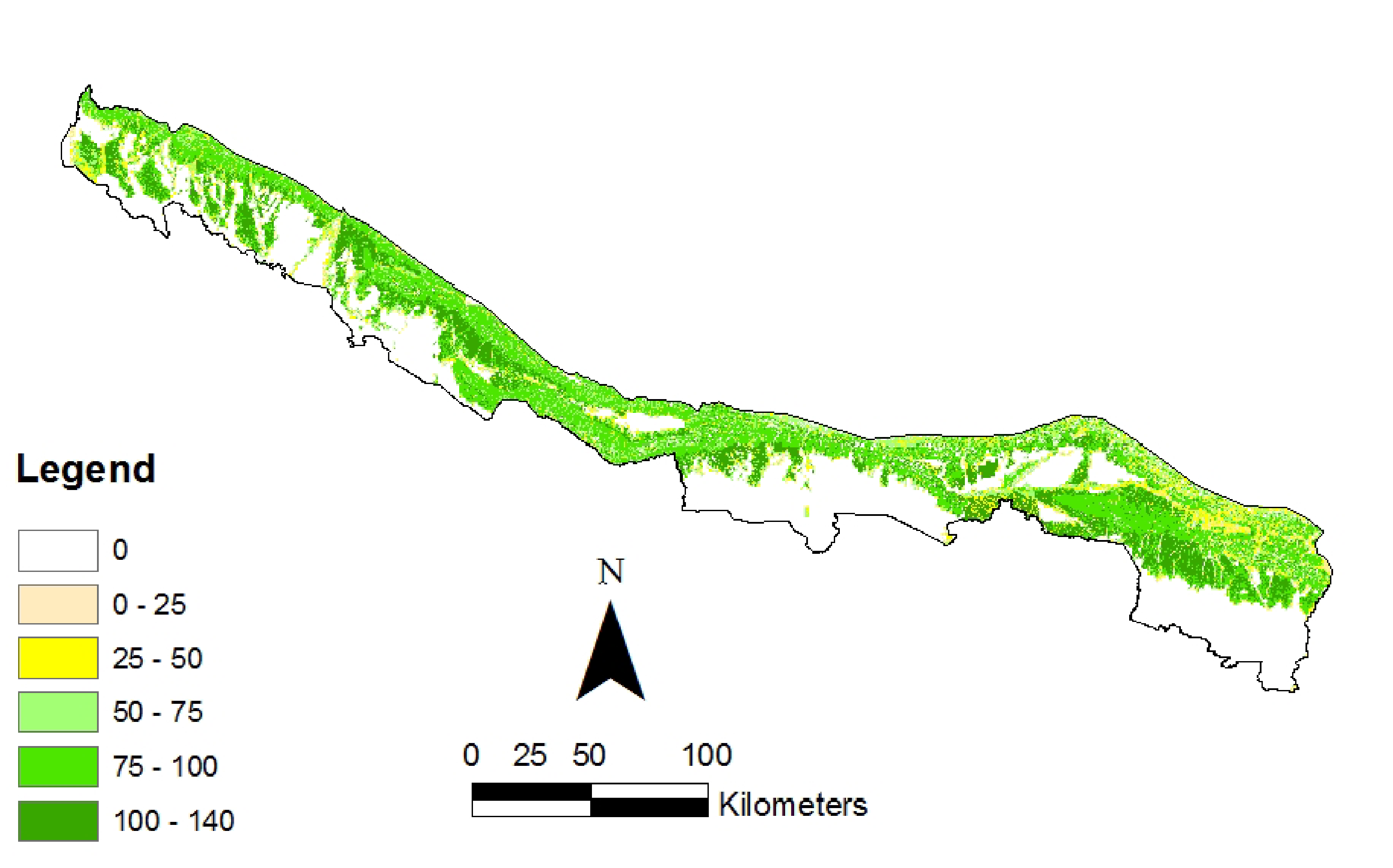
Fractional Method - CLASlite

- Median Photosynthesis Value (PV) from CLASSlite fractional cover is given median Above ground Carbon Value for each forest type
- The pixels with higher or lower than median PV values are adjusted for the Carbon values
- Above ground Carbon Density (ACD) map is produced for the entire project area



TAL Fractional Cover 2010
N
W
E
S
Legend
Bare Soil (S)
Photosynthesis Vegetation (PV)
Non-photosynthesis vegetation (NPV)
0 25 50 100
Kilometers

Above Ground Carbon Distribution - Terai Arc Landscape (TAL)



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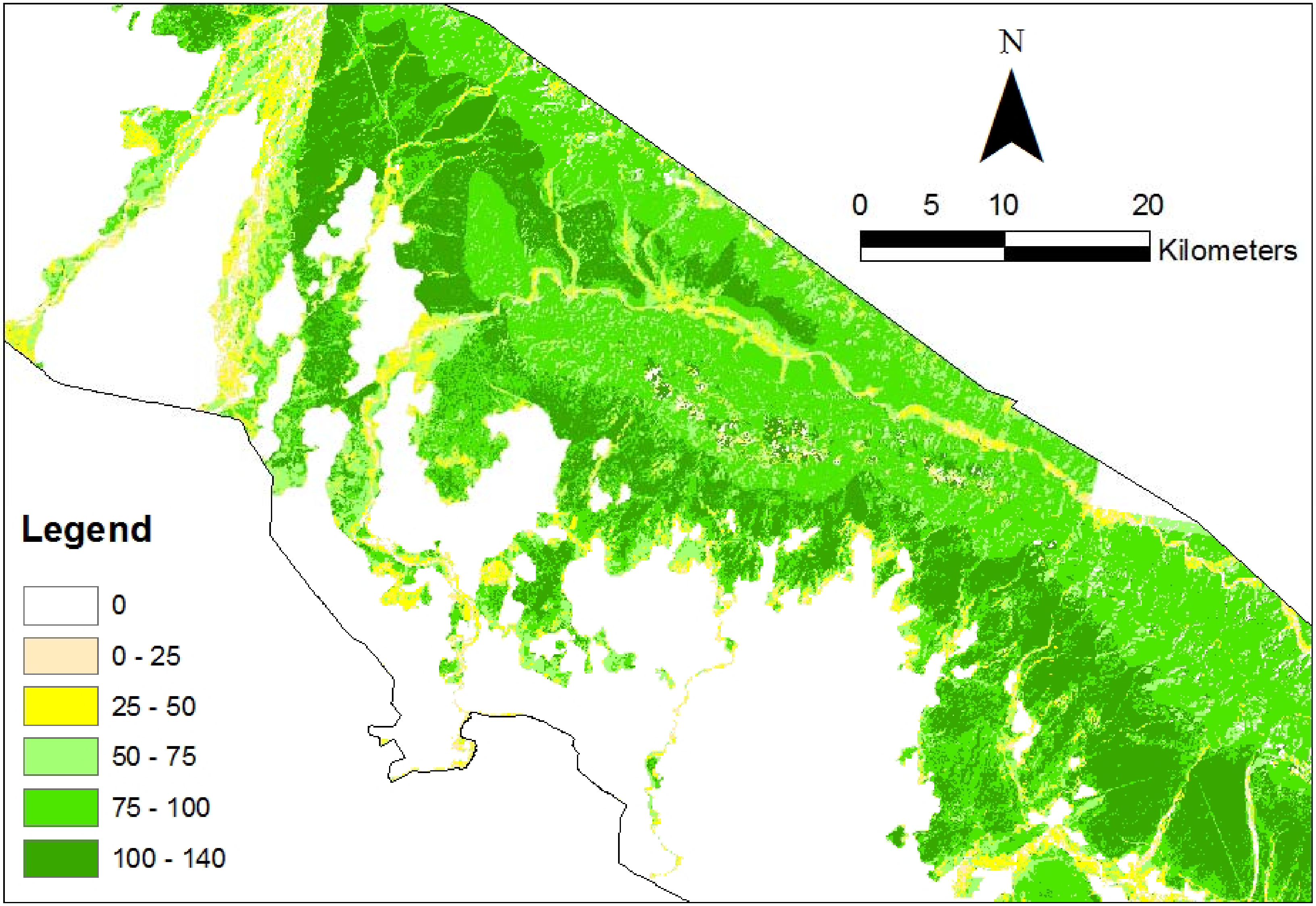
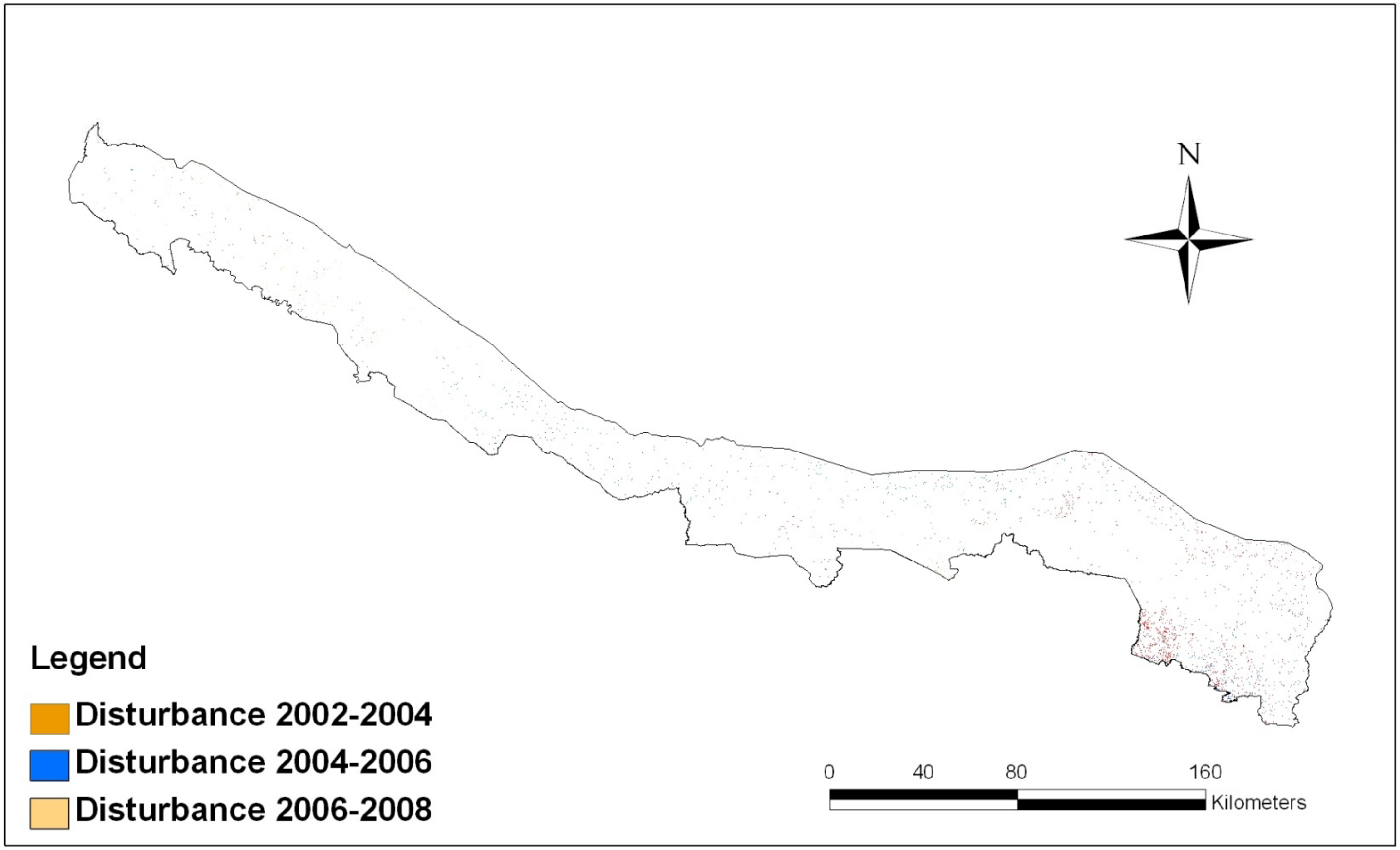


How Can We Measure Deforestation and Forest Degradation?

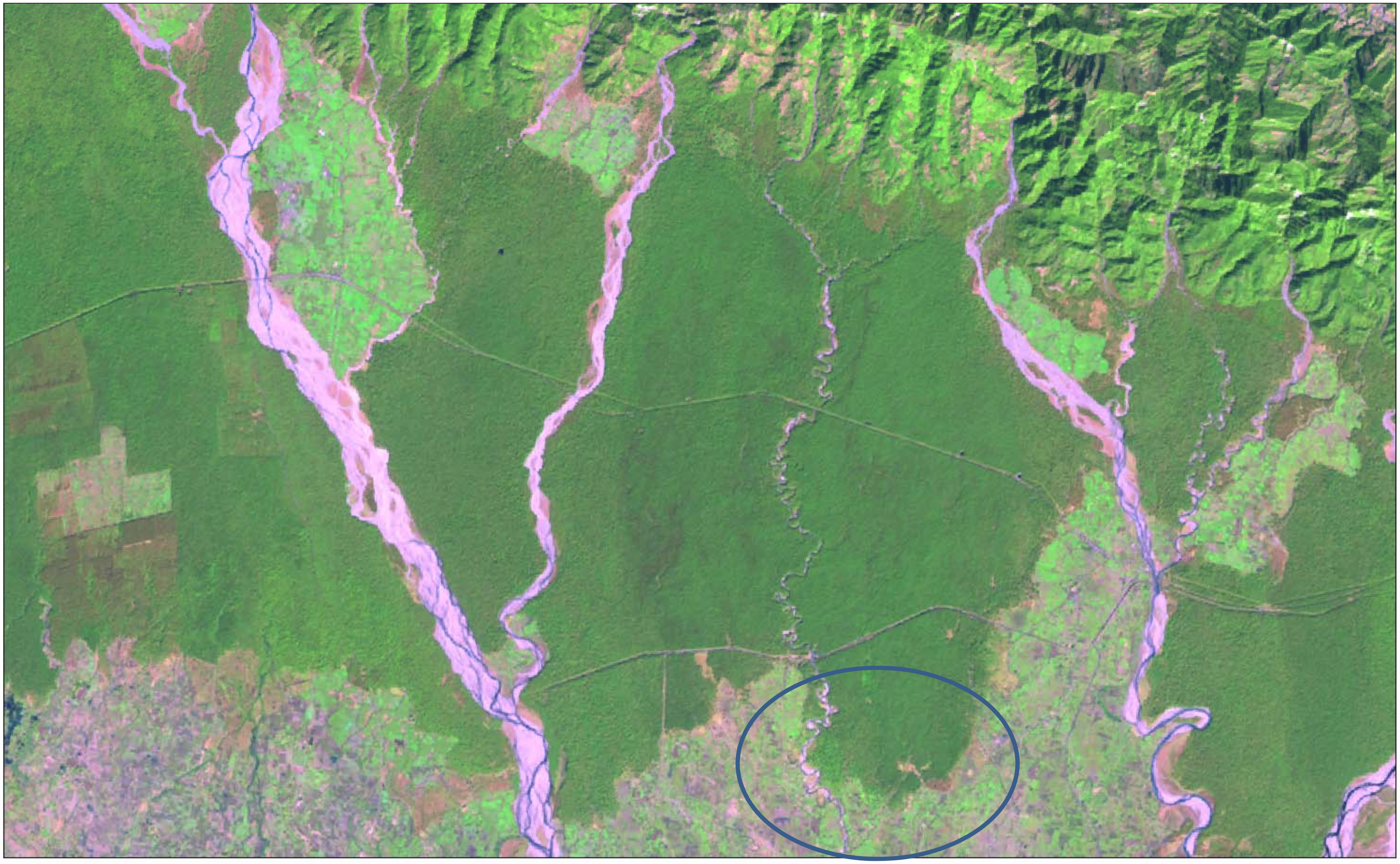
Deforestation & Degradation

- CLASlite is only software known at present that calculate deforestation and forest degradation directly
- It uses proportions of PV, NPV and S between same pixels from 2 time periods to calculate deforestation and forest degradation

TAL Forest Disturbance 2002 - 2008

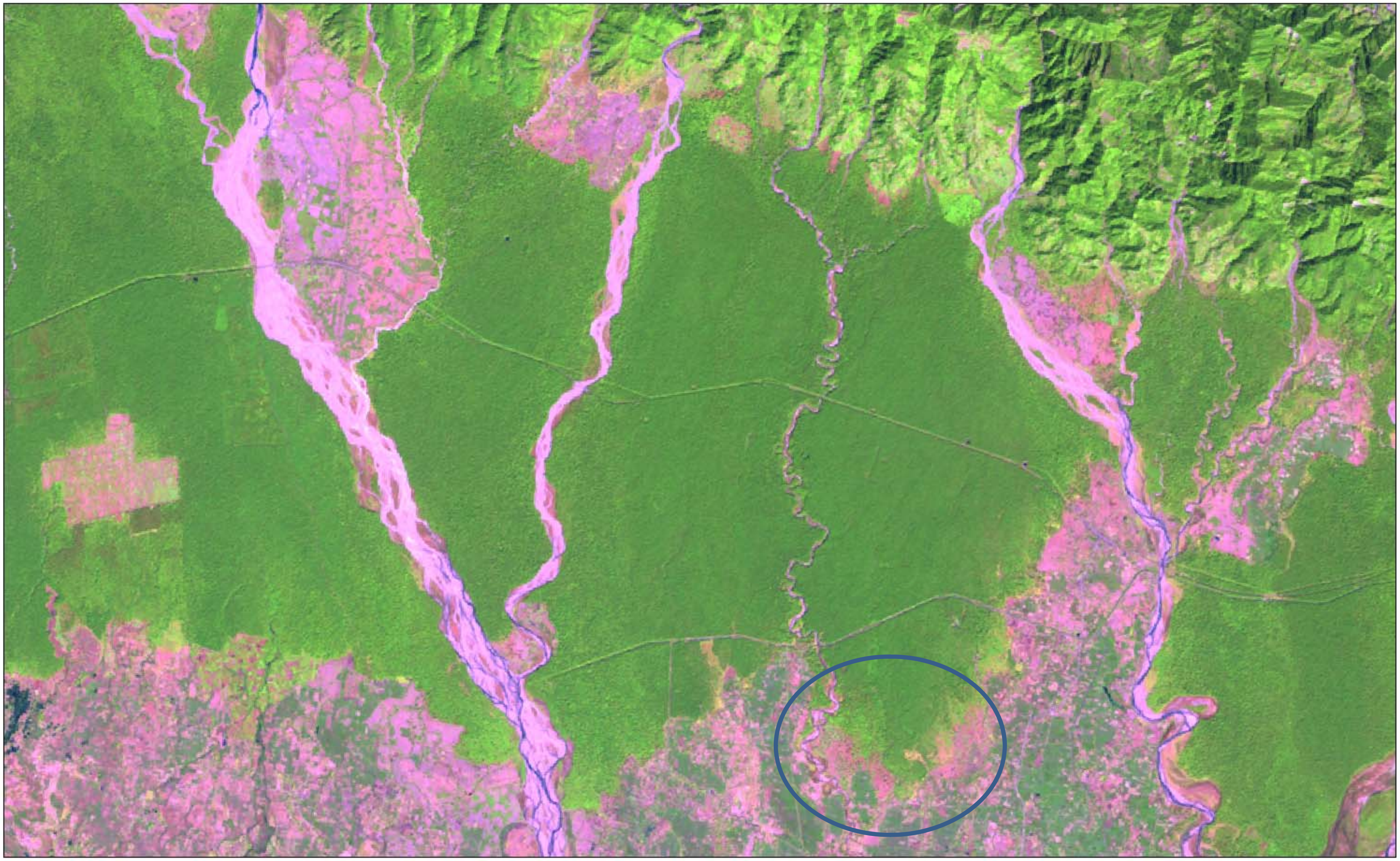


Raw Landsat Satellite Image of Eastern Nepal



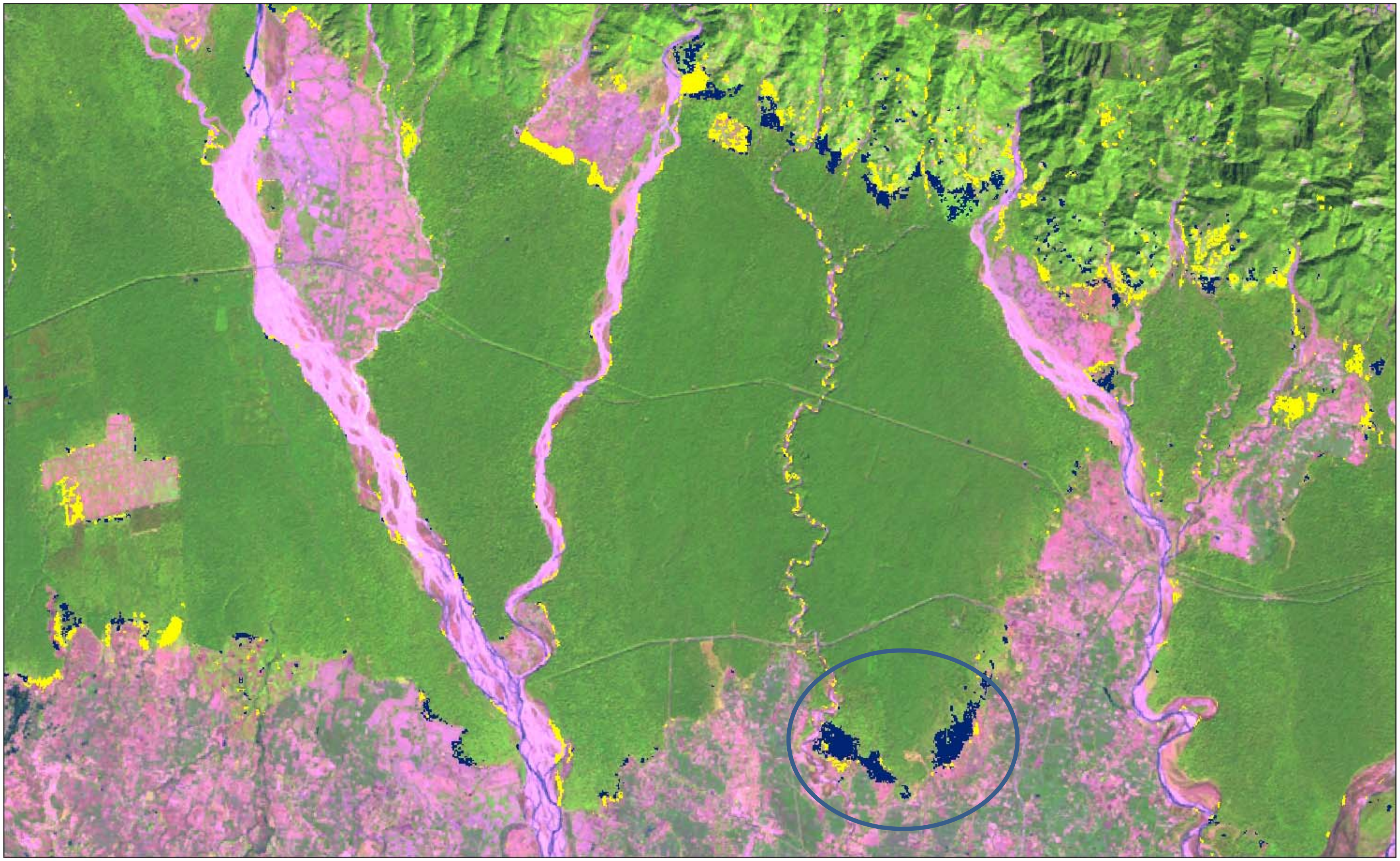
Satelite Image 2002

Raw Landsat Satellite Image of Eastern Nepal



Satellite Image 2006

Raw Landsat Satellite Image with Deforestation

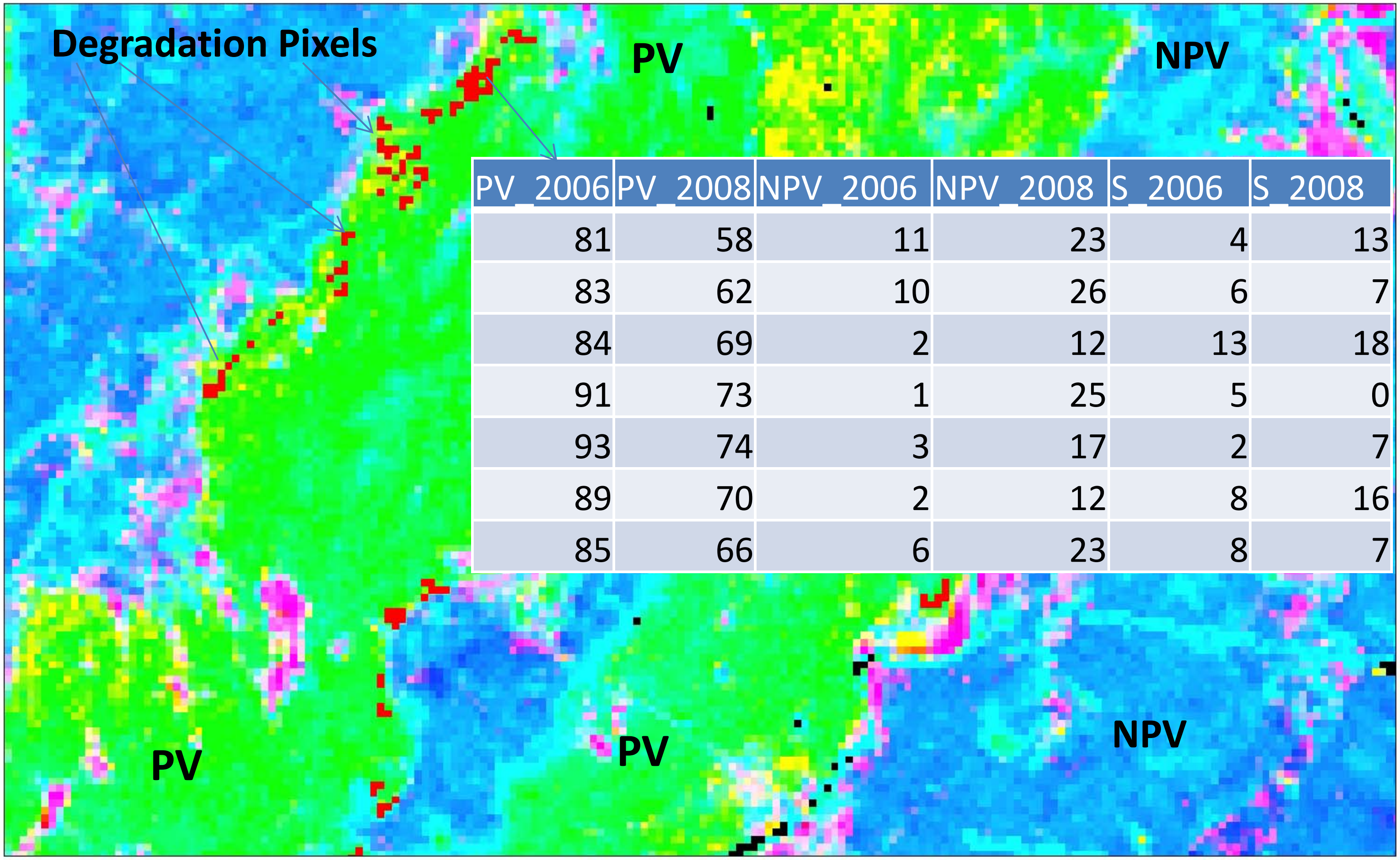


Legend

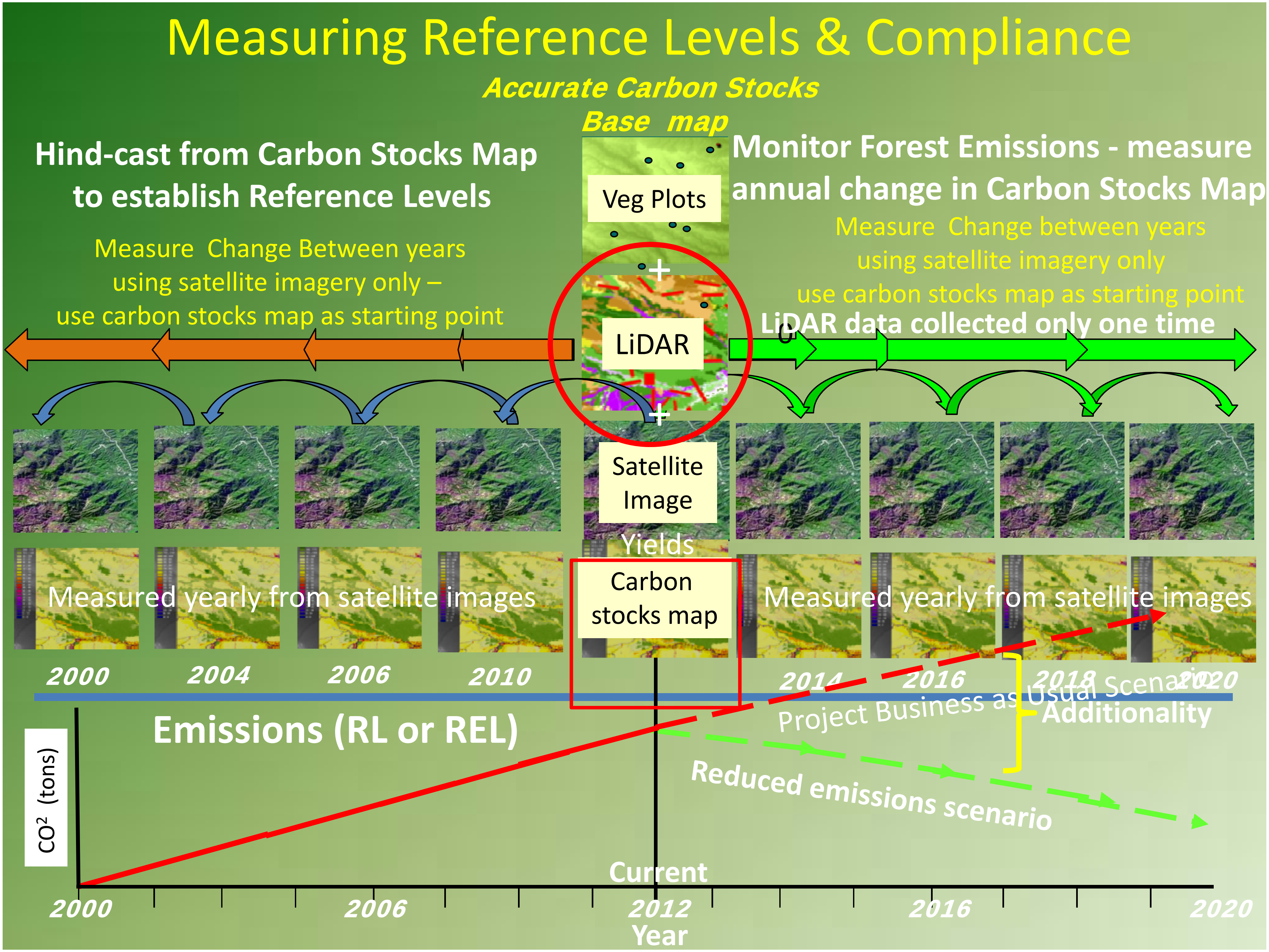
- Deforestation 2004-2006
- Deforestation 2002-2004

Deforestation between 2002 - 2006

Degradation 2006-2008 Using Fractional Coverage



PV_2006	PV_2008	NPV_2006	NPV_2008	S_2006	S_2008
81	58	11	23	4	13
83	62	10	26	6	7
84	69	2	12	13	18
91	73	1	25	5	0
93	74	3	17	2	7
89	70	2	12	8	16
85	66	6	23	8	7



Measuring Reference Levels & Compliance
Accurate Carbon Stocks
Base map
Hind-cast from Carbon Stocks Map to establish Reference Levels
Measure Change Between years using satellite imagery only – use carbon stocks map as starting point
Monitor Forest Emissions - measure annual change in Carbon Stocks Map
Measure Change between years using satellite imagery only use carbon stocks map as starting point
LiDAR data collected only one time
Veg Plots
+
LiDAR
+
Satellite Image
Yields
Carbon stocks map
Measured yearly from satellite images
Measured yearly from satellite images
2000
2004
2006
2010
2014
2016
2018
2020
Emissions (RL or REL)
Project Business as Usual Scenario
Additionality
Reduced emissions scenario
CO^2 (tons)
Current
2000
2006
2012
2016
2020
Year

Lidar-carbon Methods

1. Fractional method developed by Carnegie Institute, USA

2. LAMP method developed by Arbonaut Ltd., Finland

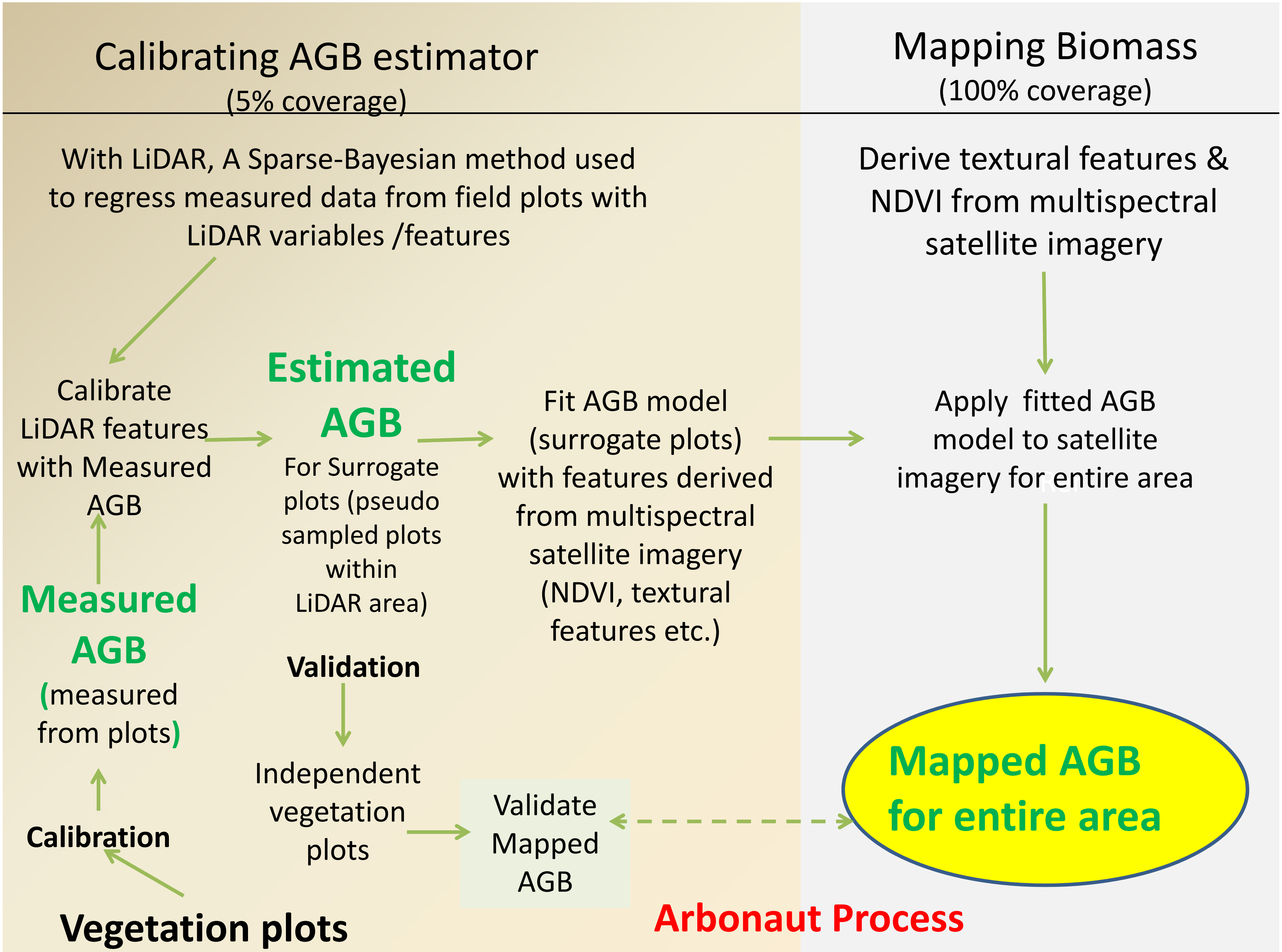
Arbonaut Method
LiDAR Assisted Multisource Program (LAMP)

LAMP Process

1. Set up random sampling plots in the LiDAR sampling blocks
2. Measure field data coincidence with LiDAR campaign
3. Develop A Sparse-Bayesian models for each forest type to predict above ground biomass
4. Choose A Best Fit Model using one-leave-out method

LAMP Process (Contd..)

5. Surrogate plots of size corresponding to that of field plots (500 m^2) were generated.
6. Lidar-based AGB estimates were calculated for each surrogate plots using forest type specific models.
7. Surrogate plots were used for modeling AGB estimates on satellite image features
8. This model is then fitted to satellite image features of the entire TAL to estimate AGB



Calibrating AGB estimator
(5% coverage)
Mapping Biomass
(100% coverage)
With LiDAR, A Sparse-Bayesian method used to regress measured data from field plots with LiDAR variables /features
Derive textural features & NDVI from multispectral satellite imagery
Calibrate LiDAR features with Measured AGB
Estimated AGB
For Surrogate plots (pseudo sampled plots within LiDAR area)
Fit AGB model (surrogate plots) with features derived from multispectral satellite imagery (NDVI, textural features etc.)
Apply fitted AGB model to satellite imagery for entire area
Measured AGB
(measured from plots)
Validation
Independent vegetation plots
Validate Mapped AGB
Mapped AGB for entire area
Calibration
Vegetation plots
Arbonaut Process

arbonaut

Model errors

Lidar model (field measured values vs. lidar estimates)

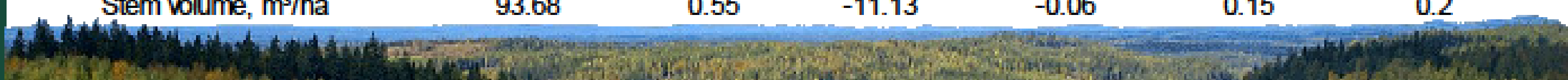
Parameter	RMSE	Relative RMSE	bias	Relative bias	Bias, p-value	R^2
AGB, tons/ha	100.42	0.50	-0.74	0	0.85	0.55
Mean DBH	10.62	0.30	0.03	0	0.93	0.62
Basal area, m2/ha	7.15	0.39	-0.04	0	0.89	0.54
Mean height, m	3.93	0.22	0.02	0	0.90	0.65
Stem count	346.44	0.53	-3.39	-0.01	0.79	0.39
Stem volume, m3/ha	79.45	0.50	-0.54	0	0.86	0.55

LAMP model (lidar estimates vs. LAMP estimates, from lidar surrogate plots)

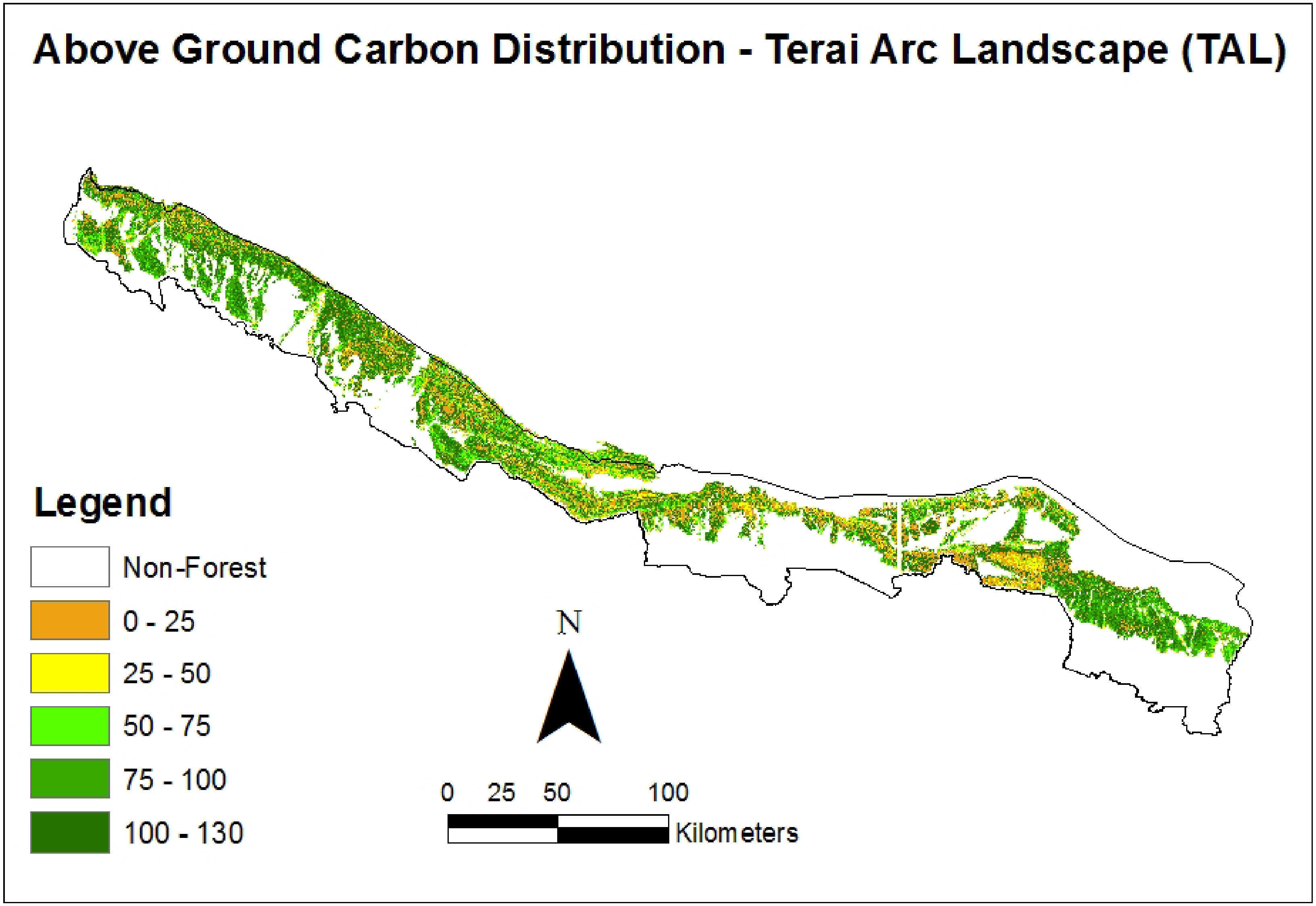
Parameter	RMSE	Relative RMSE	bias	Relative bias	Bias, p-value	R^2
AGB, tons/ha	73.58	0.40	-0.3	0	0.68	0.47
Mean DBH	9.5	0.29	0	0	0.98	0.35
Basal area, m2/ha	5.3	0.31	-0.01	0	0.80	0.52
Mean height, m	3.83	0.23	0	0	0.99	0.4
Stem count	167	0.26	0	0	1.00	0.28
Stem volume, m3/ha	58.95	0.40	-0.24	0	0.68	0.47

LAMP estimates, independent validation with FRA field plots

Parameter	RMSE	Relative RMSE	bias	Relative bias	Bias, p-value	R^2
AGB, tons/ha	115.76	0.55	-7.65	-0.04	0.43	0.22
Basal area, m^2/ha	7.48	0.41	-0.51	-0.03	0.42	0.19
Stem volume, m^3/ha	93.68	0.55	-11.13	-0.06	0.15	0.2



LAMP Process




Time for Discussions?