Theory of Remote Sensing Part-2 (No.1)

Technical Training
March 3rd - 16st, 2015

DOF/FIPD KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

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Forest Remote Sensing

CONTENTS

Ⅰ. Review of Theory of RS - Part 1

1. Introduction

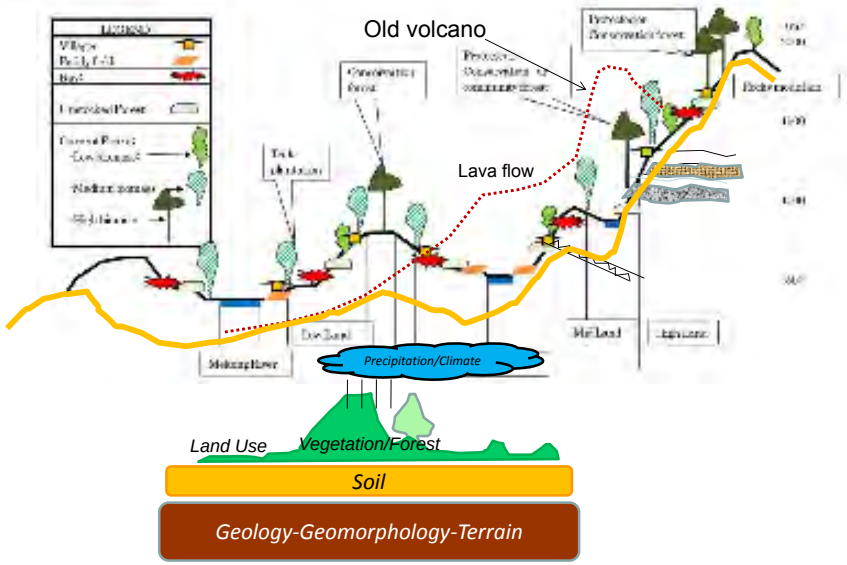
◇Remote sensing uses sensors to measure the amount of electromagnetic radiation from an object from a distance.
◇RS extracts valuable information from the data for forest monitoring and management .
◇RS needs many fundamental knowledge of sciences and technologies.

◇"Theory of Remote Sensing" aims to contribute for improving fundamental knowledge of remote sensing practices in the field of Forestry.

The Remote Sensing Process

Statement of The Problem	Data Collection	Data-to-Information Conversion	Information Presentation
◇Formulate Purpose and Result ◇Select Appropriate Logic -Inductive -Deductive -Technological ◇Select Appropriate Model -Empirical -Knowledge-based -Process-based	✚*In Situ* Measurements -Field (GPS, biomass, spectroradiometer) -Laboratory measurements ✚Collateral Data -DEM -Soil/Geology Map -Climate -etc. ✚Remote Sensing -Passive Camera, Multispectral scanner Hyperspectral sensor -Active Radar Lidar	●Visual Image Processing -Image interpretation ●Digital Image Processing -Preprocessing =Enhancement -Photogrammetric Analysis -Parametric, such as -Maximum likelihood -Nonparametric, such as -Artificial neural networks -Nonmetric, such as -Expert system -Decision-tree classification -Change detection -Modeling using GIS	◎Accuracy Assessment ◎Analog and Digital Maps - Paper maps -GIS databases -Simulation results ◎Statistics ◎Graphs

Elements of Forest Remote Sensing Survey

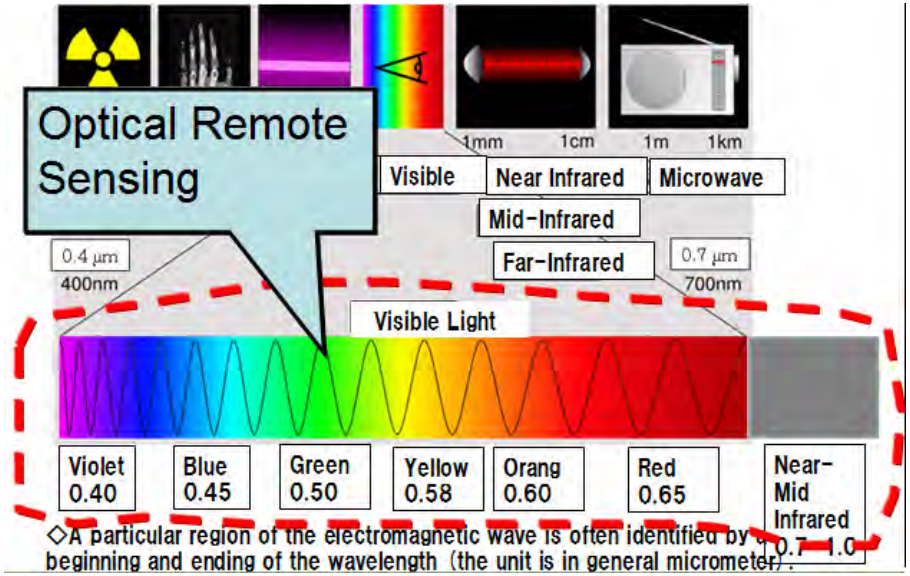


2.Radiation Physics

2. Characteristics of the Light (Sun Light) for Forest Remote Sensing

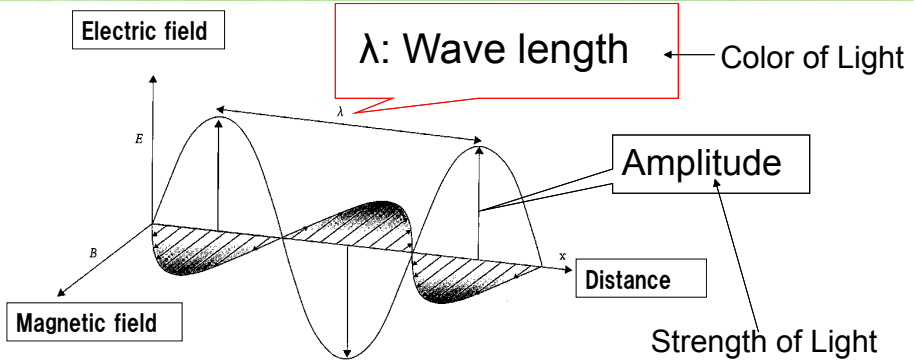
Namha National Protected Area, Oudom Xay

Electromagnetic Spectrum



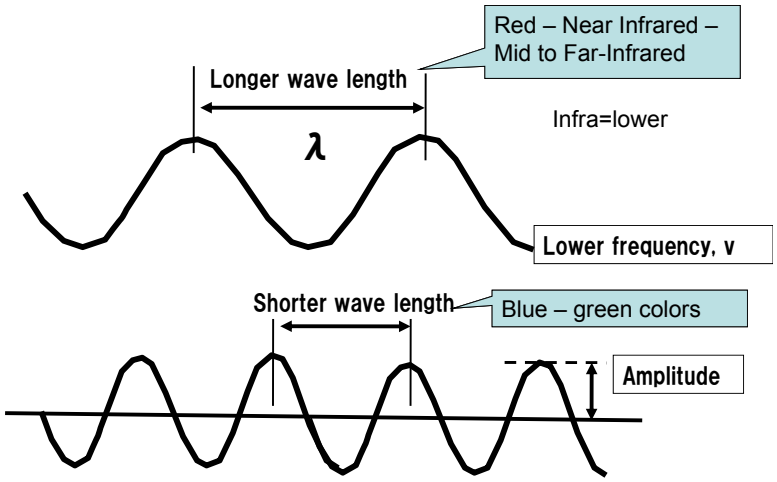
◇A particular region of the electromagnetic wave is often identified by the beginning and ending of the wavelength (the unit is in general micrometer).

Electromagnetic Radiation

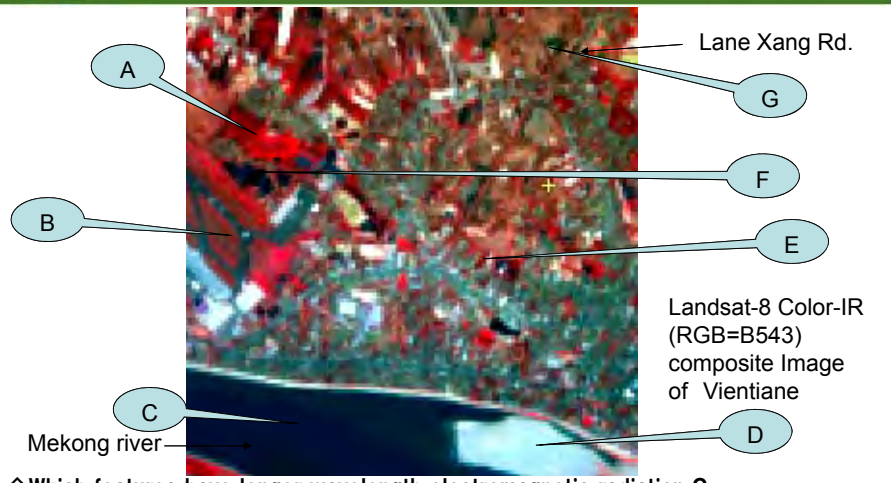


◇Electromagnetic radiation from the object is a key element of Remote Sensing.
◇Electromagnetic radiation consists of time-varying electric and magnetic fields that travel in the form of a wave at the speed of light c (3×10^8 ms^{-1}).
◇Once the wave has been formed, it will continue to travel directly from the source, and does not require a medium in which to travel.

Elecromagnetic Radiation



Elecromagnetic Radiation



Landsat-8 Color-IR (RGB=B543) composite Image of Vientiane

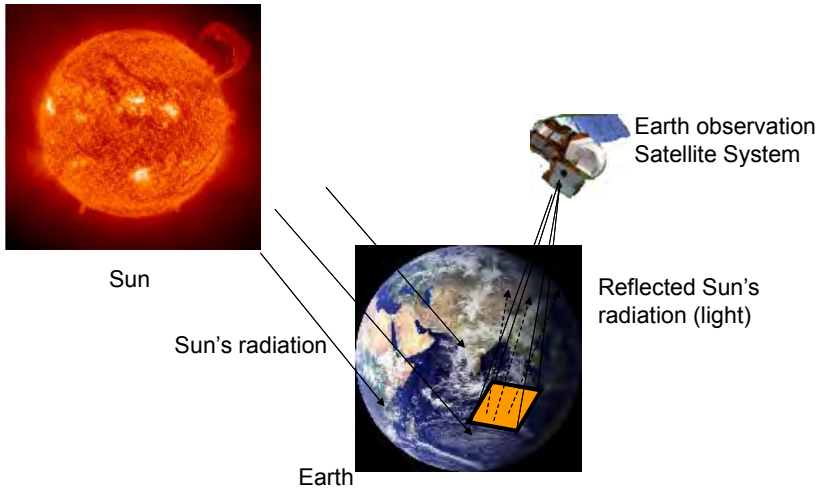
◇Which features have longer wavelength electromagnetic radiation ?

( )A ( )B ( )C ( )D ( )E ( )F ( )G

◇ Which features have higher amplitude electromagnetic radiation ?

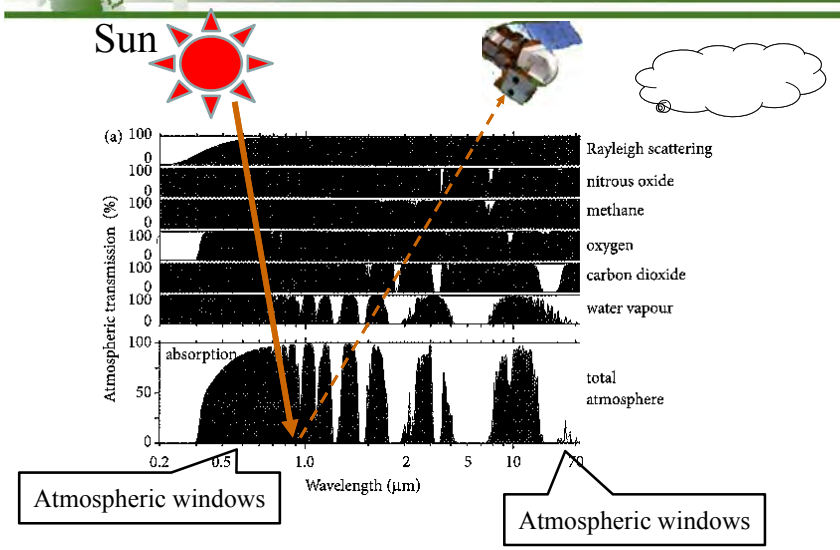
( )A ( )B ( )C ( )D ( )E ( )F ( )G

Elecromagnetic Radiation



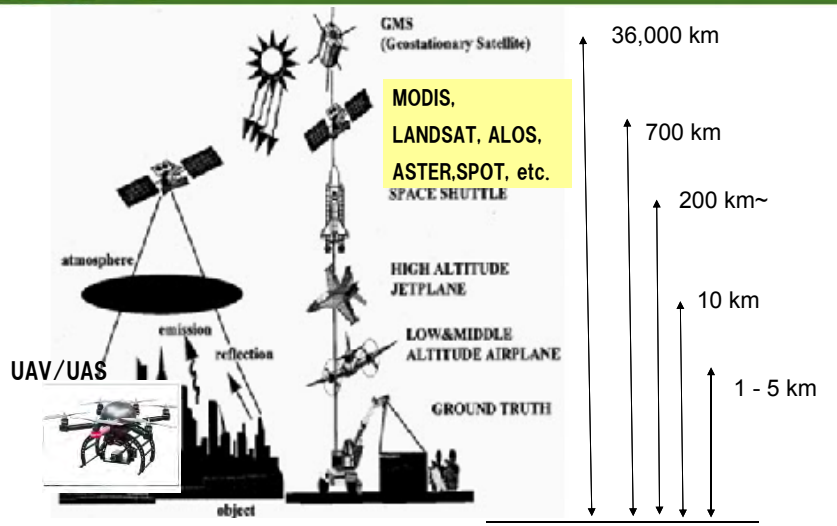
◊**The Sun's radiation is a primary source of Earth's radiation.**

Atmospheric Absorption and Transmission

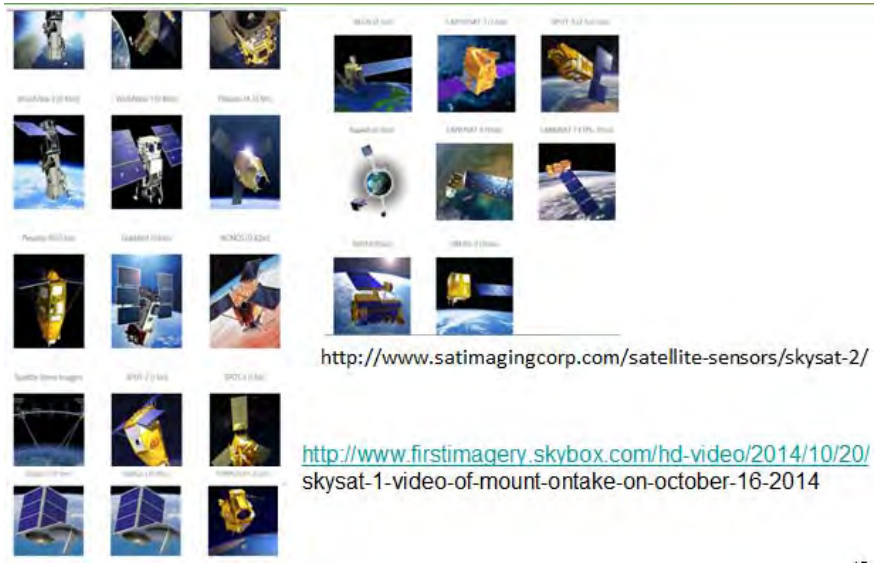


Atmospheric Transmission

3. Earth Observation Systems



(NASA: http://rst.gsfc.nasa.gov/Intro/Part2_1x.html)



http://www.satimagingcorp.com/satellite-sensors/skysat-2/

http://www.firstimagery.skybox.com/hd-video/2014/10/20/
skysat-1-video-of-mount-ontake-on-october-16-2014

http://www.firstimagery.skybox.com/hd-video/2014/10/20/
skysat-1-video-of-mount-ontake-on-october-16-2014

Remote Sensing Platforms

Classification of Remote Sensing Satellites

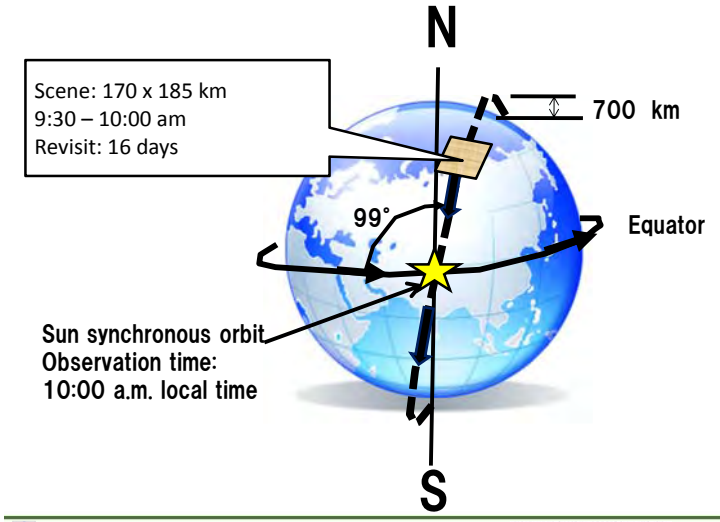
Satellite Class	Mass	Cost (US$)
Large satellite	> 1000 kg	> 20 million
Minisatellites	100 – 1000 kg	5- 20 million
Microsatellites	10 – 100 kg	2 – 5 million
Nanosatellites	1 – 10 kg	< 1 million
Picosatellites	0.1 – 1 kg	
Femtosatellites	1 – 100 g	Satellite-on-a-chip

(H.G.Jones)

Small and multi-satellites may be useful for increasing temporal resolution of remote sensing and to improve chances to obtain cloud-free optical images.

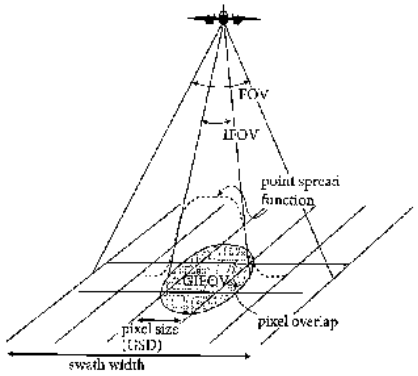
RS Observation System

[Satellite Observation System （Ex. Landsat）]



Sensor Design

◇Ground resolution (Spatial resolution)-Pixel Size
- 0.5m – 1 km



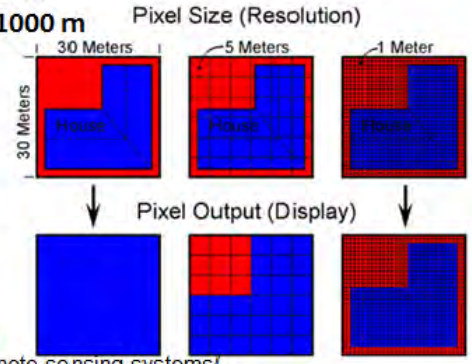
FOV: Field of View
IFOV: Instantaneous field of View
GIFOV: Ground Instantaneous Field of View
GSD: Ground Sampling Distance

Spatial Resolution

Characterization of Satellite Remote Sensing Systems

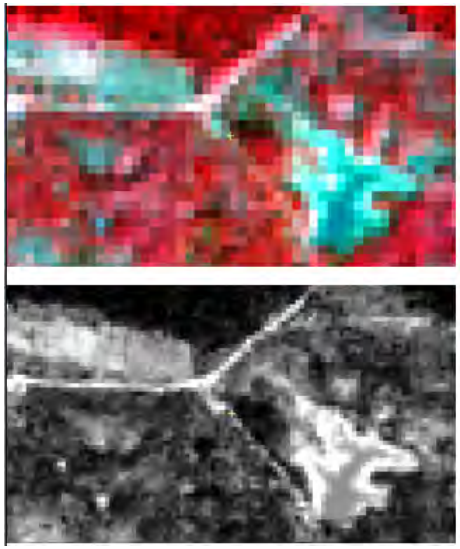
Spatial Resolution

High spatial resolution: 0.41 - 4 m
Low spatial resolution: 30 - > 1000 m



http://www.satimagingcorp.com/services/resources/characterization-of-satellite-remote-sensing-systems/

Spatial Resolutions of Multispectral and Panchromatic Sensors (Landsat-8)



Multispectral Image
Bandwidth: 0.1 micron

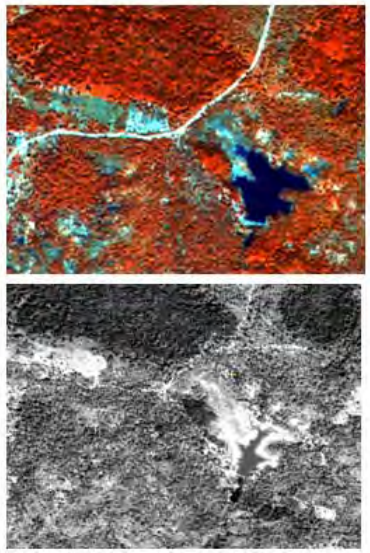
30 m

Pan-sharpen CIR Image

Panchromatic Image
Bandwidth: 0.3 micron

15

Spatial Resolution (Examples)



RapidEye

(6 m)

ALOS/PRISM-Panchromatic

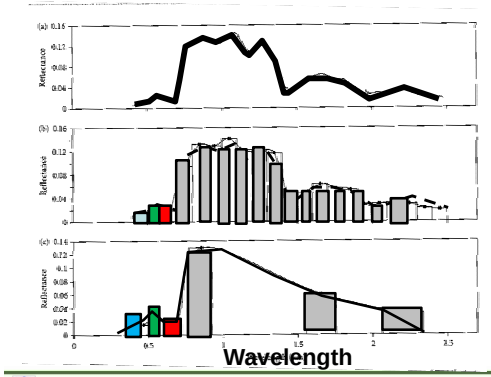
(2.5 m)

Satellite Data with Different Resolutions

Sensor resolution	Examples of present sensors	Minimum mapping units	Cost	Utilization for Monitoring
Coarse (250-1000m)	SPOT-VGT(1998-) Terra-MODIS(2000-) Envisat-MERIS (2004-)	～ 100ha ～ 10-20ha	Low or free	Consistent pan-tropical annual monitoring to identify large clearings and locate "hotspots" for further analysis with mid Resolution
Medium (10-60m)	Landsat-TM or ETM+, Terra-ASTER IRS AWiFS or LISS Ⅲ CBERS HRCCD DMC SPOT HRV	0.5 – 5 ha	Landsat and CBERS became free from 2009; Past data <$0.001/km2 Recent Data $0.02 - $0.5/km2	Primary tool to map deforestation and estimate area change.
Fine (<5m)	IKONOS Quick Bird Aerial Photos	< 0.1 ha	High or extremely high	Validation of results from analysis with coarser resolution and training of algorithm.

Sensor Design

◇ Spectral resolution
- Number of bands and spectral regions



Spectral Characteristic of Vegetation (Example)

Hyperspectral Sensor

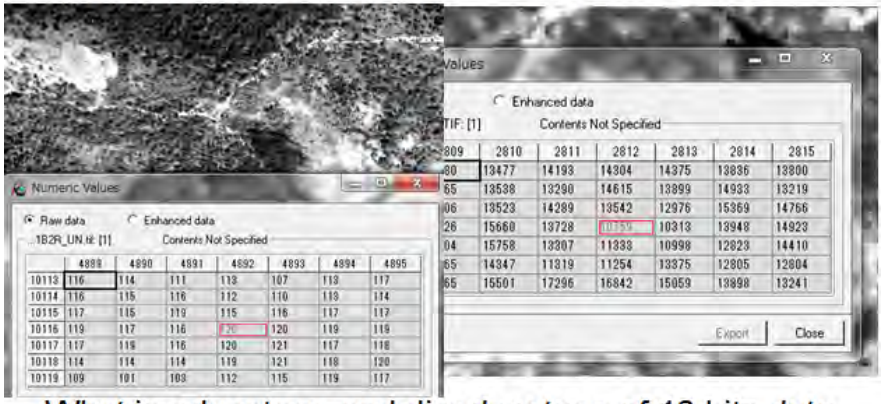
Typical Optical Sensor (Example)

Spectral Resolution

- High spectral resolution: - 220 bands
- Medium spectral resolution: 3 - 15 bands
- Low spectral resolution: - 3 bands

Sensor Design

◇Radiometric resolution - 8-bits or 16-bits



What is advantage and disadvantage of 16 bits data over 8 bits data?

Sensor Design

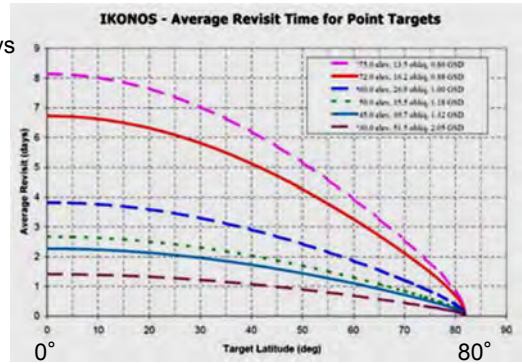
◇Temporal resolution (Re-visited time)
- 2 – 16 days

- Landsat 8: 16 days
- Rapid Eye: 6 satellites/
- Spot
- MODIS

Temporal Resolution

High temporal resolution: < 24 hours - 3 days
Medium temporal resolution: 4 - 16 days
Low temporal resolution: > 16 days

9 days

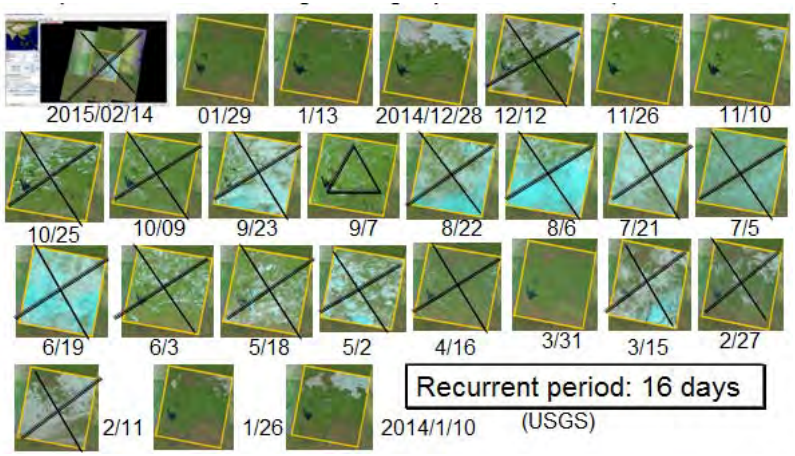


0 day

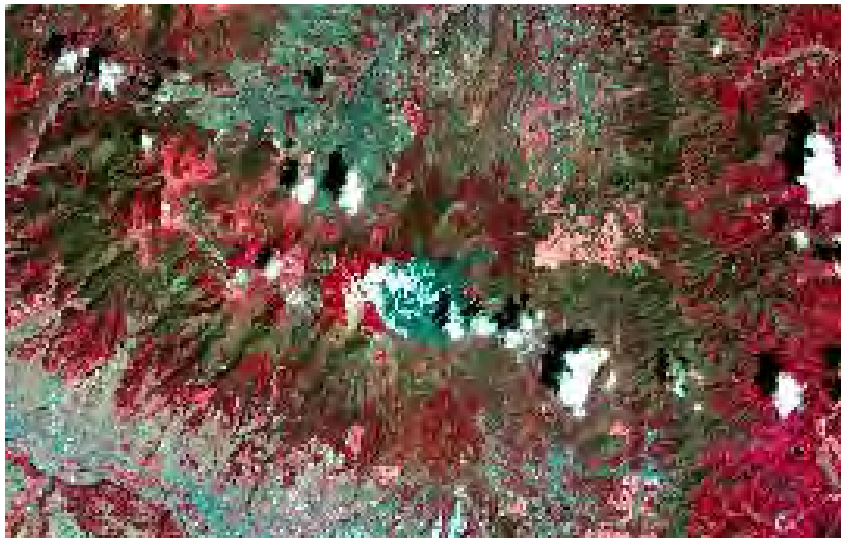
Latitude(degrees)

Actual Earth Observation Data

Landsat 8 Observation Data 2014-2015 (Difficulty to acquire cloud-free image using Optical Sensors)

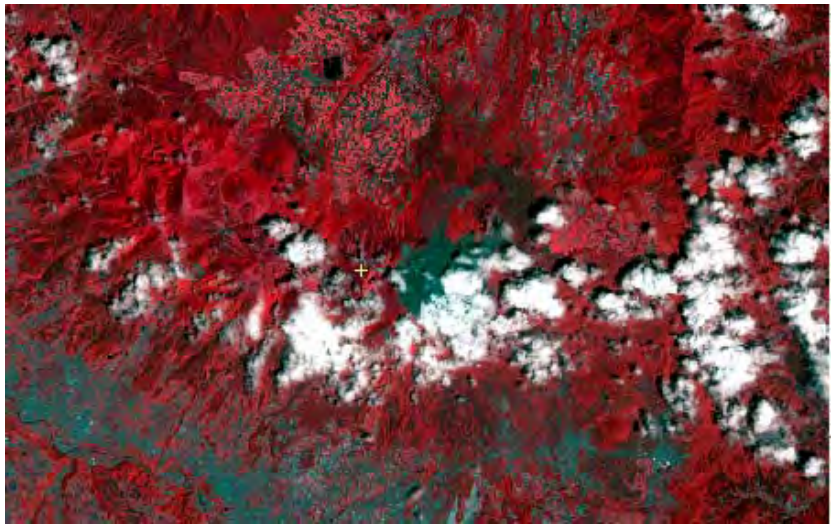


Multi-temporal Image (Spring)-Examples



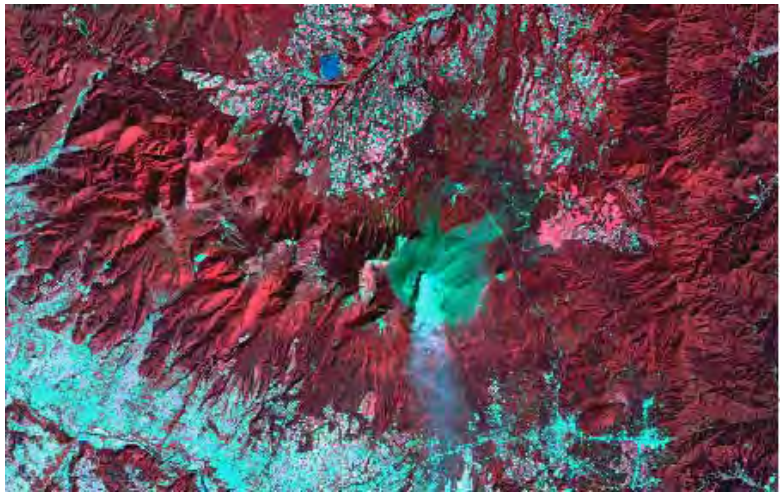
25 May, 2014 Landsat 8 Image

Multi-temporal Image (Summer)



25 July, 2014 Landsat 8 Image

Multi-temporal Image (End of Summer)

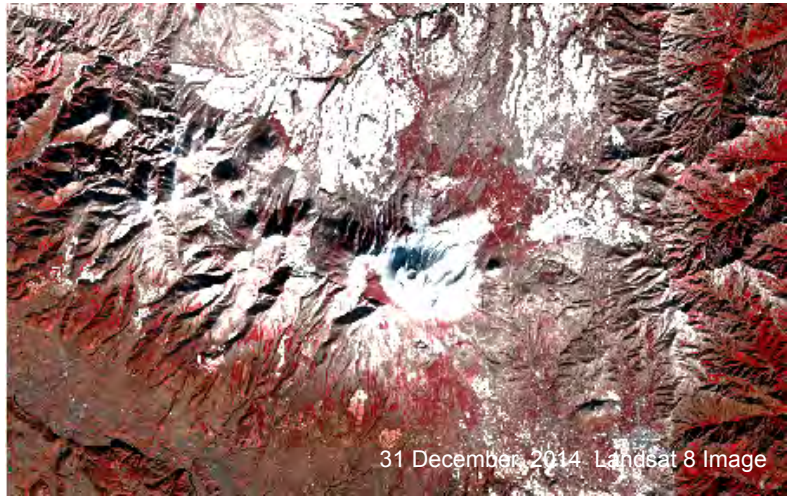


15 September, 2004 Landsat ETM+ Image

Multi-temporal Image (Autumn)

31 October, 2014 Landsat 8 Image

Multi-temporal Image (Winter)



Multi-temporal images provide a lot of information on the ground features.
However, it is not easy to acquire the good multi-temporal images in practice.

Trees in the Area----- Japan Cedar

Japan Cedar

Trees in the Area ----Larch tree

Beech

Pine trees

White birch

Silver Fir

Resolution Trade-Off

Resolution Trade-Off

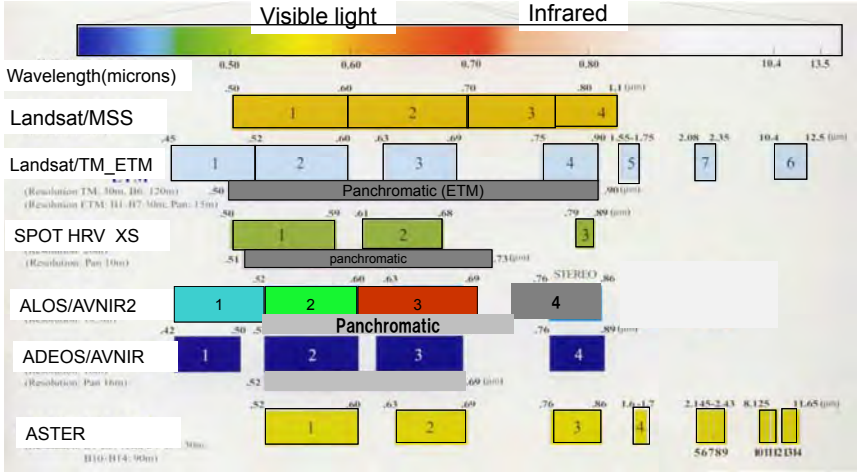
- **The different spatial, temporal and spectral resolutions are the limiting factor for the utilization of the satellite image data for different applications.**

- **A high spatial resolution is associated with a low spectral resolution and vice versa.**

- **That means that a system with a high spectral resolution can only offer a medium or low spatial resolution.**

Various Optical Passive Remote Sensors

[Sensing Spectral Bands]

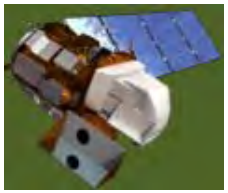


- Various spectral bands are designed in order to observe the spectral signatures (characteristics) of objects.

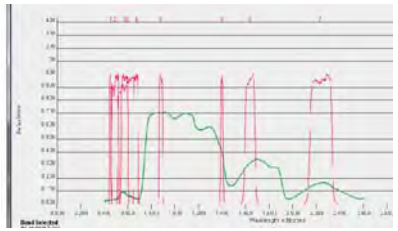
Landsat 8 OLI Sensor (Example)

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) Launched February 11, 2013	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 - Coastal aerosol	0.43 - 0.45	30
	Band 2 - Blue	0.45 - 0.51	30
	Band 3 - Green	0.53 - 0.59	30
	Band 4 - Red	0.64 - 0.67	30
	Band 5 - Near Infrared (NIR)	0.85 - 0.88	30
	Band 6 - SWIR 1	1.57 - 1.65	30
	Band 7 - SWIR 2	2.11 - 2.29	30
	Band 8 - Panchromatic	0.50 - 0.68	15
	Band 9 - Cirrus	1.36 - 1.38	30
	Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100 * (30)
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100 * (30)

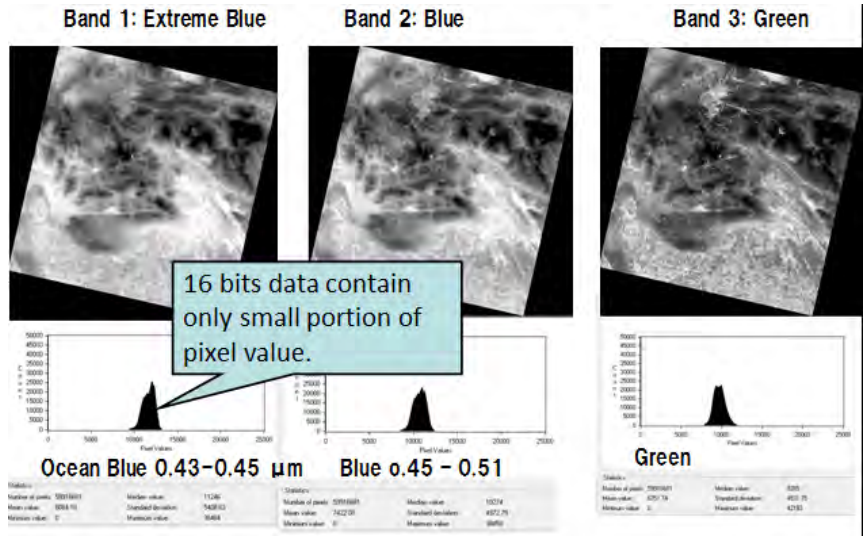
* TIRS bands are acquired at 100 meter resolution, but are resampled to 30 meter in delivered data product.



(USGS)

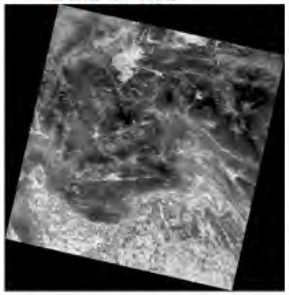


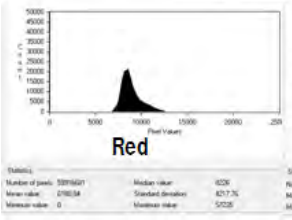
Example of RS Imagery



Example of RS Imagery

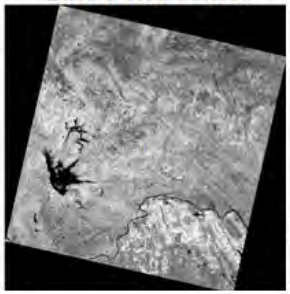
Band 4: Red

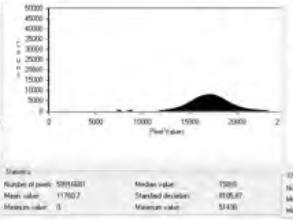




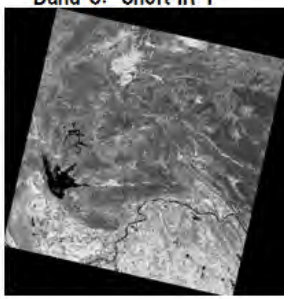
Red

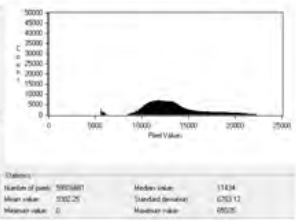
Band 5: Near Infrared





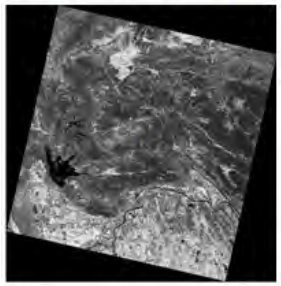
Band 6: Short IR 1

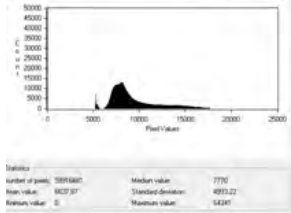




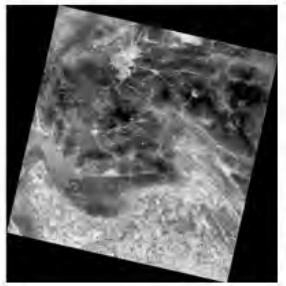
Example of RS Imagery

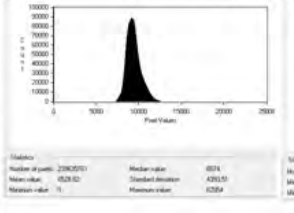
Band 7: Short IR 2



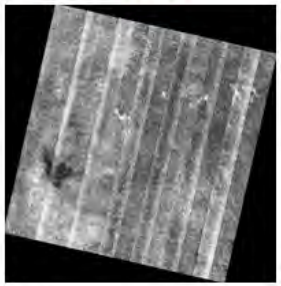


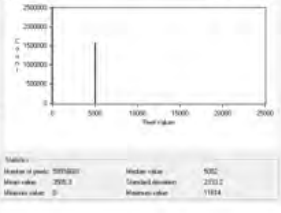
Band 8: Panchromatic





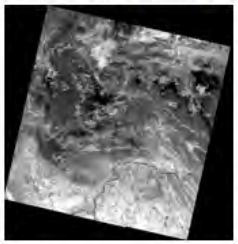
Band 9: Sceera

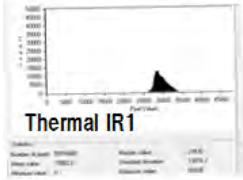




Example of RS Imagery

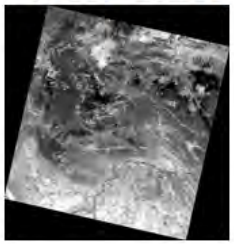
Band 10: Thermal 1

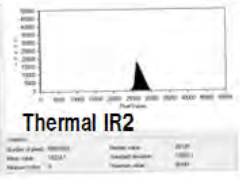




Thermal IR1

Band 11: Thermal 2



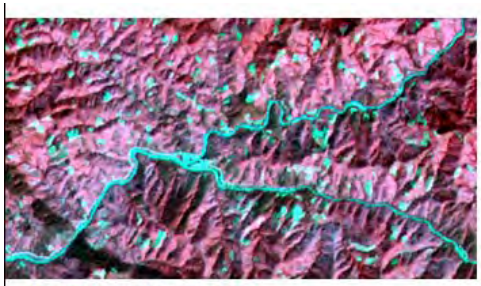


Thermal IR2

Band BQA

Quality Analysis Data

SPOT 5 Image (Example)

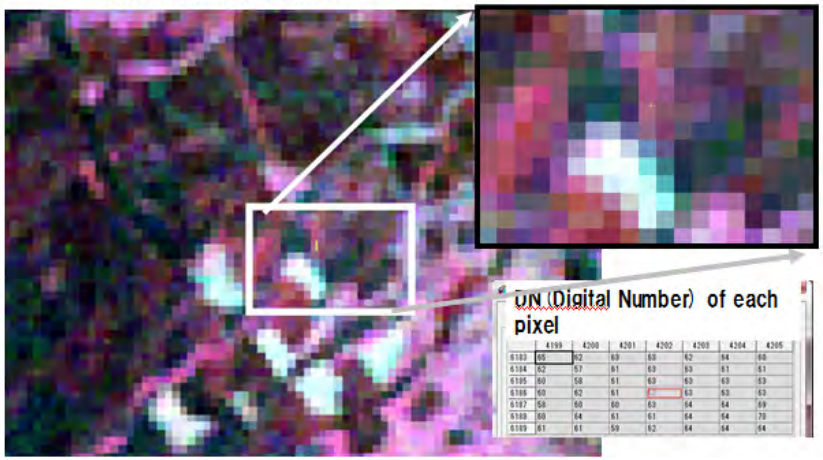


Ground resolution: 10 m

Pixel

[Picture and Pixels]

Pixel = Element of Image



Remote sensing System

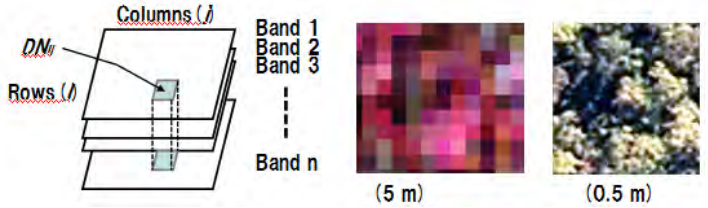
What is in a Pixel?

◇ Pixel: A two-dimensional picture element

◇Each pixel at row *(i)* and column *(j)* in the image has an original brightness value associated with a digital number (DN) value.

◇The data set may consist of *n* individual bands of multi-spectral imagery.

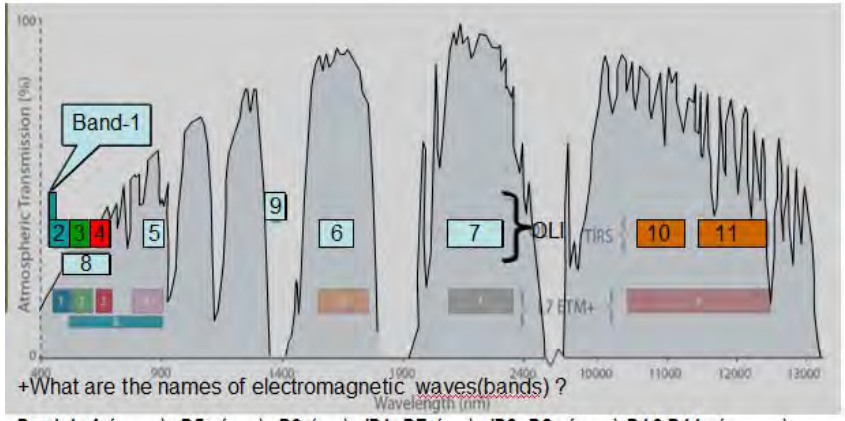
◇The *n* band are all geometrically registered to one another.



Remote Sensor's Observation Bands

LANDSAT 8 Sensors: OLI: Optical Land Imaging

TIRS: Thermal Infrared Imaging Sensor

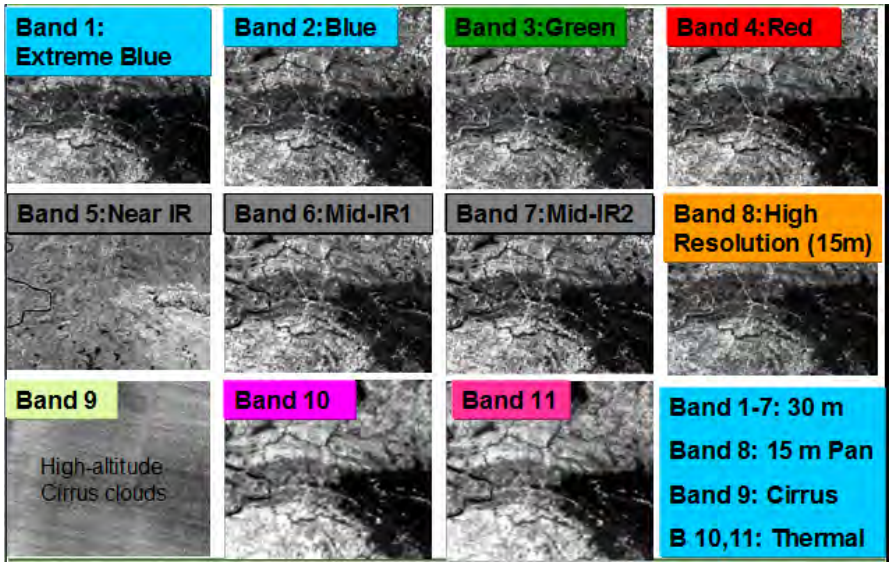


+What are the names of electromagnetic waves(bands) ?

Band 1-4: ( ), B5: ( ), B6: ( )-IR1, B7: ( )-IR2, B8: ( ), B10,B11: ( )

+Ground resolution of Band5 is ( )m. How about Band8 ? ( )m. Why it is possible?

LANDSAT 8 Sensors (Example)



(S. Savannakhet)

Spectral Bands and Their Characteristics

Landsat-8 OLI and TIRS Sensors

Band_1: 0.433－0.453μm,Extreme Blue, Detection of Atmospheric Particles, Coastal Water Mapping

B_2: 0.450－0.515μm, Blue, Coastal Water Mapping, Soil/Vegetation and Coniferous/Broad Leaf Discrimination

B_3: 0.525－0.600μm, Green, Visible Greenlight, Measurement of Reflected Light from Healthy Vegetation

B_4: 0.630－0.680μm,Red, Discrimination of Different Types of Vegetation based on Chlorophyll Absorption of Light

Landsat 8 - Bands

Landsat-8 OLI and TIRS Sensors

B_5: 0.845－0.885μm,Near-Infrared, Biomass Survey and Water Mapping

B_6: 1.560－1.660μm,Shortwave Infrared_1, Water Stress of Vegetation, Discrimination of Cloud and Snow

B_7: 2.100－2.300μm,Shortwave Infrared_2, Rock Type Classification

B_8: 0.500－0.680μm, Panchromatic, Cultural Details and Topographic Mapping

Thermal Bands

Landsat-8 OLI and TIRS Sensors

B_9: 1.360－1.390μm, Cirrus Mapping for Evaluating Atmospheric Effect

B_10: 10.300－11.300μm, Thermal Infrared_1,Earth's Surface Temperature Mapping, Water Stress of Vegetation, Soil Moisture Mapping

B_11: 11.500－12.500μm, Thermal Infrared_2, Infrared_1, Surface Temperature Mapping, Water Stress of Vegetation, Soil Moisture Mapping

** Bands 2 – 8 can be used for Forest Mapping.*

Terrain and Landform Interpretation

4. Terrain and Landform Interpretation

- A landform is defined as a certain arrangement and configuration of surficial materials to produce characteristic land features.
- Topography, tone, drainage pattern, gully erosion, vegetation or land use and boundary characteristics are the photo interpretation features used to interpret landforms.

Topography

❶Topography

Topography feature gives an indication of how the material got to its present location, and/or the resistance of the material to erosion:

- flat topography is usually formed by the deposition of materials in still water;
- hilly topography indicates bedrock control;

The first item to look at on RS image is the topography.

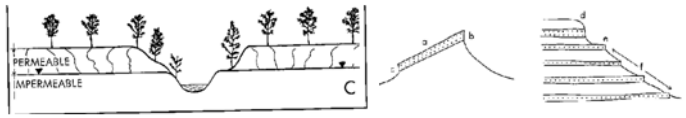


Photo tone of landform

❷Photo Tone of Landform

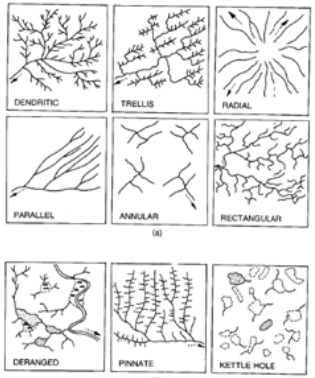
- This feature gives an impression of soil moisture:
- A light tone indicates dry soil which is usually coarse textured.
- A medium tone indicates a moist soil.
- A dull, monotonous tone indicates a wet soil which is usually fine textured. However, the hot dry weather can air-dry the silty and clay soils, thus making them highly reflective. Such air-dry soils can appear very light to whitish on RS image.
- A uniform tone indicates a uniform soil condition.
- A mottled tone (e.g. light and dark) indicates a variable soil condition.

Drainage Patterns

❸Drainage Patterns

Drainage patterns give an indication of parent material, and/or bedrock control.

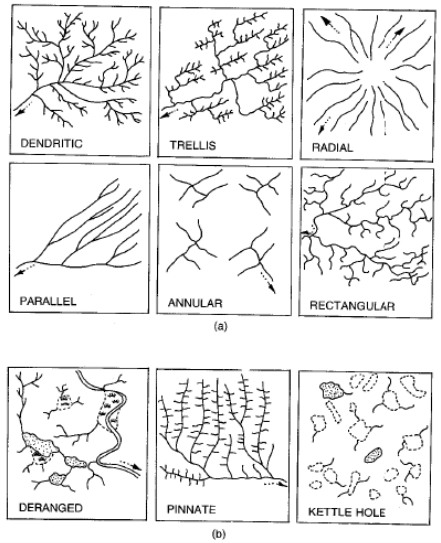
- ***Dendritic*** drainage patterns indicate fine textured parent material such as till and lacustrine silts or clay.
- ***Parallel*** drainage patterns indicate gently sloping topography, usually because of bedrock control.



Drainage Patterns

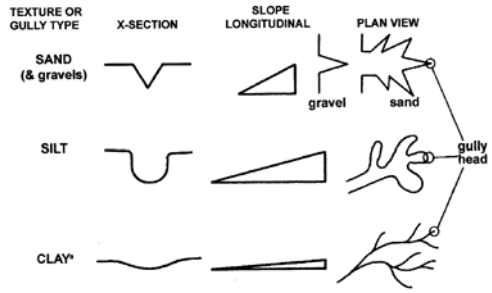
❸Drainage Patterns (2)

- ***Trellis*** patterns, with short parallel and long parallel patterns joining in a central river, indicate tilted, interbedded, sedimentary bedrock.
- ***Radial :*** Seen on cone-like hills such as volcanoes.
- ***Rectangular***: flat lying, jointed, sedimentary bedrock



❹Gully Erosion

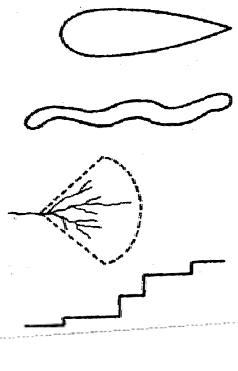
Gully erosion analysis gives another clue to soil texture. To analyse gully features look at the head of the gully, the place where water would start to flow. Gully patterns are best described in terms of the peaks of the soil texture triangle, i.e. and, silt, and clay.

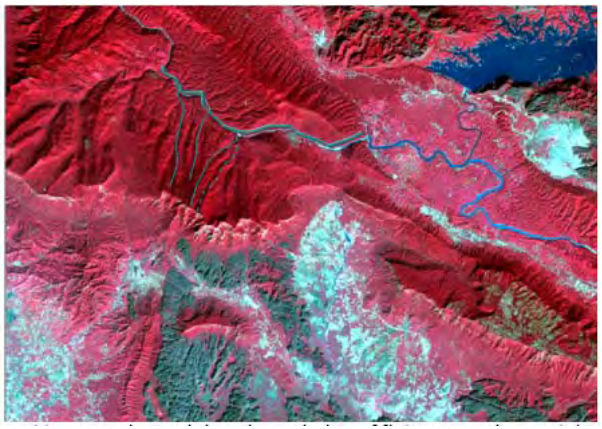


❺Boundary Characteristic

This is the outline of the landform as seen on a RS image showing landform characteristic of the area.

LANDFORM	OUTLINE
DRUMLIN	bullet - shape
ESKER	snake - like
ALLUVIAL FAN	fan - like
TERRACE	stepped





1. Interpret topography and draw boundaries of flat area and mountainous terrain.
2. Interpret and draw drainage pattern.
3. Interpret and draw boundaries of land cover/forest types.
4. How these factors are correlated ?

Results of a Field Survey at the Phou Khao Khouay National Park

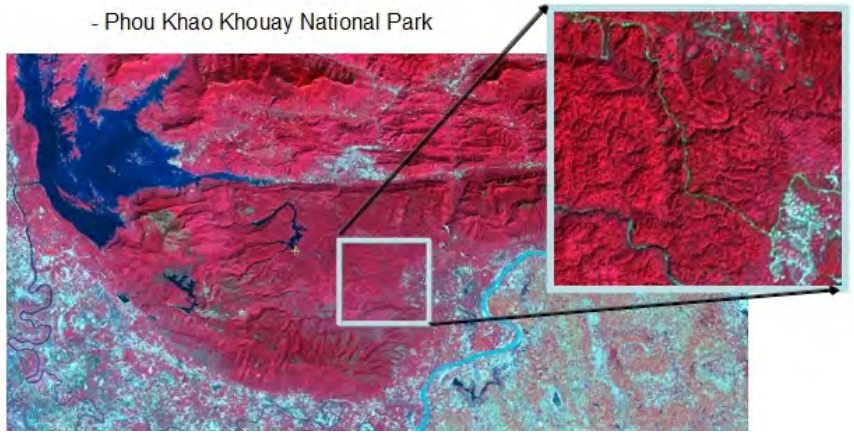
March 7, 2015

DOF/FIPD KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

Mitsuru NASU, Ph.D.
Forest Remote Sensing

Location

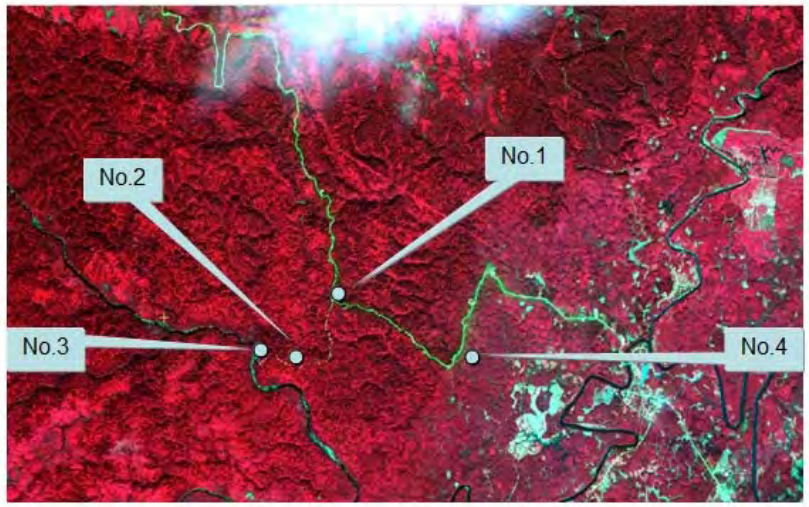
1. Location of the Survey Area



(Landsat-8 acquired on 29 January, 2015)

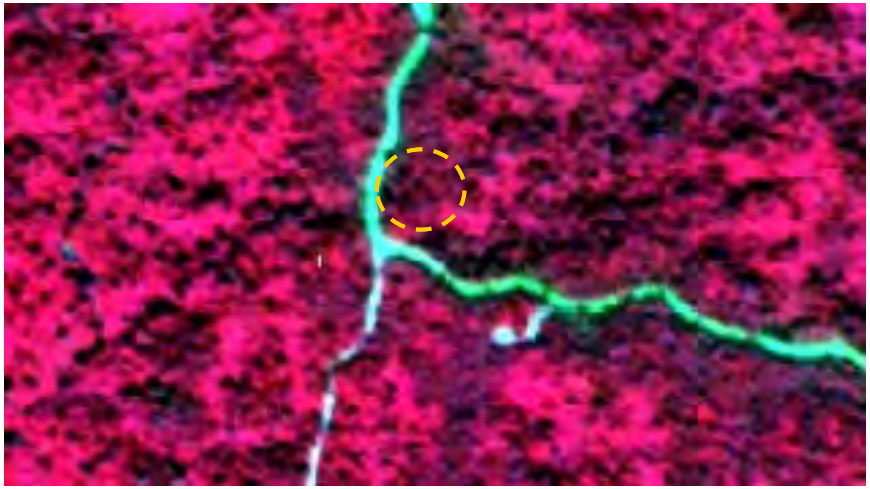
Topographic Map

Survey Plots on RaidEye Image



RapidEye Image (RGB=Band532)

No.1 Survey point



RapidEye Imagery (RGB=Band532)

No.1 Survey Point

No.1 Survey Point

No.1 Survey Point

No.1 Survey Point

Trees in dense bamboo.

No.1 Survey Point

Understory is covered by dense bamboo (height: 5 m)

No.1 Survey Point

+ Surface soil contains silt.

No.1 Survey Point

+ In bamboo forest (height is about 5 m).

No.1 Survey Point

Remaining logging evidence

No.1 Survey Point

No.1 Survey Point

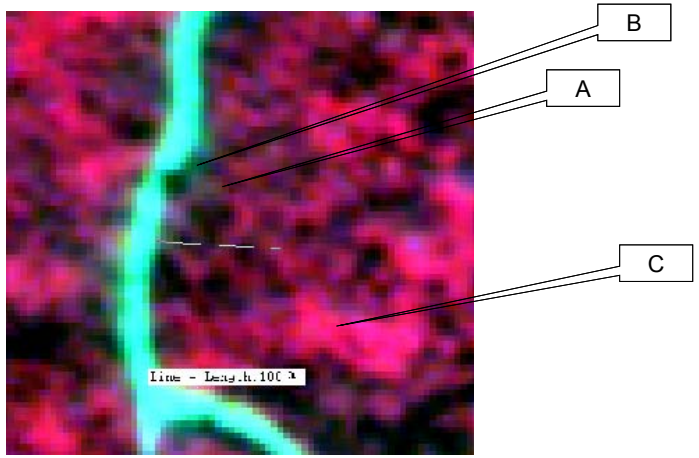
Some trees in the DD family forest.
Height: 25 m (highest), DBH: 40 – 45 cm

No.1 Survey Point

No.1 Survey Point

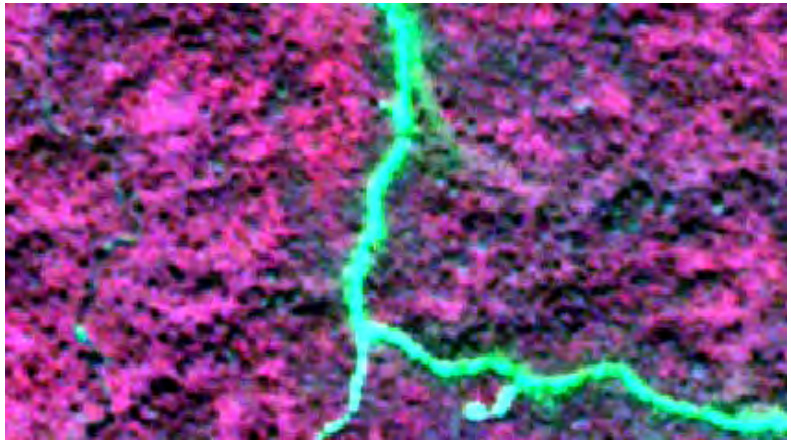
Area of No.1 Survey Point

No.1 Survey Point



What are A, B, C features on the image ? Why ?
Draw crown boundaries on the imagery.

No.1 Survey Point

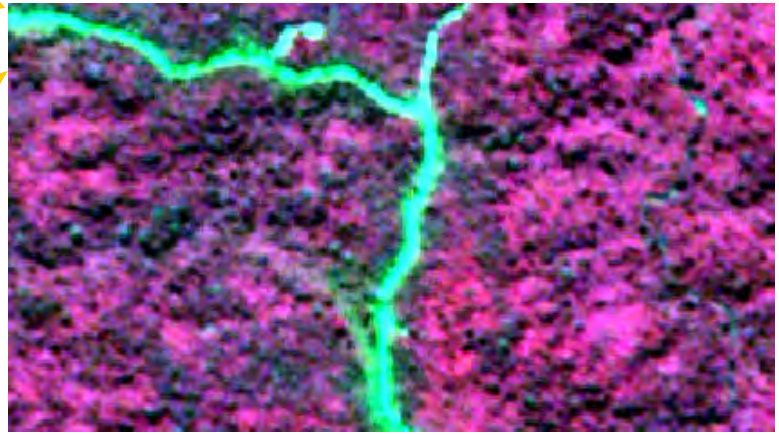


RapidEye(RGB=B532)

Interpret trees and other features in the forest.

180° Rotated Image for Shadow Effect

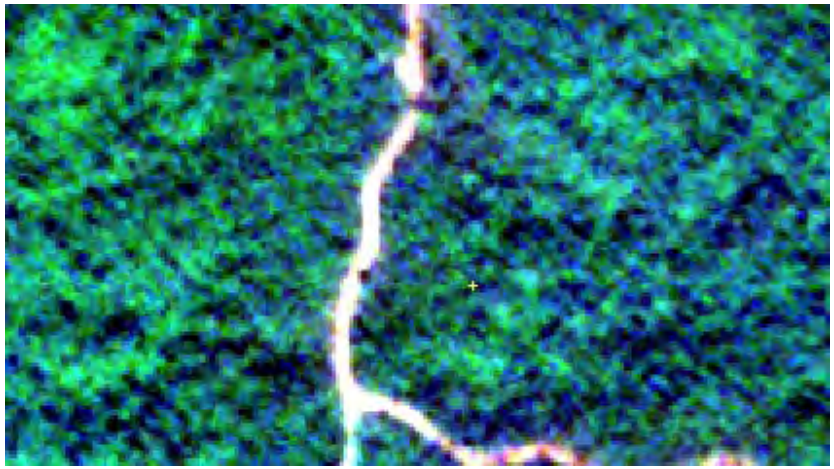
Sun



+Shadow effect sometimes helps to improve 3D effect.

N

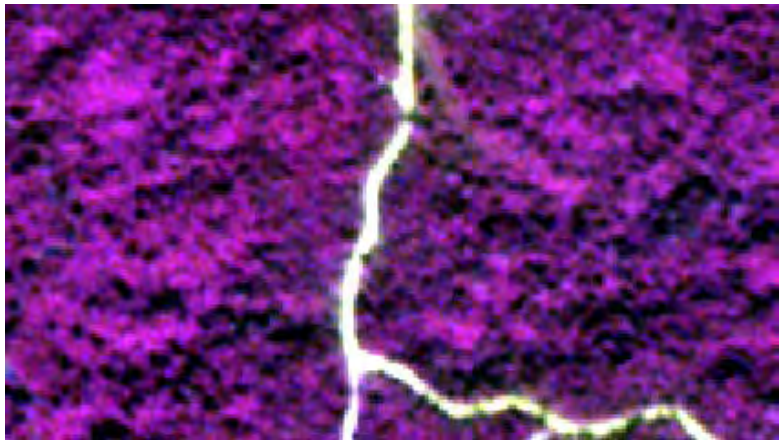
No.1 Survey Point



RapidEye(RGB=B321)

Try to find the composite image the most useful for forest survey.

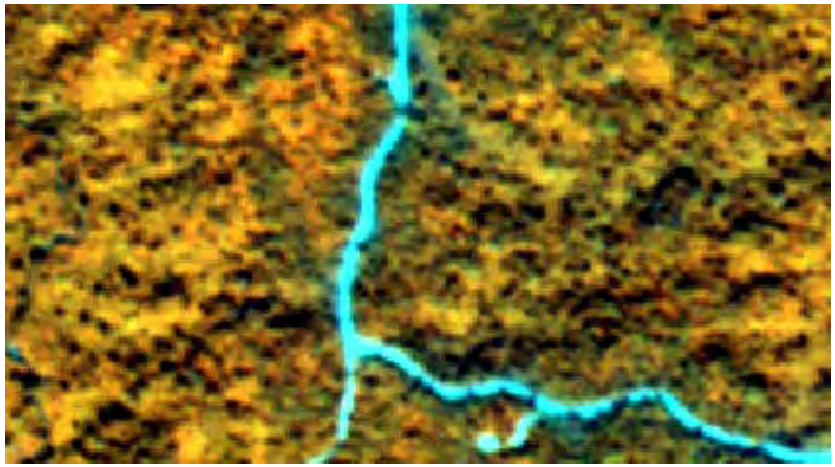
No.1 Survey Point



RapidEye(RGB=B432)

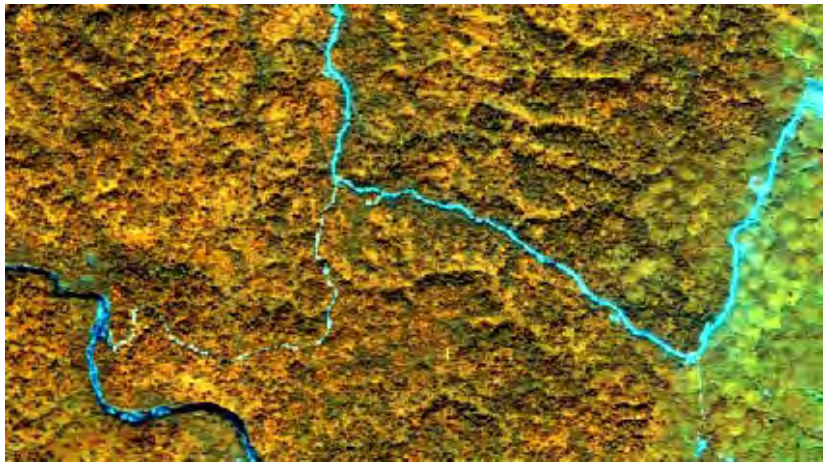
Composite image with RGB=B432 combination.

No.1 Survey Point



Composite image with RGB=B543 combination. RapidEye(RGB=B543)
Bamboo and shadows are more discernible !?

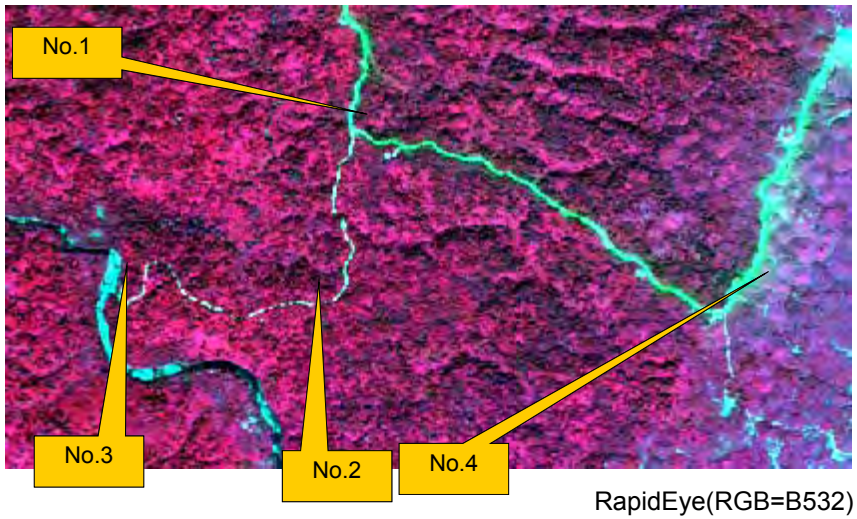
No.1,2,3 Survey Point



(Wider view)

RapidEye(RGB=B543)

No.1,2,3,4 Survey Points



RapidEye(RGB=B532)

RGB=B532 is still the best combination !?

Field Photos (No.2 Survey Point)

No.2 Survey Point

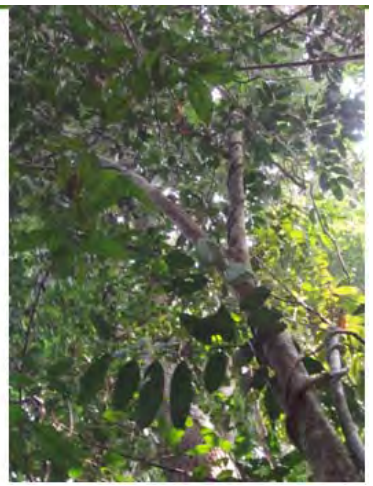
No.2 Survey Point

No.2 Survey Point

No.2 Survey Point

Some sandstone Rocks

No.2 Survey point



More trees in the forest.
DBH: 70 cm, Tree Height: 25 – 30 m

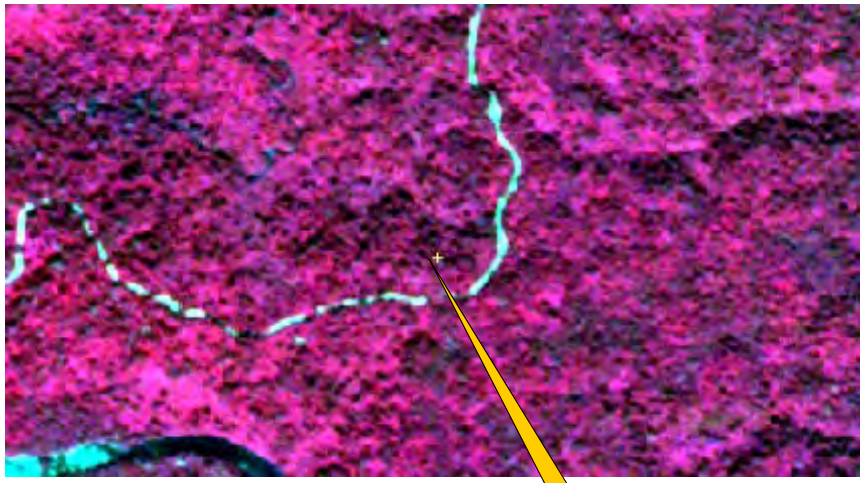
No.2 Survey points

Lantern

No.2 Survey Point

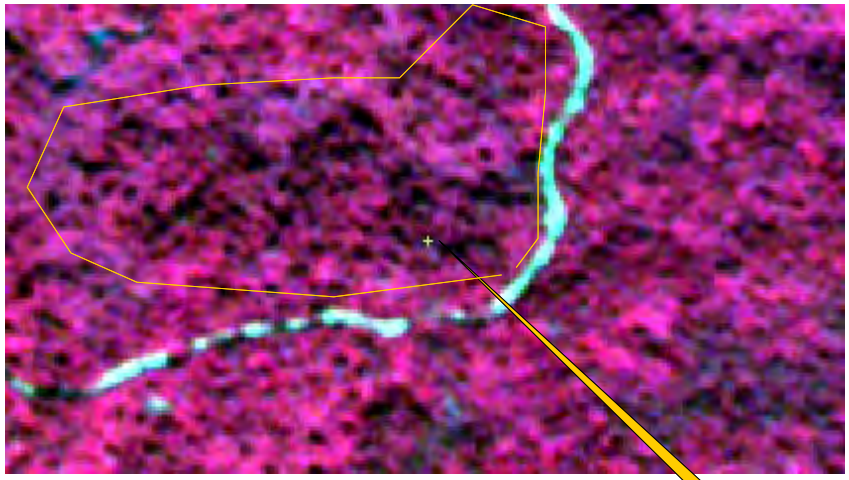
No,2 Survey Point

No.2 Survey Point



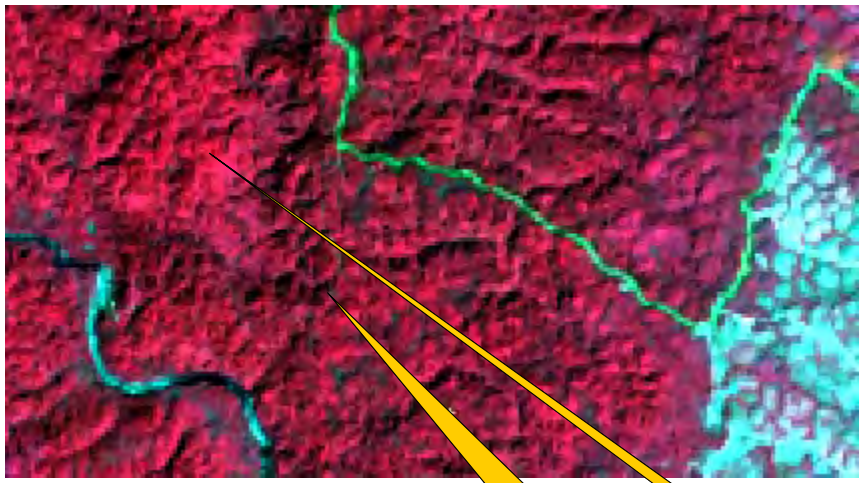
RapidEye=B532)

No.2 Survey Point



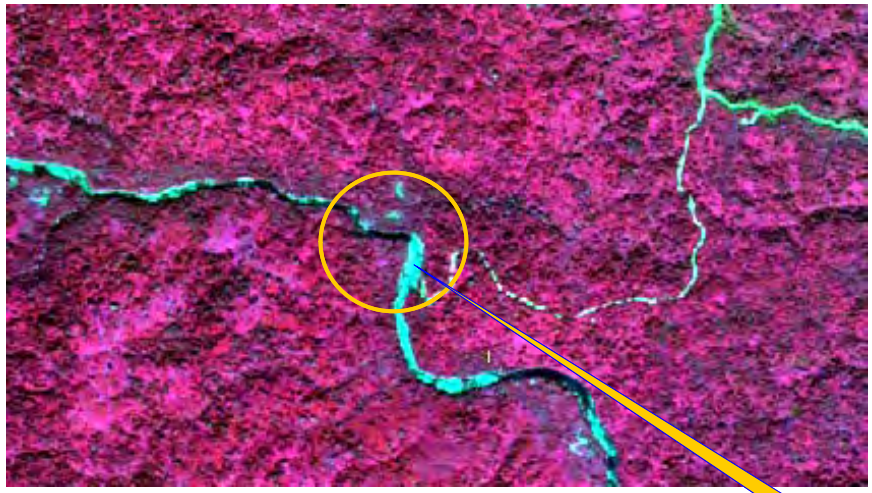
Why area A is darker than other areas ?

Comparison with Landsat-8 Imagery



Why area A is lighter ?
Find the slope direction.

No.3 Survey Point



No.3 Survey Point near river and camping area.

No.3 Survey Point

No.3 Survey Point

No.3 Survey Point

No. 3 point area

No. 3 point area

No.3 Survey Point

No.3 Survey Point

Around No.3 Survey Point

Direction of Up-stream

Up-stream (North) direction

Around No.3 Survey Point

West-ward

Around No.3 Survey Point

Photo taken toward down-stream of the river

No.3 Survey Point

East-ward

No.3 Survey Point

Near No.3 Survey Point

West-direction

Fall

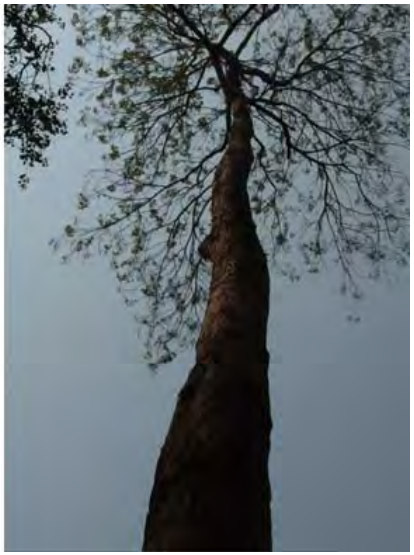
Around No.3 Survey Point

Inter-bedded Sandstone Rock

Geology

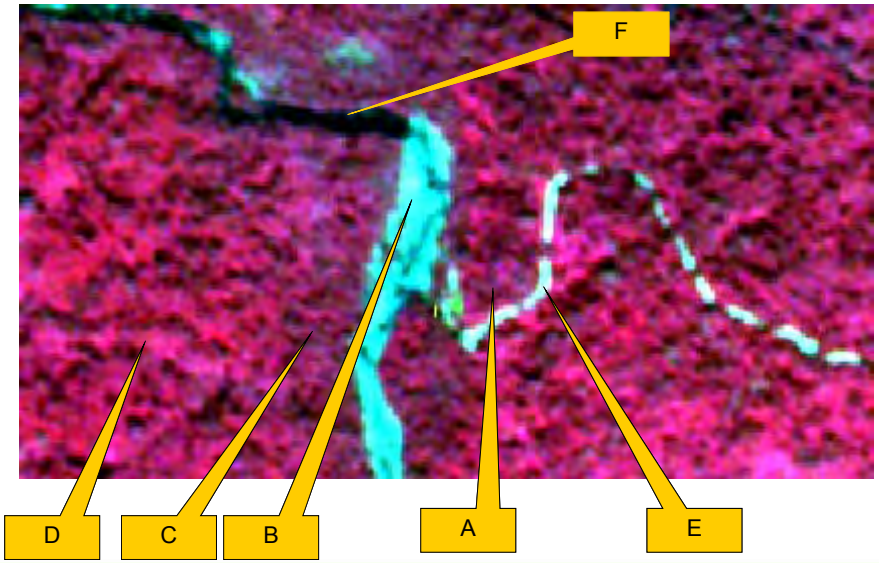
Geology

Trees (No.3 Survey Point)

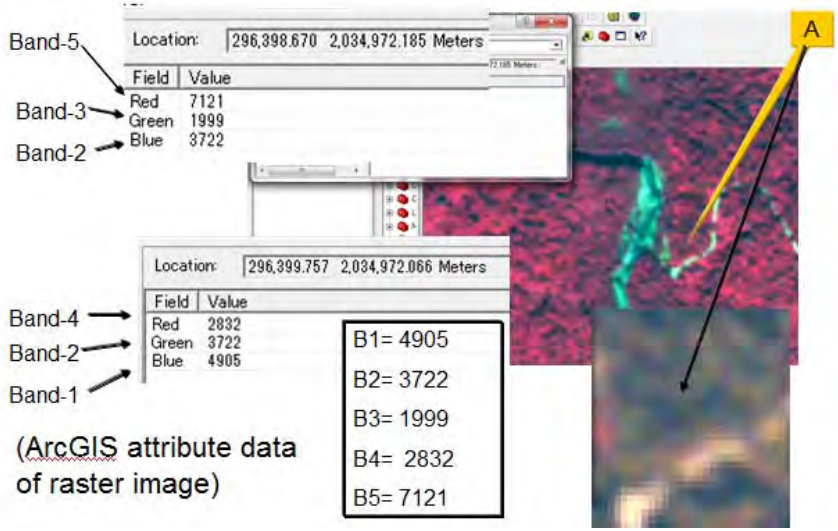


Trees (No.3 Survey Point)

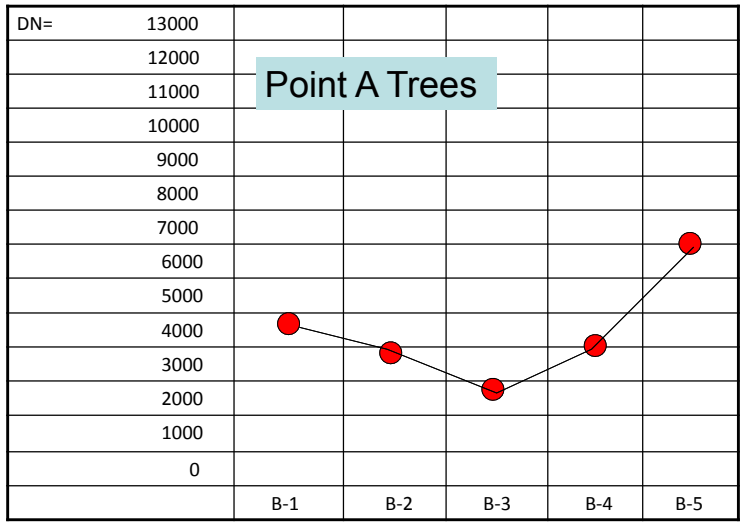
Spectral Characteristic Analysis of A – F



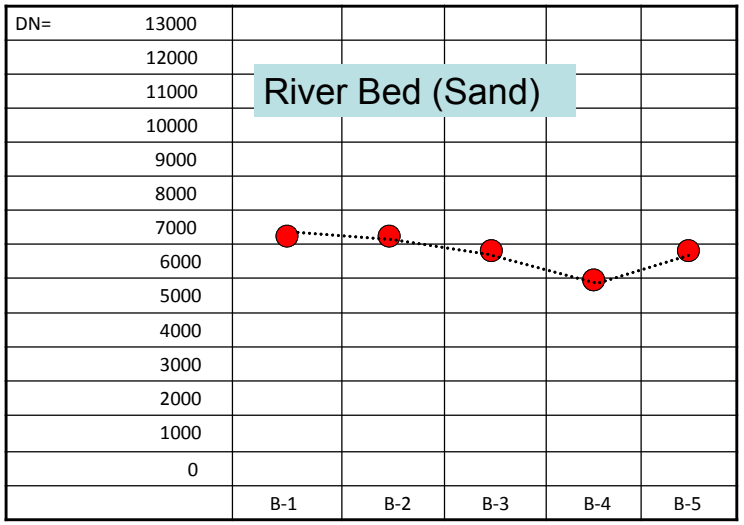
Spectral Data (DN) of Feature A



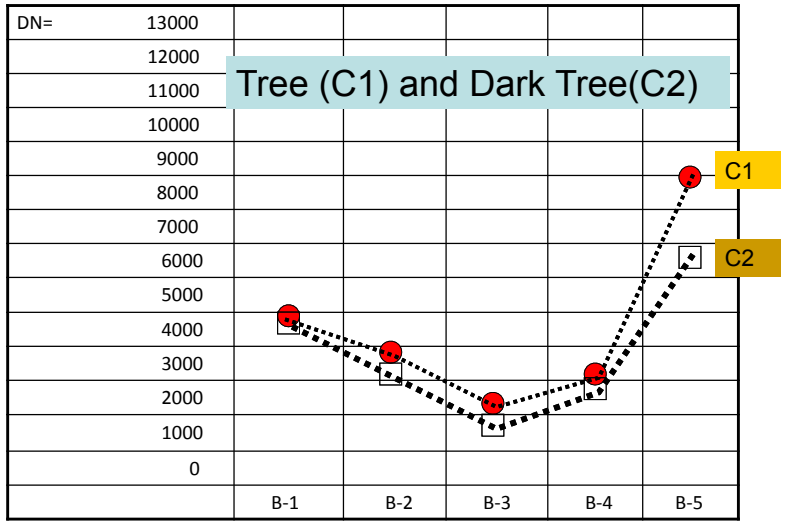
Spectral Data (DN) of Feature A



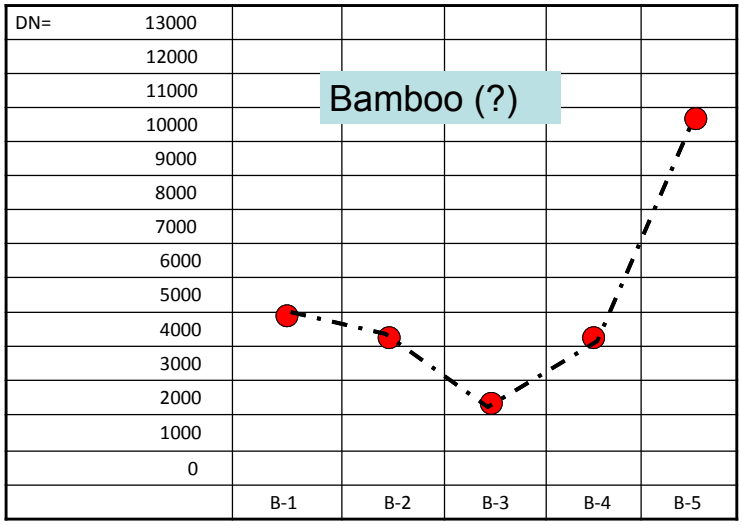
Spectral Data (DN) of Feature B



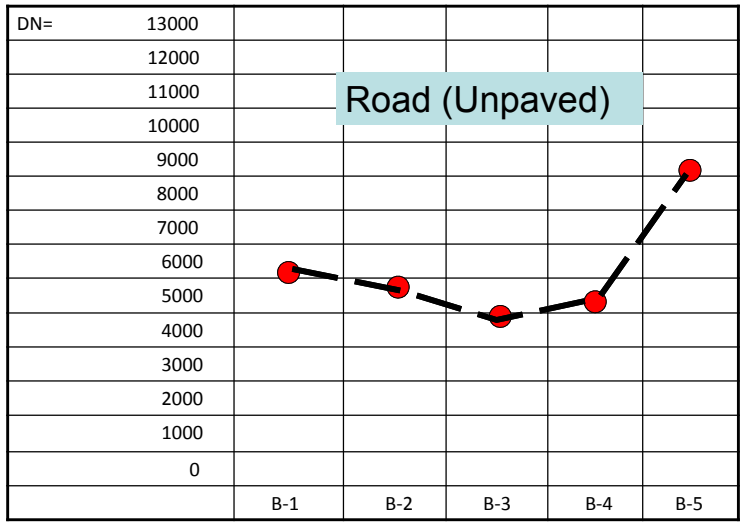
Spectral Data (DN) of Feature C1 & C2



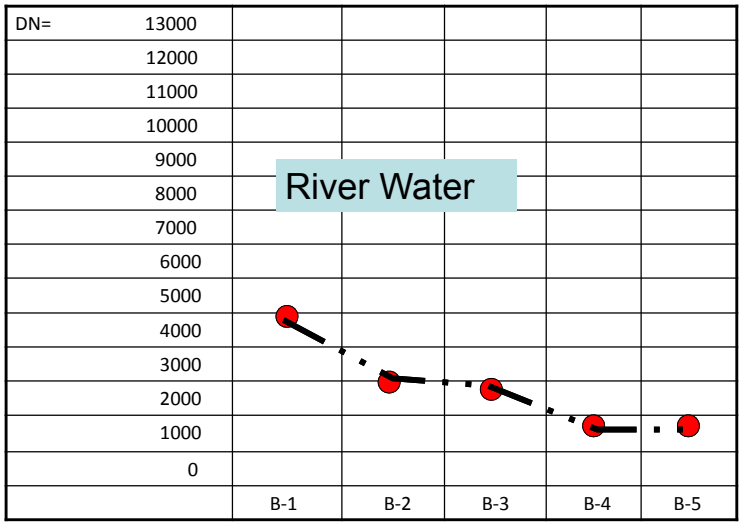
Spectral Data (DN) of Feature D



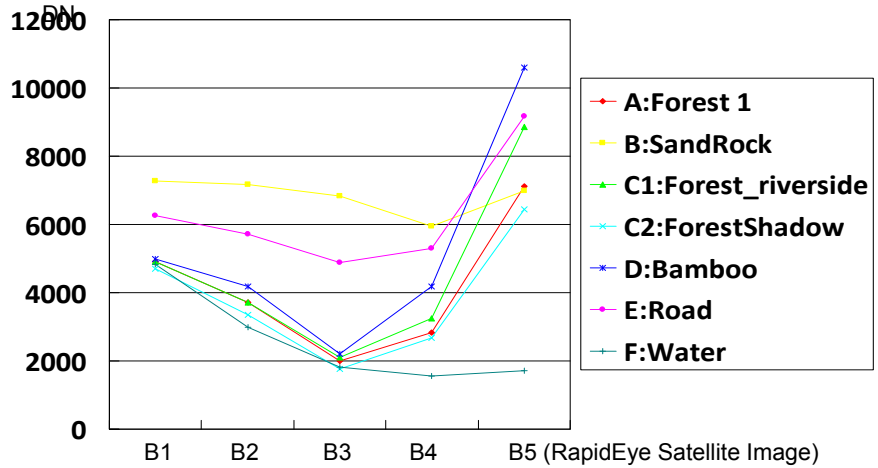
Spectral Data (DN) of Feature E



Spectral Data (DN) of Feature F



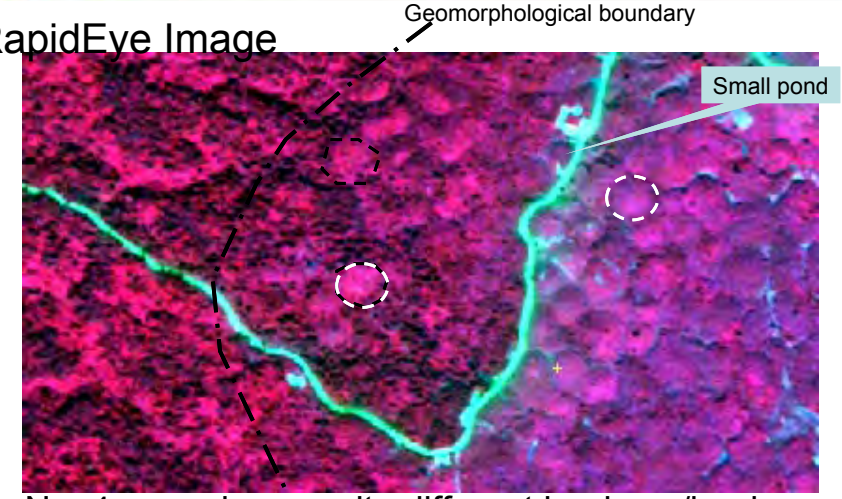
Spectral Characteristics of Features



+ Bamboo shows high reflectance. + Forest 1, Forest_riverside, and its ForestShadow show similar shape of curves. + High DN values in B1(blue band) shows high effect of the atmospheric noise. (Path radiance)

No.4 Survey point

RapidEye Image



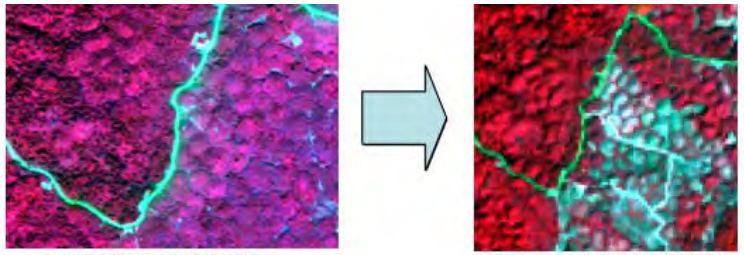
No. 4 area shows quite different land use/land cover and colors.

No.4 Survey Point

No.4 Survey point

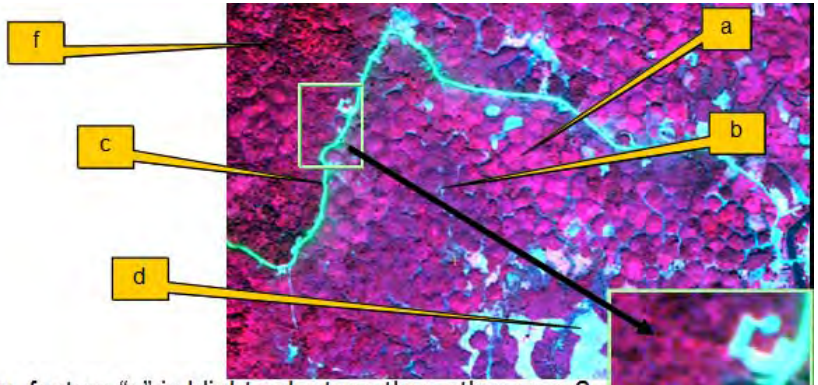
+Topography with many small hills covered by the silt soil
+Possibly, flood plain or lakebed sediments in geological age

Changing Land Use and Land Cover



+ Now, converted to rubber plantation

Photo Interpretation Keys

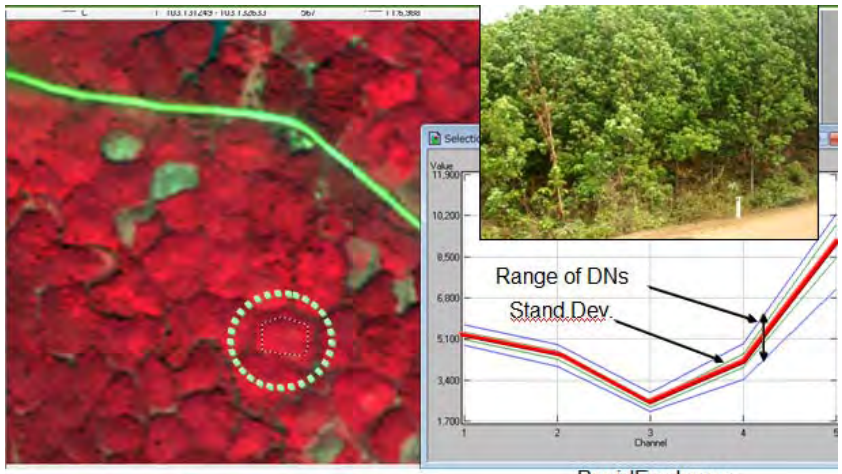


+ Why feature “a” is blight color tone than other area ?
+ Why “b” is darker tone with some texture ?
+ Why road “c” is so bluish white and sometimes curved
+ Why area “d” is white ?
+ What is dark tone feature “e” ?

No.4 Survey Point Area

No.4 Survey Point Area

Spectral Data (DN) of Feature “a”

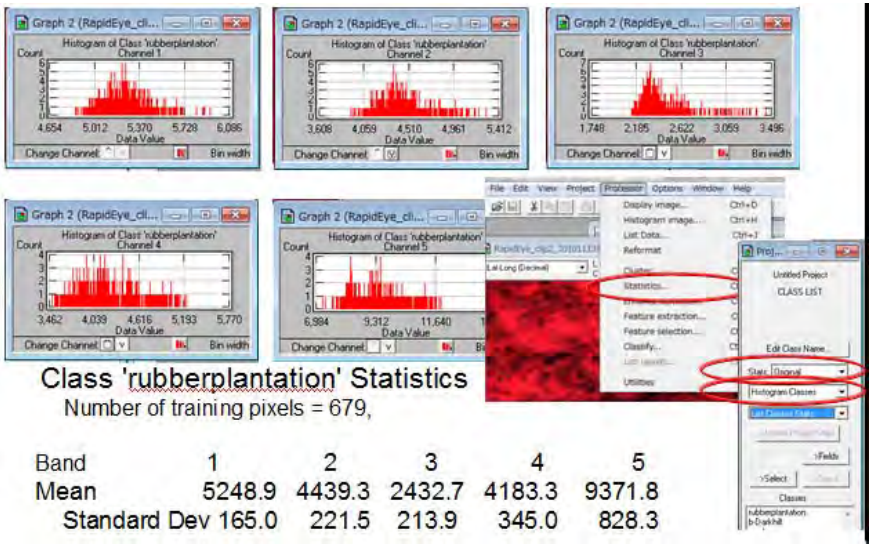


Rubber Plantation (?)

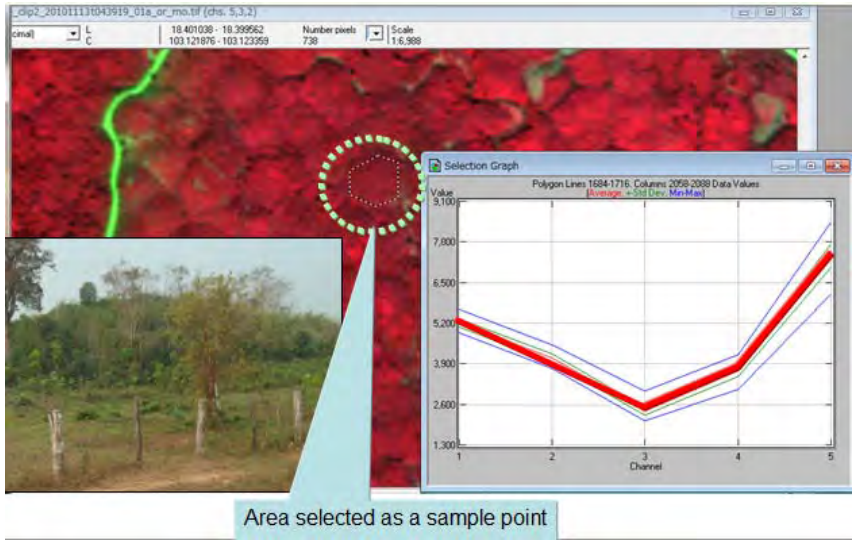
RapidEye Image

(Output from MultiSpec software)

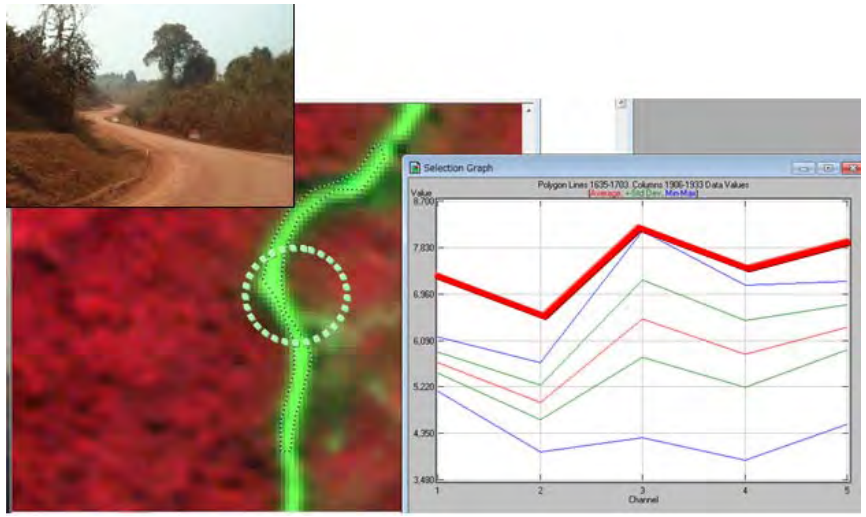
Variations of DN Values for Different Bands



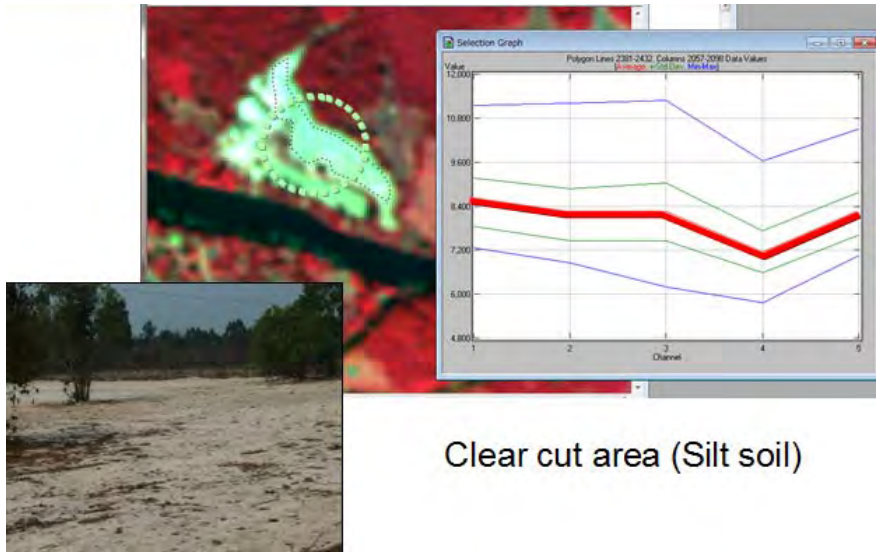
Spectral Data (DN) of Feature “b”



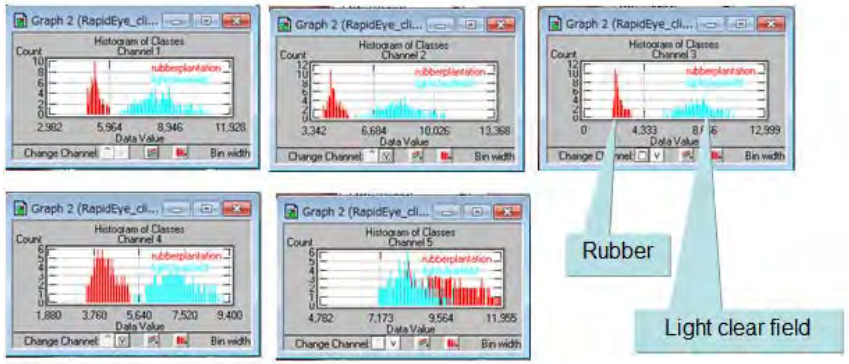
Spectral Data (DN) of Feature “c”



Spectral Data (DN) of Feature “d”



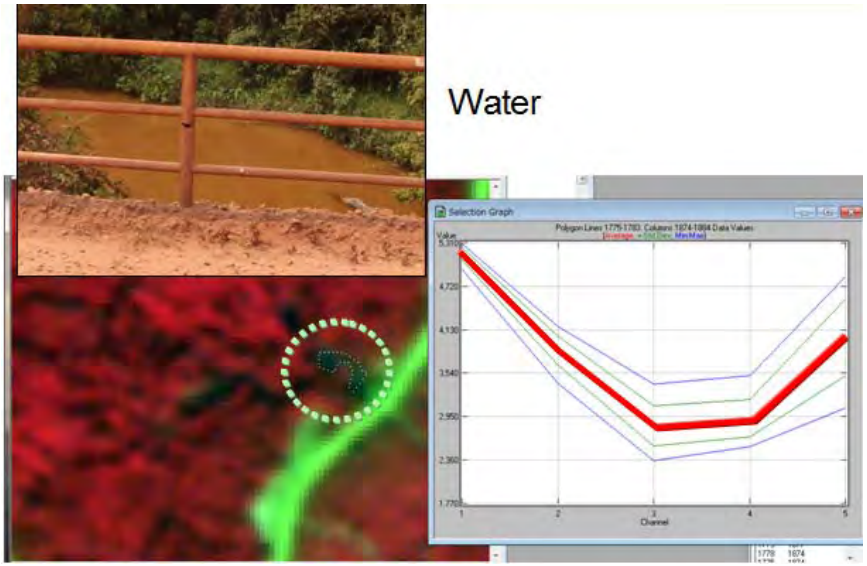
Histogram of “d”



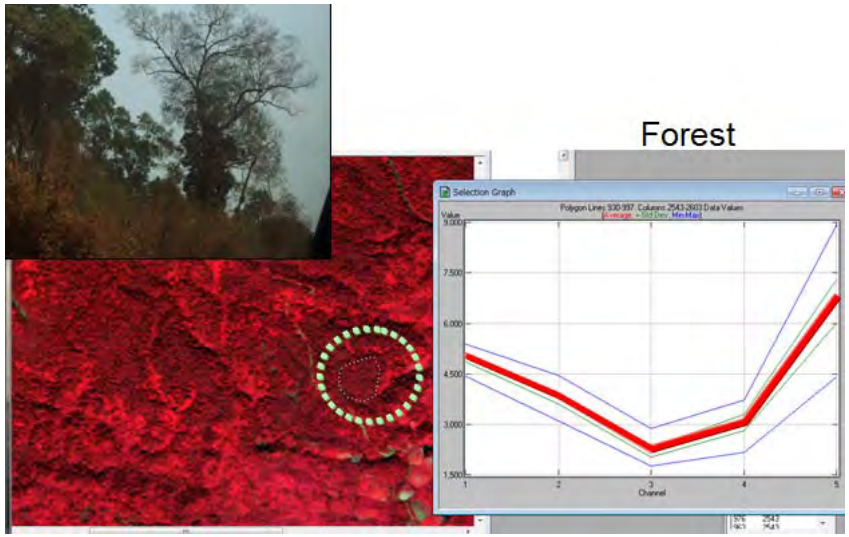
Class 'lightclearfield' Statistics
Number of training pixels = 500,

Channel	1	2	3	4	5
Mean	8401.8	8083.8	8162.2	7118.1	8187.8
Standard Dev	669.8	695.3	778.2	538.7	533.8

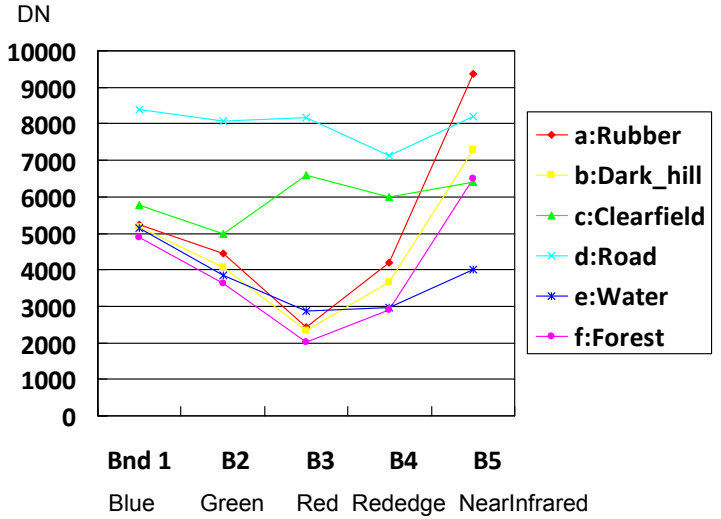
Spectral Data (DN) of Feature “e”



Spectral Data (DN) of Feature “f”



RapidEye Spectral Characteristics Curves



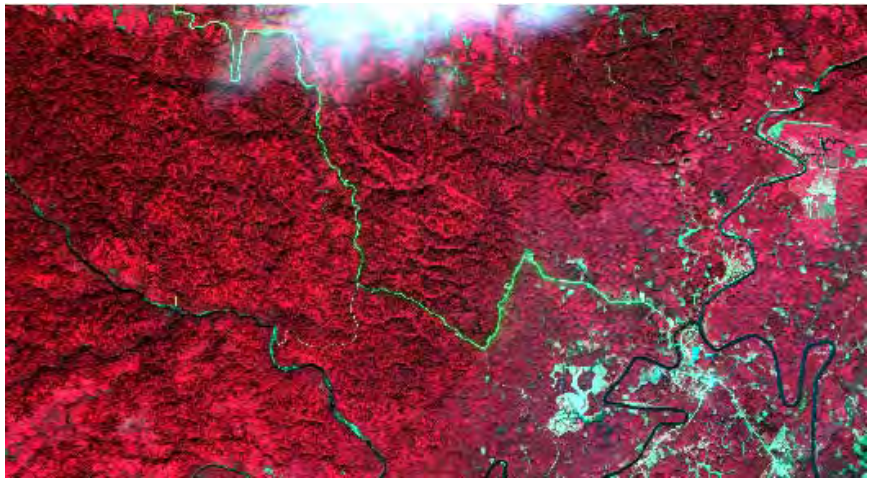


Photo interpret topography and land use/land cover of whole area of this scene.

Drainage Pattern

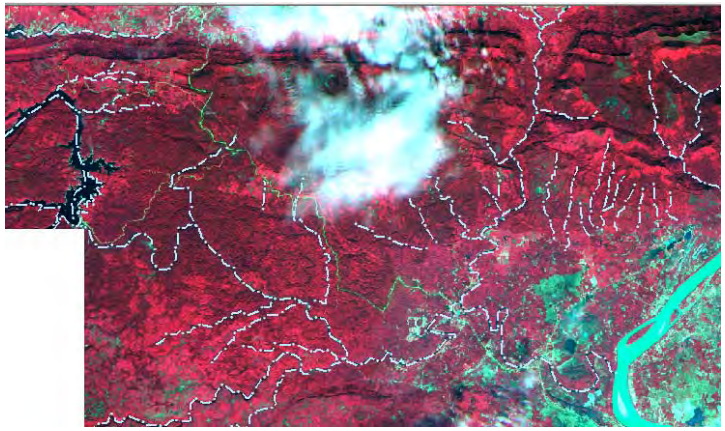


Photo interpret topography and land use/land cover of whole area of this scene.

Results of the Field Survey

- What kinds of information we did we get by the field survey ?

1)
2)
3)
4)
5)

Analyses of Multitemporal Remote Sensing Imageries

- Case Study at South Savannakhet Production Forest -

March 11, 2015

DOF/FIPD KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

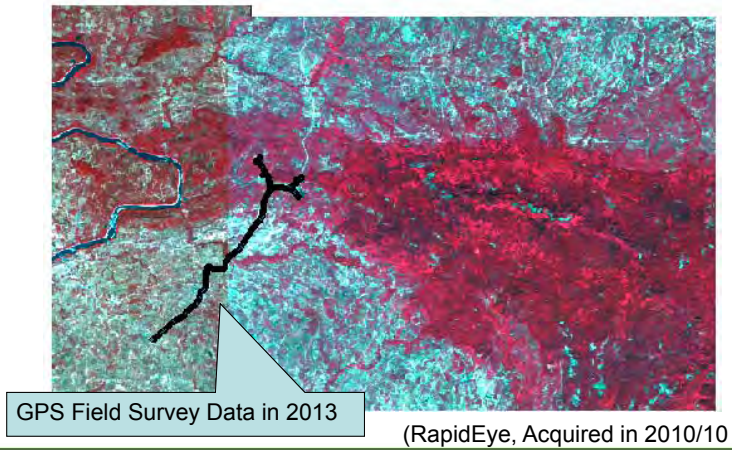
Mitsuru NASU, Ph.D.

Forest Remote Sensing

Location

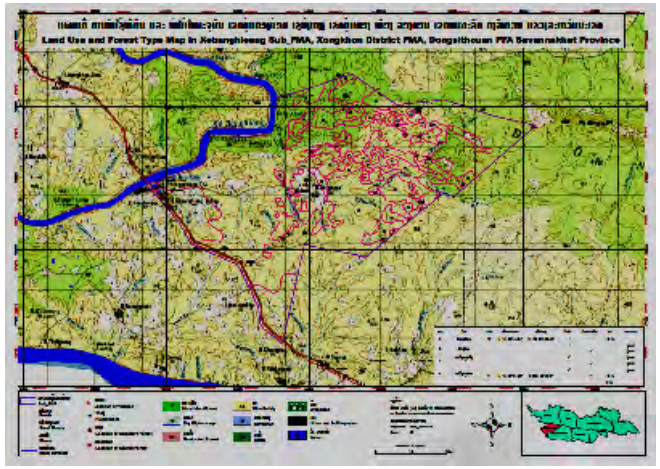
1. Location of the Survey Area

●Xebanghieang Sub_FMA, Xongkhon District FMA, Savannakhet Province



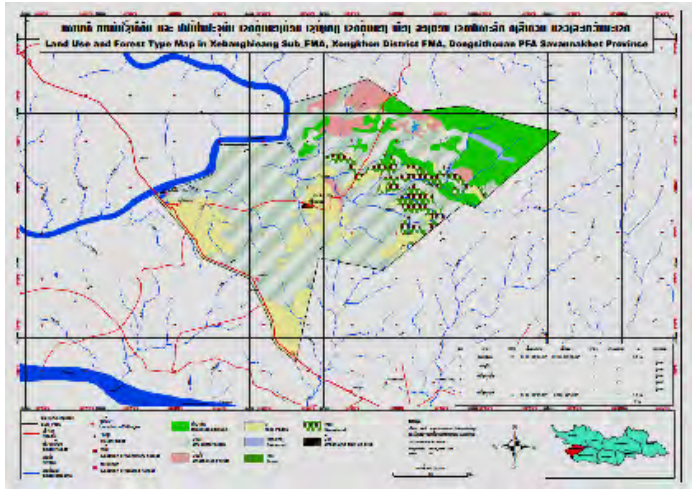
(RapidEye, Acquired in 2010/10 and 2010/12)

Topography, Land Use and Forest Type Map



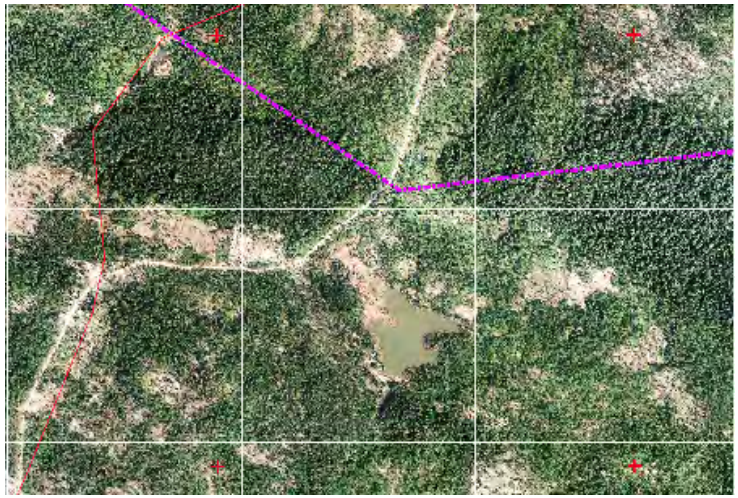
Savannakhet Production Forest Area (Xebanghieang Sub_FMA)

Land Use and Forest Type Map



Xebanghieang Sub_FMA, Savannakhet

Orthophoto Map

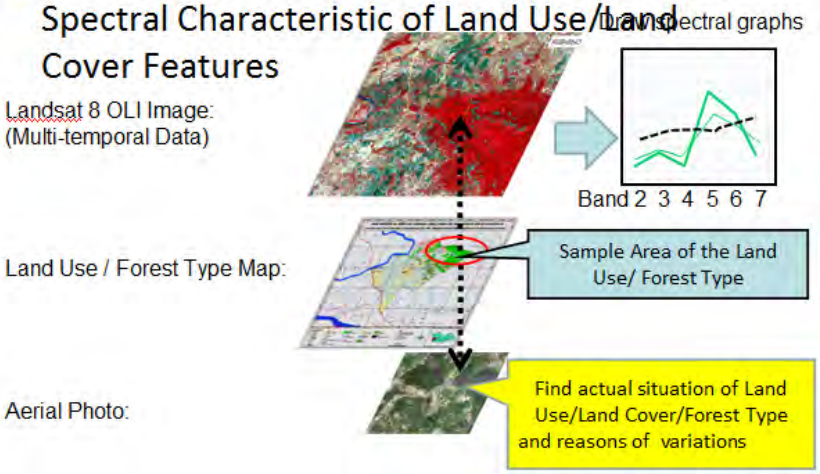


Xebanghieang Sub_FMA

DD Forest

Spectral Characteristic

- Multi-temporal and Multi-sensor Analysis of Spectral Characteristic of Land Use/Land Cover Features

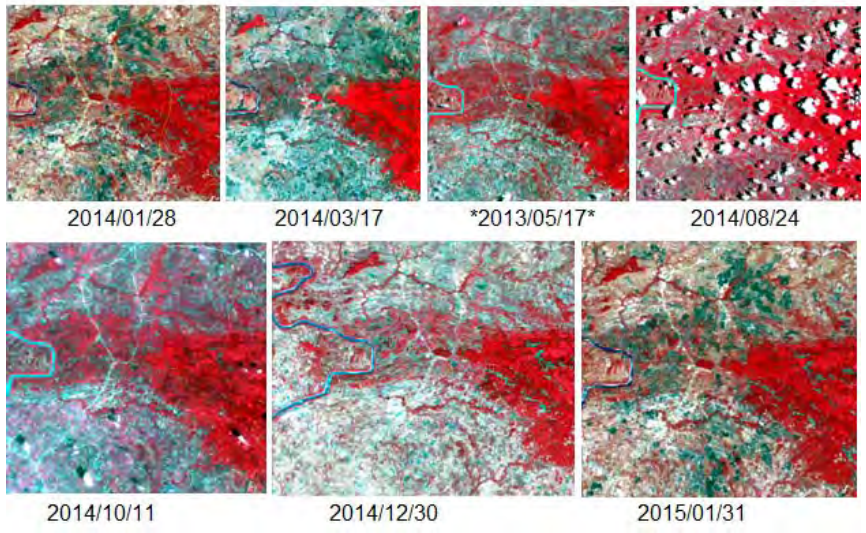


Remote Sensing Data

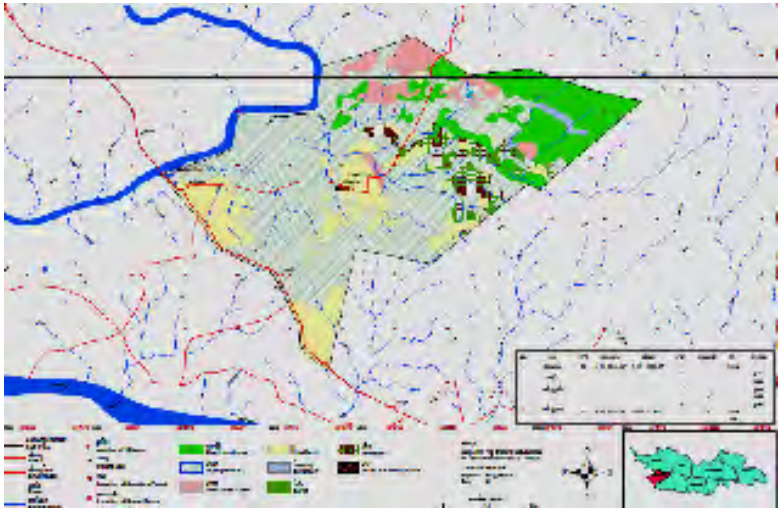
- Multi-temporal RapidEye and Landsat-8 Images
  - Xebanghieang Sub_FMA, Savannakhet
    - 2014/01/28
    - 2014/03/17
    - 2013/05/17(***)
    - 2014/08/24
    - 2014/10/11
    - 2014/12/30
    - 2015/01/31

Average Monthly Precipitation over the Year at Savannakhet

Color IR Composite Landsat8 Images (RGB=Band543,Savannakhet)

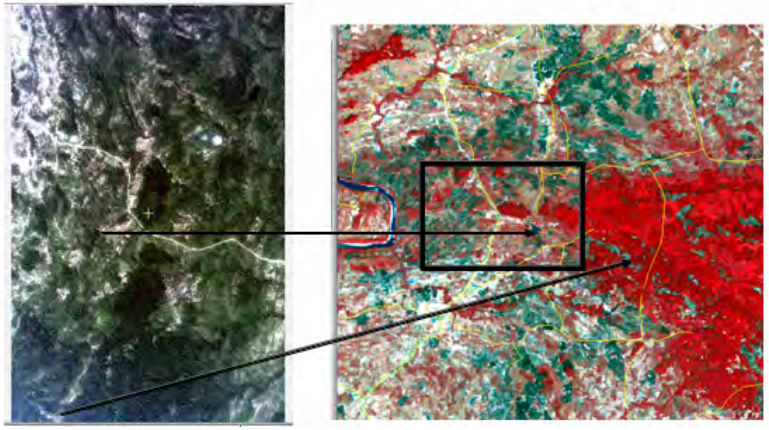


Forest Map



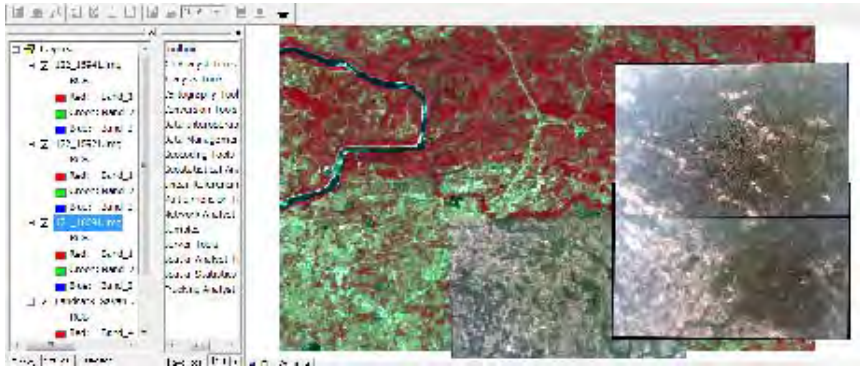
Registration of Aerial Photo on Landsat8 Image

Georeference and Rectification of Aerial Photos to Landsat 8 Image (UTM48N Coordinate System)

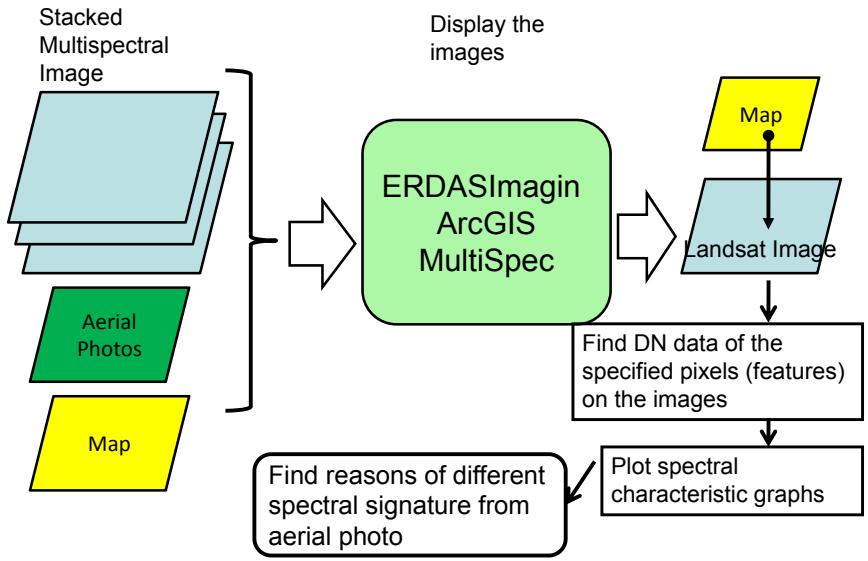


Overlaid Images

After the georeference, the aerial photos are rectified for overlaying.



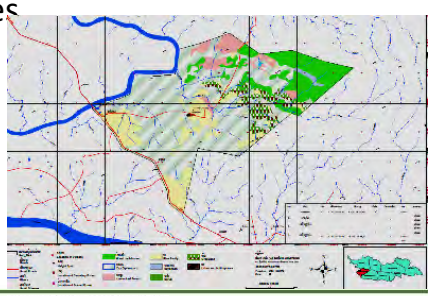
Acquisition of Spectral Signatures



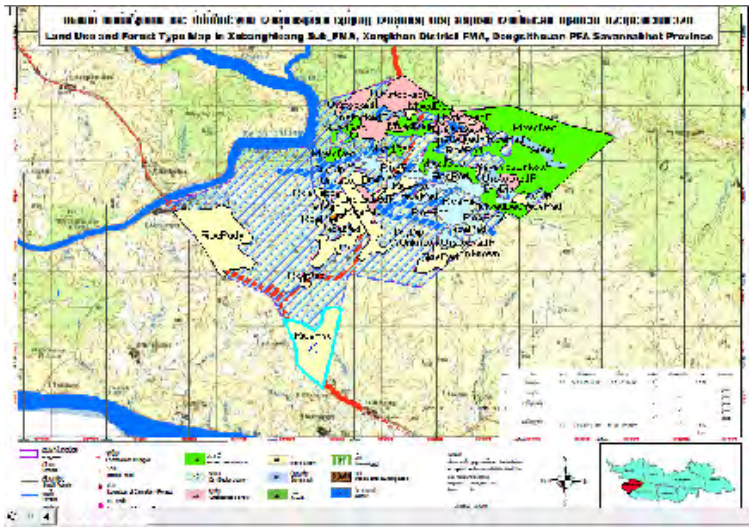
Land Use/Land Cover and Forest Types

Features to be specified on the Forest Map and RapidEye and Landsat 8 Images

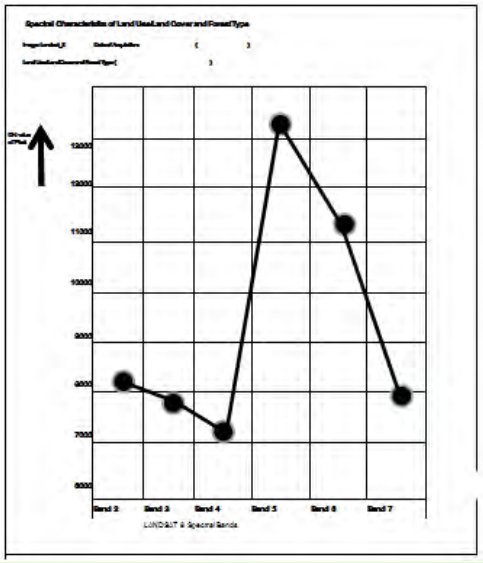
(1) 13 Mixed deciduous: 3 samples
(2) 15 Dry Dipterocarp : 3 samples
(3) 22 Unstocked Forest : 3 samples
(4) 41 Rice Paddy : 3 samples
(5) 31 Savannah : 3 samples
(6) 61 Water : 3 samples



Digitized Land Use and Forest Type Map



Spectral Characteristic Graph

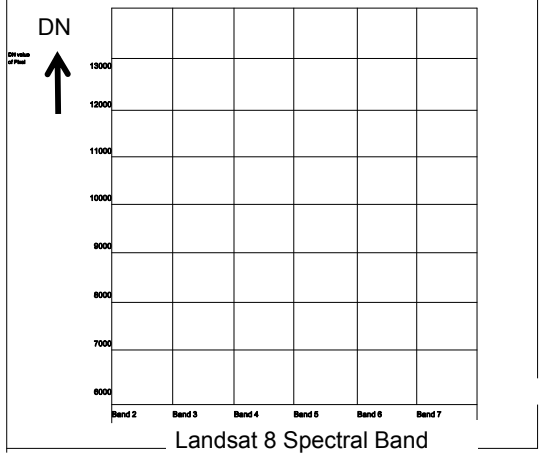


Example:

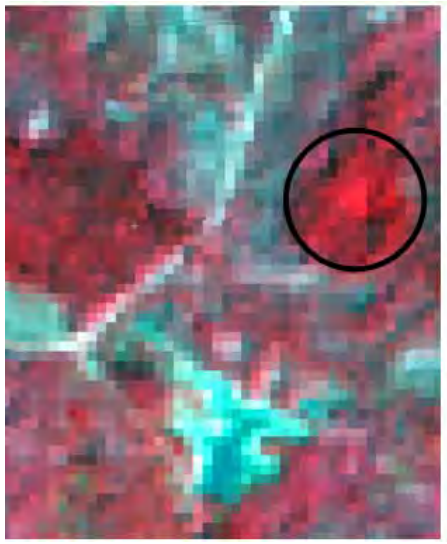
- Savannakhet's DD forest
- 2014/01/28 (Dry winter)
- B1: 8390
  B2: 7837
  B3: 7244
  B4:133987
  B5: 11279
  B6: 7997

Spectral Characteristic Graph

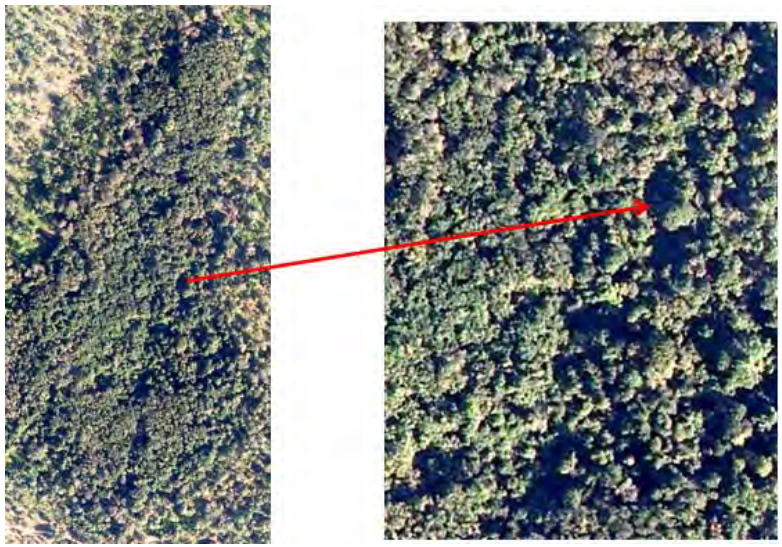
Spectral Characteristics of Land Use/Land Cover and Forest Type
Image: Landsat 8 Date of Acquisition:
Land Use/Land Cover and Forest Type:



[Remarks]

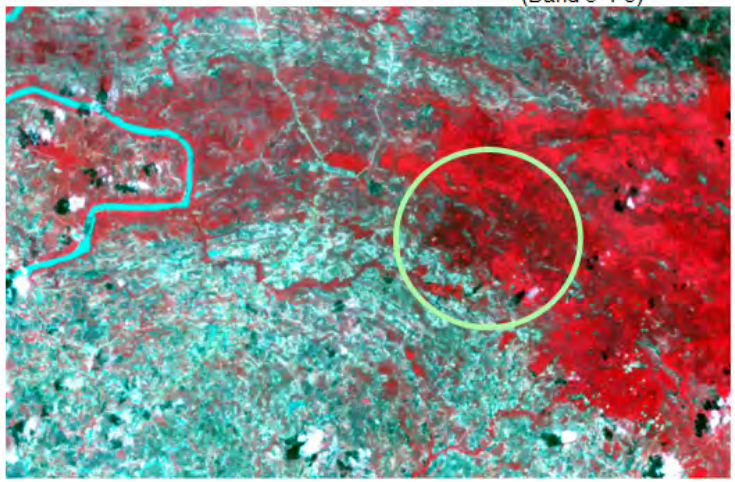


Evidence of Spectral Characteristics



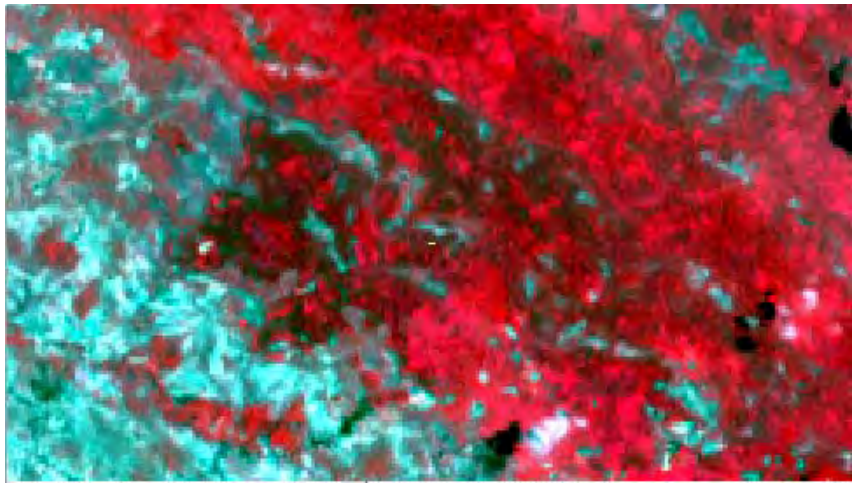
Analysis of Spectral Characteristics

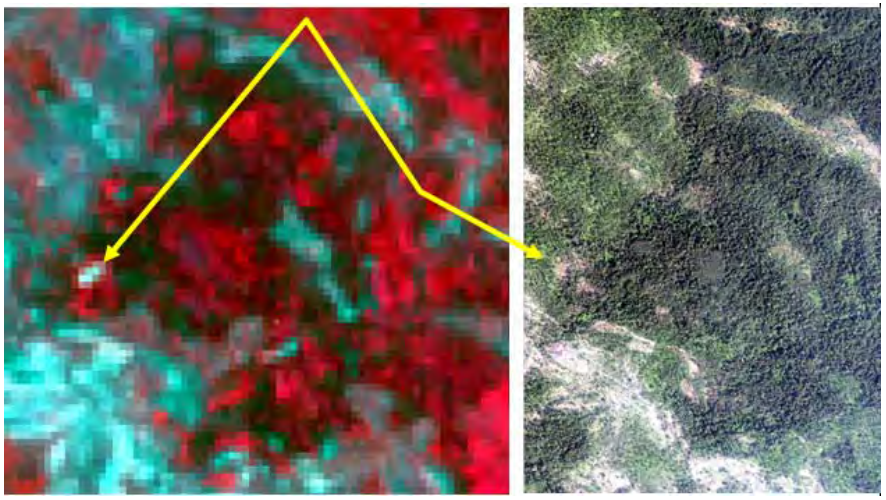
2013/05/17 Landsat_8 Image
(Band 5-4-3)



Partially Enlarged Image_Landsat 8

2013/05/17



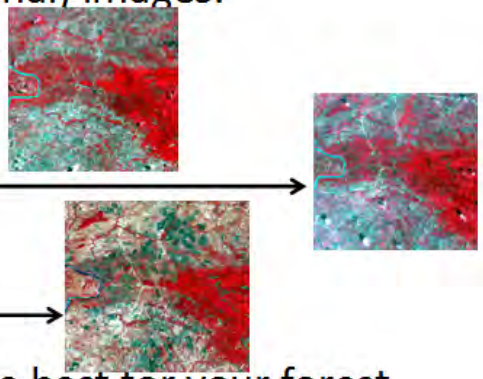


Digital Canopy Data

Temporal Change of Spectral Characteristics

Compare similar spectral graphs for multi-temporal (seasonal) images.

- 2013/05/17 →
- 2014/10/11 →
- 2015/01/31 →

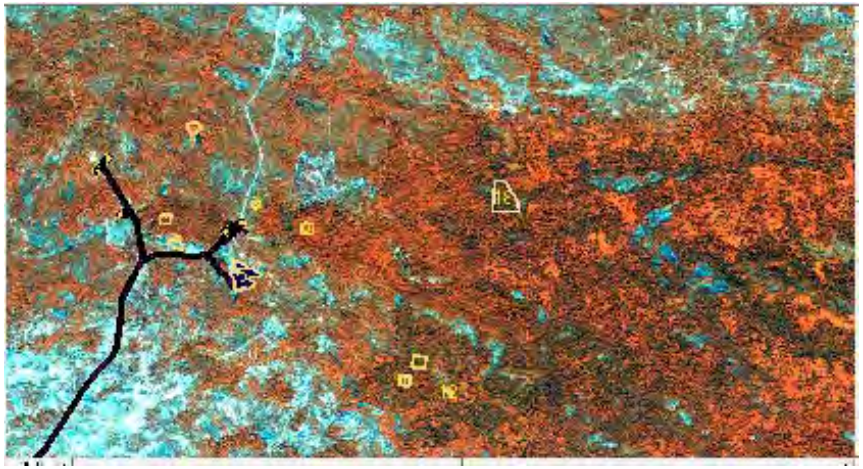


Which image is the best for your forest survey? Why?

RapidEye Composite Image

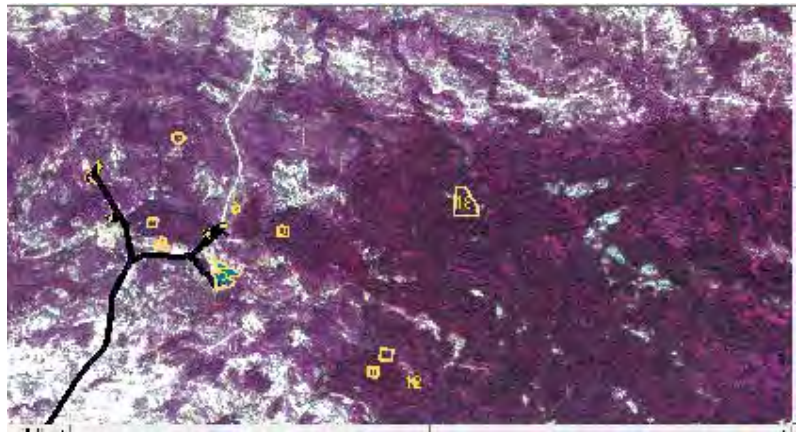
RapidEye RGB=B321

RapidEye Composite Image



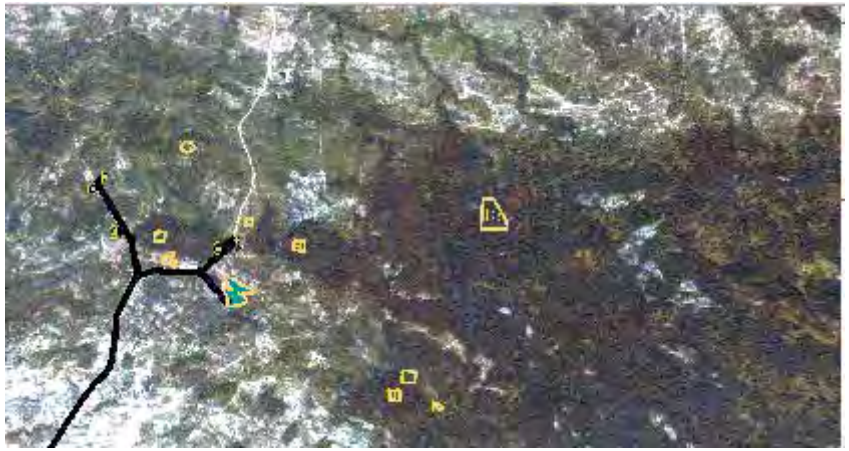
RapidEye RGB=B543

RapidEye Composite Image



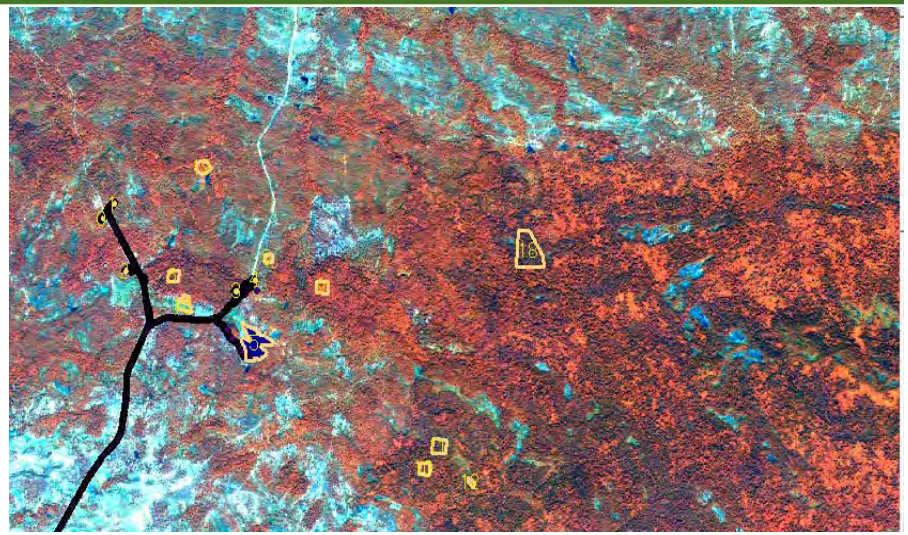
RapidEye RGB=B432

RapidEye Composite Image



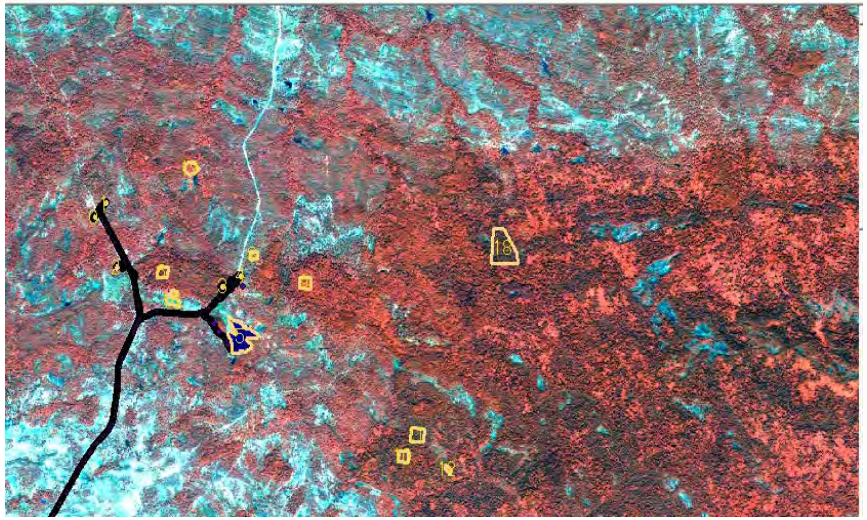
RapidEye RGB=B421

RapidEye Composite Image



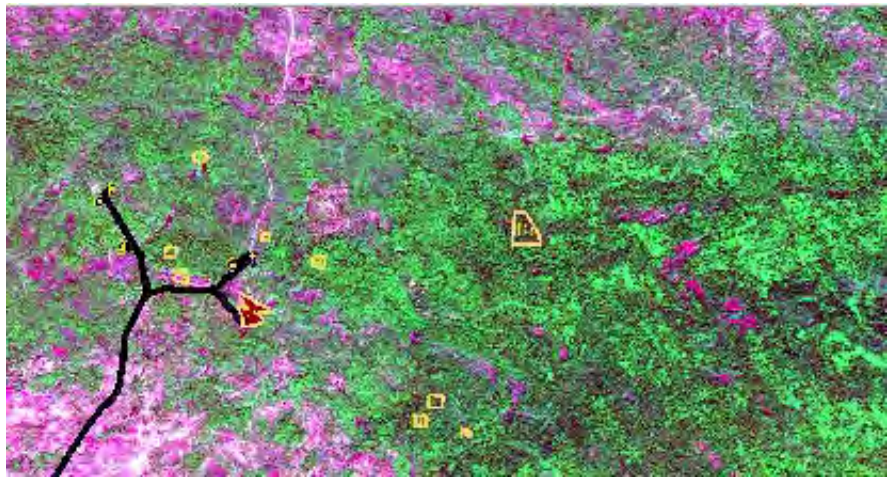
RapidEye RGB=B541

RapidEye Composite Image



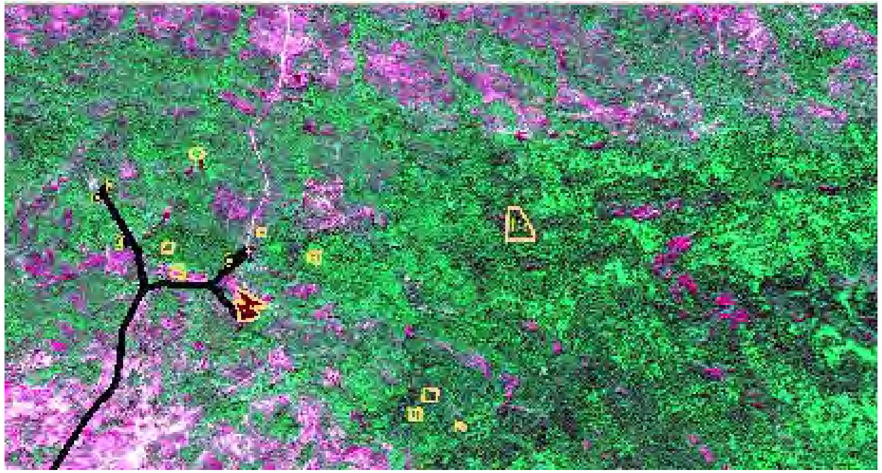
RapidEye RGB=B542

RapidEye Composite Image



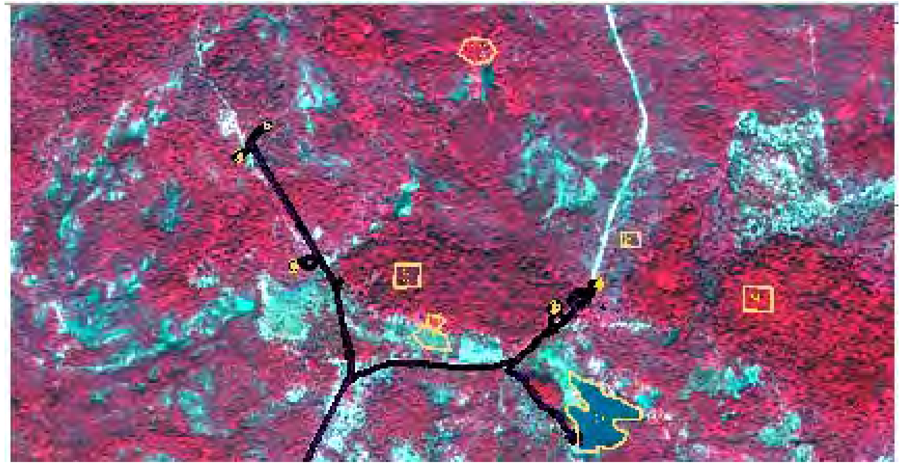
RapidEye RGB=B154

RapidEye Composite Image

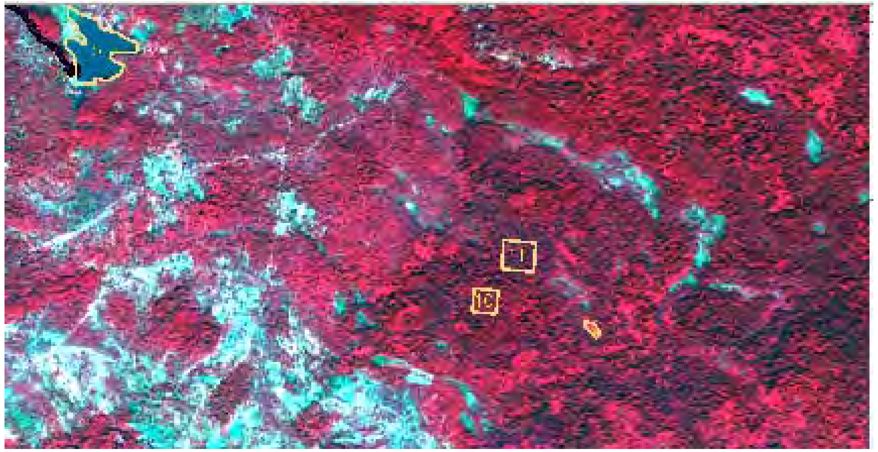


RapidEye RGB=B354

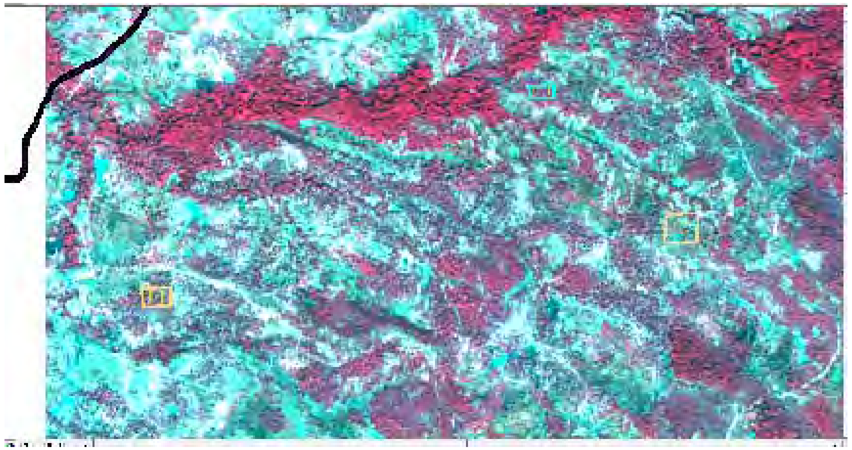
RapidEye Composite Image



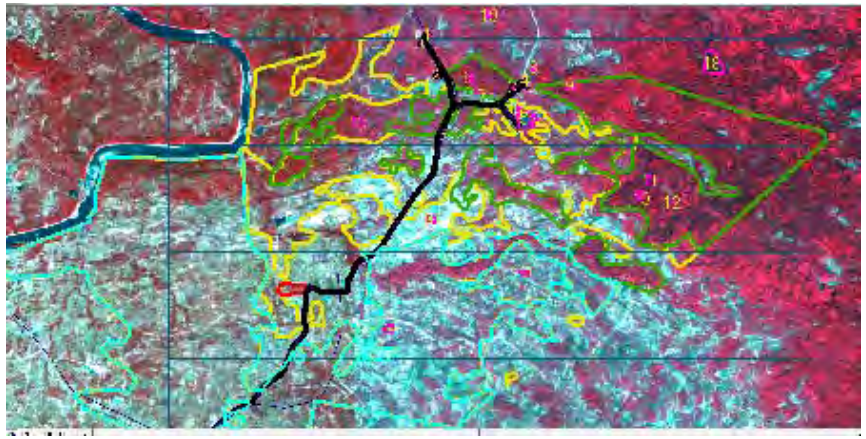
RapidEye Composite Image



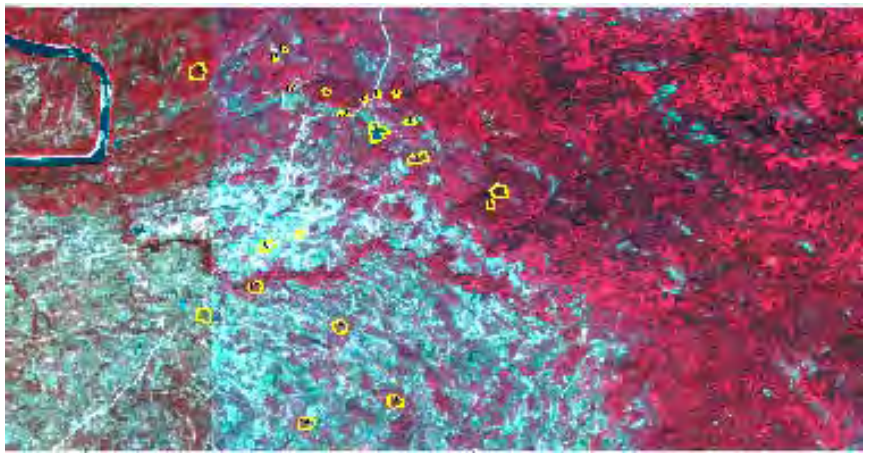
RapidEye Composite Image



Forest Map Overlaid

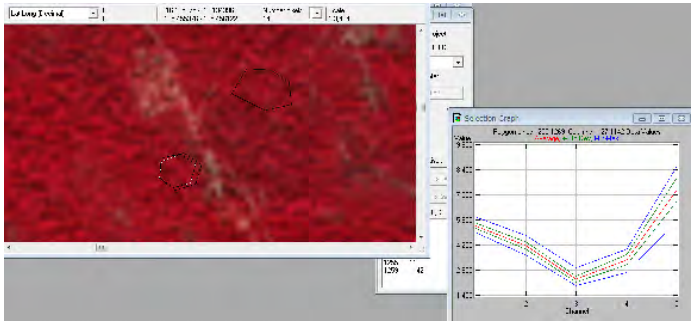


Plots Selected on the Image



Spectral Characteristics of Plot 1 (DD)

- No. 16 Plot

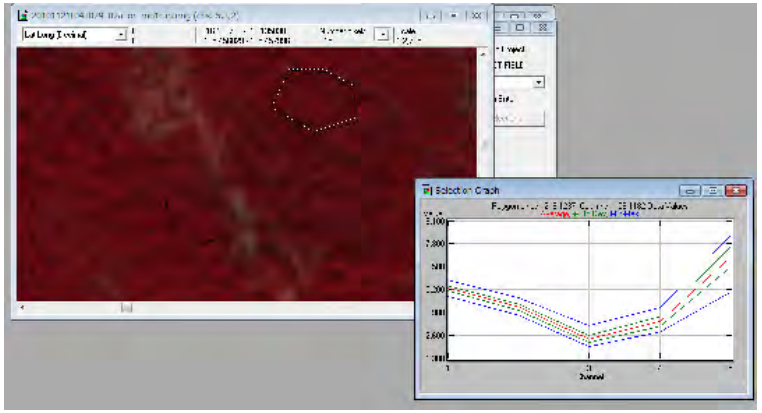


Class 'No 16' Statistics

Number of training pixels = 149, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5291.3	4193.3	2310.7	3395.5	7295.9
Standard Deviation	149.5	195.0	160.7	272.3	658.5

No.17---Plot 2 (DD)

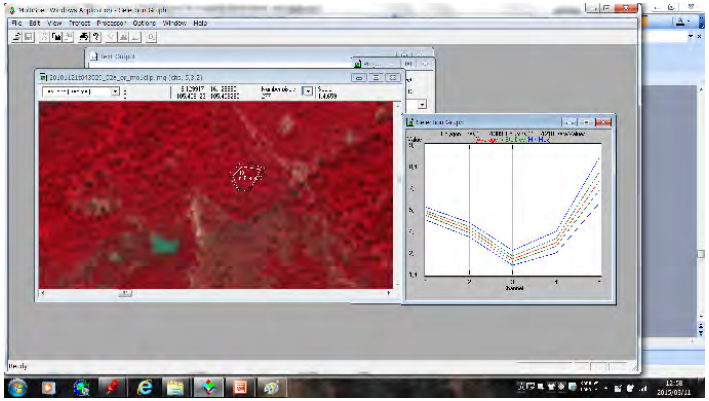


Class 'Class 17' Statistics

Number of training pixels = 315, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5273.2	4207.8	2386.5	3385.7	7046.3
Standard Deviation	150.4	176.1	199.3	257.9	579.5

No.18----Plot 3 (DD)

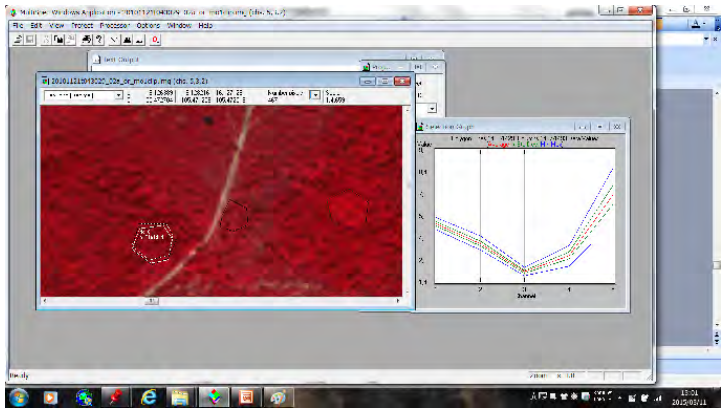


Class '18-1' Statistics

Number of training pixels = 169, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5400.6	4312.4	2412.0	3490.7	7529.9
Standard Deviation	143.0	210.5	205.2	254.4	577.5

No.0----Plot 4 (Mixed Deciduous)

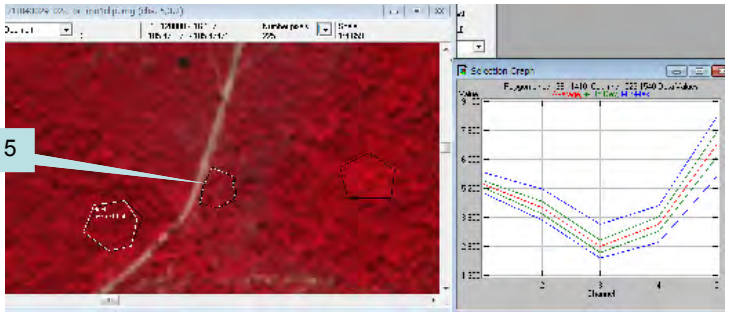


Class 'No-0' Statistics

Number of training pixels = 448, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5130.6	3886.9	2086.5	3150.3	7017.2
Standard Deviation	136.9	156.0	101.5	236.4	610.7

No.1----Plot 5 (DD)

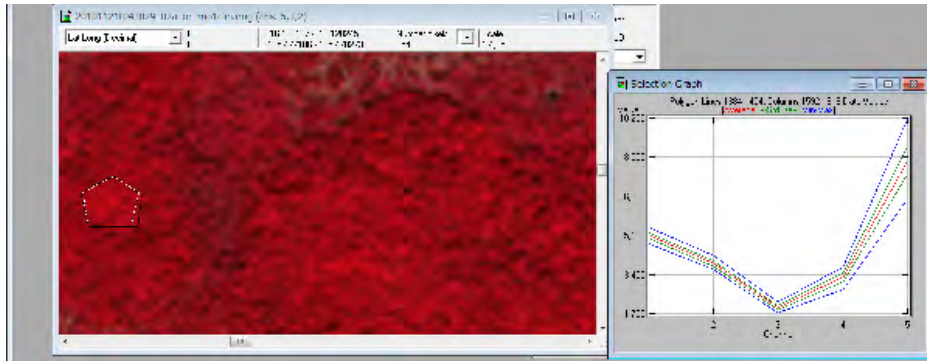


Class '1' Statistics

Number of training pixels = 225, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5399.0	4354.3	2612.5	3612.4	7157.9
Standard Deviation	156.7	273.1	289.4	327.0	563.6

No.3----Grass land

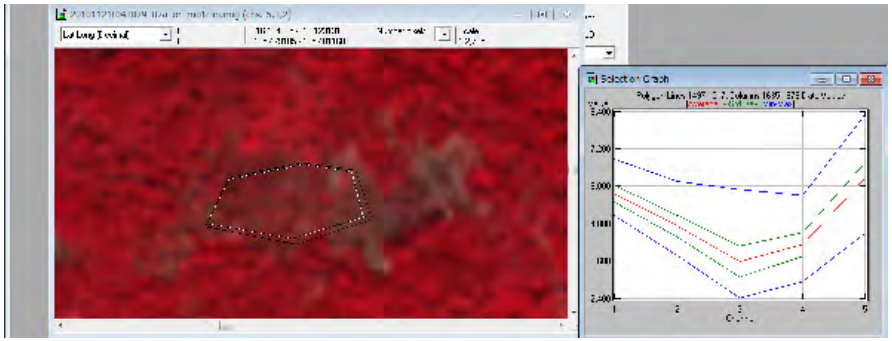


Class 'No.3' Statistics

Number of training pixels = 354, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5097.2	3888.7	1968.0	3275.4	8358.5
Standard Deviation	127.1	123.7	82.5	175.4	599.5

No.4----Rice Paddy

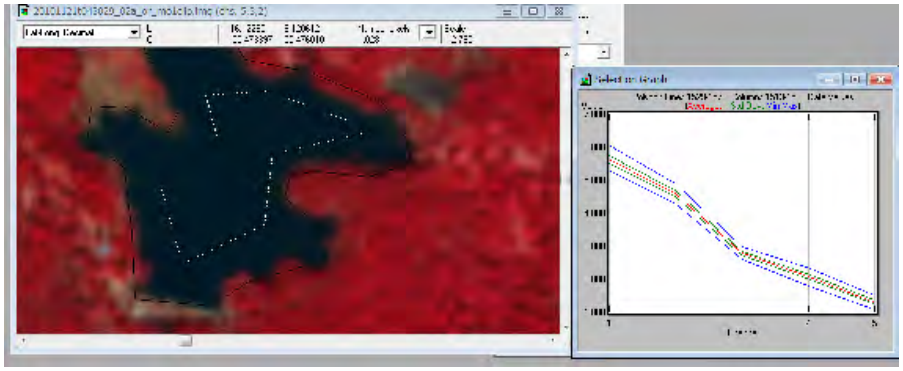


Class 'No.4' Statistics

Number of training pixels = 606, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5761.8	4719.3	3574.7	4138.0	6251.0
Standard Deviation	272.0	342.0	502.1	377.8	500.8

No.5----Water

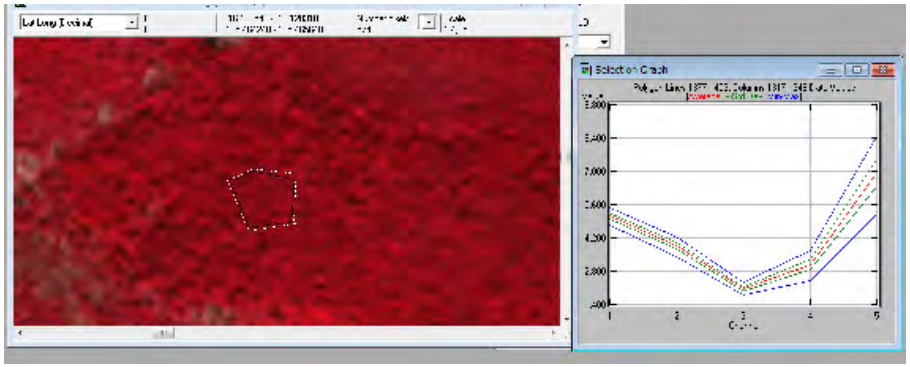


Class 'No.5' Statistics

Number of training pixels = 1028, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5626.6	4580.8	2786.6	2081.9	1301.7
Standard Deviation	120.9	90.3	66.8	77.7	61.6

No.19---Mixed Deciduous

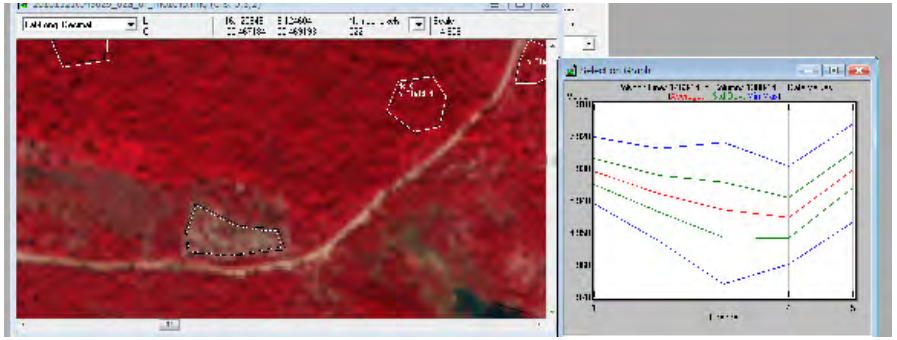


Class 'No-19' Statistics

Number of training pixels = 574, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5135.8	3876.4	2067.0	3090.6	6936.7
Standard Deviation	122.6	137.4	92.0	210.3	568.3

No.20---Rice Paddy

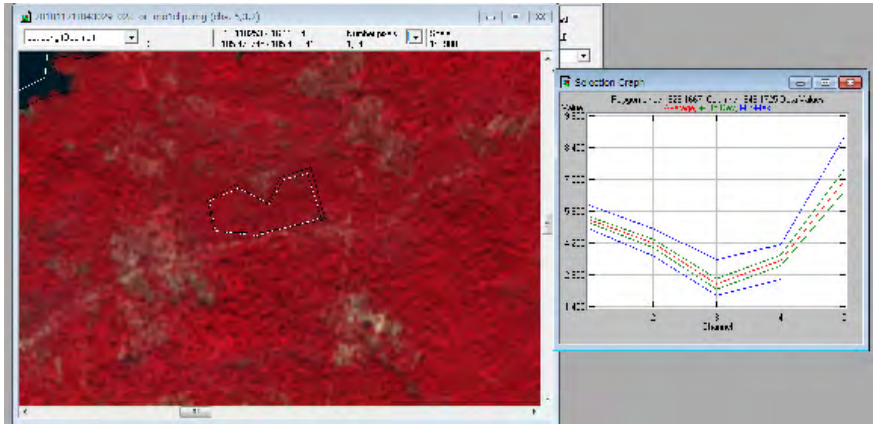


Class 'No 20' Statistics

Number of training pixels = 522, Number of training fields = 1

Channel	1	2	3	4	5
Mean	6850.6	6161.7	5664.4	5427.4	6905.9
Standard Deviation	395.9	573.5	853.7	619.3	562.0

No.2 ----Mixed Deciduous

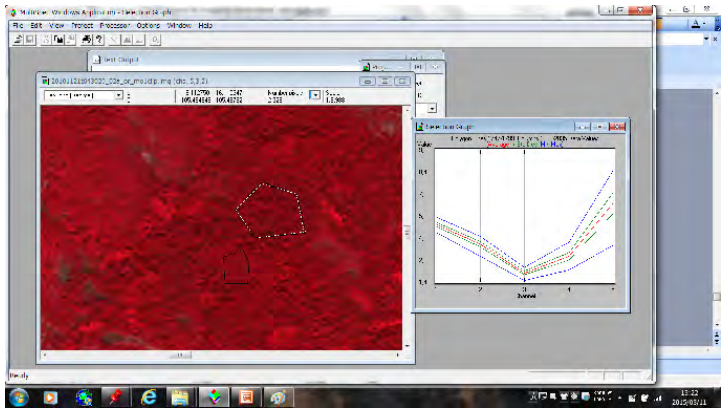


Class 'No.2' Statistics

Number of training pixels = 1842, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5255.1	4212.7	2424.4	3443.7	6965.9
Standard Deviation	142.5	179.5	227.2	235.4	492.0

No.6 ---Mixed Deciduous

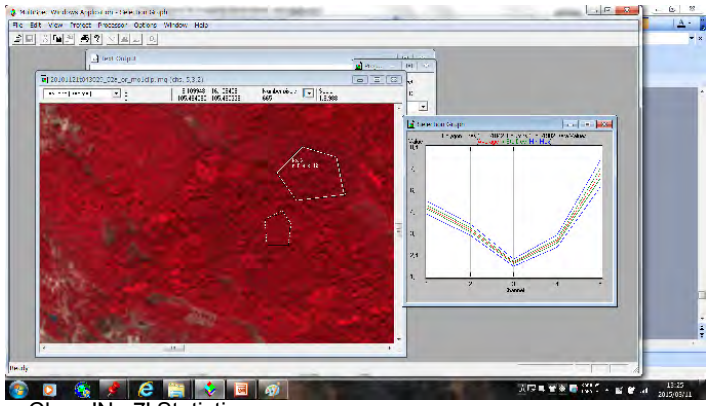


Class 'No.6' Statistics

Number of training pixels = 2328, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5071.0	3815.0	1990.9	3049.9	6412.2
Standard Deviation	136.5	160.3	110.3	245.4	663.4

No.7---Mixed Deciduous (Very Dense)

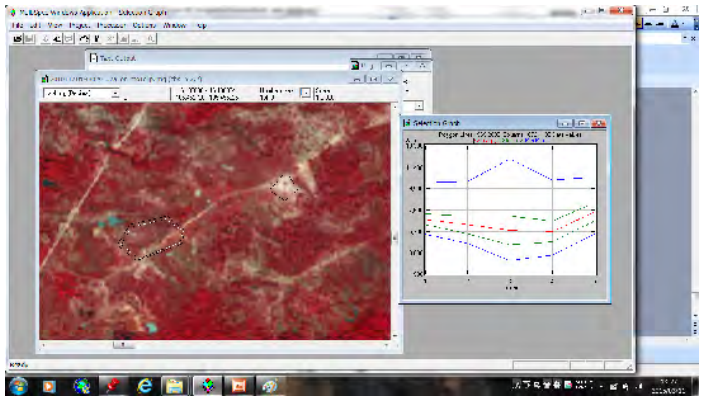


Class 'No.7' Statistics

Number of training pixels = 665, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5085.1	3814.9	1982.2	3189.7	6941.6
Standard Deviation	113.3	106.3	67.1	115.3	271.4

No.8---Rice Paddy

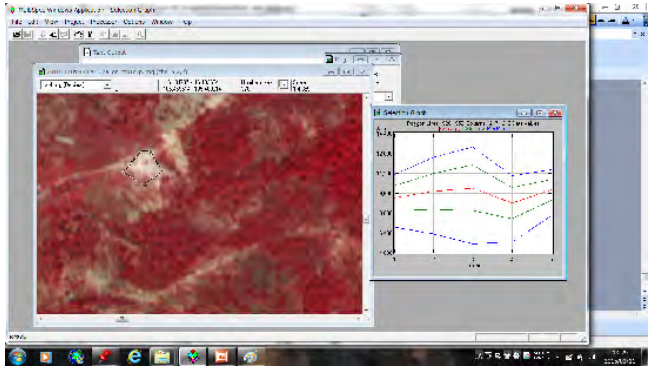


Class 'CNo.8' Statistics

Number of training pixels = 1473, Number of training fields = 1

Channel	1	2	3	4	5
Mean	6771.9	6295.2	5792.8	5689.6	7443.8
Standard Deviation	474.7	800.0	1299.9	928.2	812.4

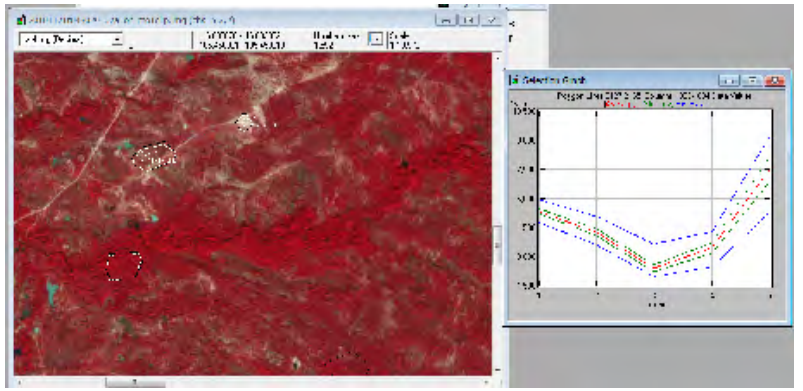
No.9---Rice Paddy (very light)



Class 'No.9' Statistics
Original class statistics are listed.
Number of training pixels = 376, Number of training fields = 1

Channel	1	2	3	4	5
Mean	9220.2	9756.1	10055.9	8834.8	9891.4
Standard Deviation	1011.1	1446.1	1865.1	1260.3	844.9

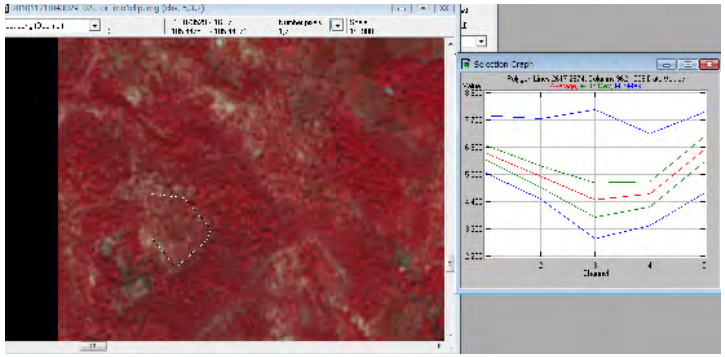
No.10 DD (near stream)



Class 'No.10' Statistics
Number of training pixels = 1592, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5355.4	4274.7	2415.6	3466.9	7522.2
Standard Deviation	137.5	180.3	172.0	260.5	653.1

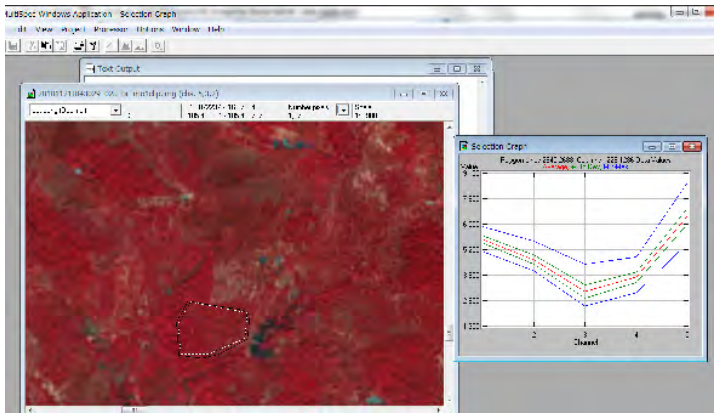
No.11---Rice Paddy covered by trees?



Class 'Class 11' Statistics
Number of training pixels = 1738, Number of training fields = 1

Channel	1	2	3	4	5
Mean	6380.2	5424.9	4478.8	4715.3	6518.4
Standard Deviation	299.8	431.1	683.1	521.7	519.9

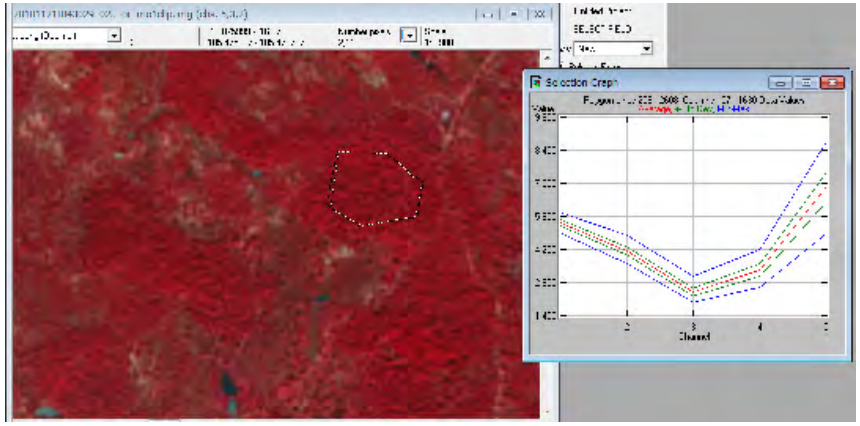
No.14---DD



Class 'Class 14' Statistics
Number of training pixels = 1870, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5731.4	4702.9	3072.7	3816.8	6918.9
Standard Deviation	187.3	226.8	336.1	265.2	400.3

No.13—Mixed Deciduous

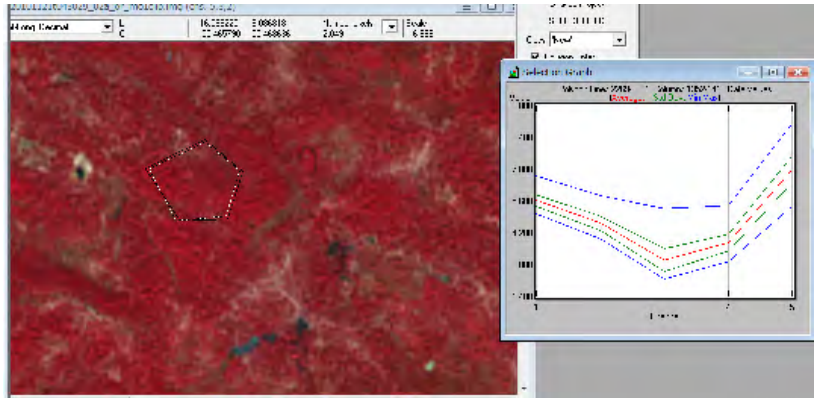


Class 'Class 13' Statistics

Number of training pixels = 2110, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5337.6	4156.8	2418.1	3350.7	6842.3
Standard Deviation	132.5	164.9	154.4	251.6	622.5

No.12 ---Mixed Deciduous

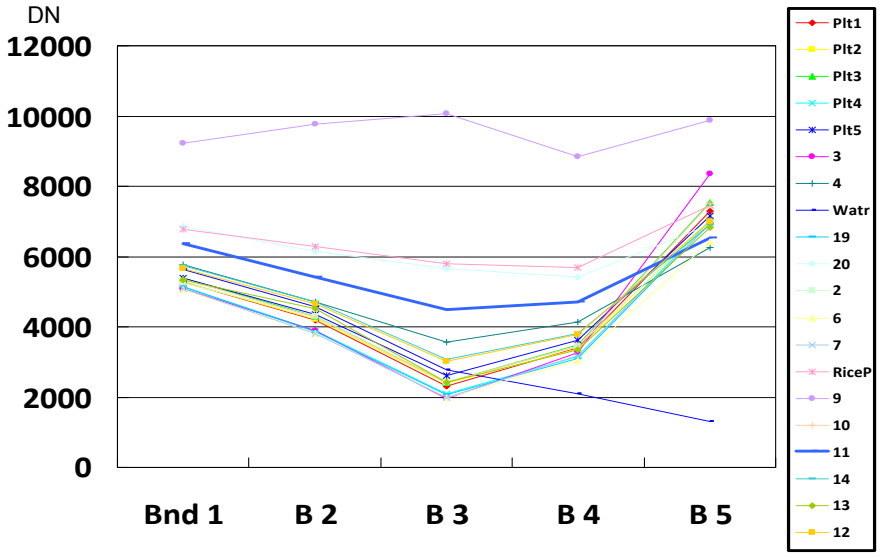


Class 'Class 12' Statistics

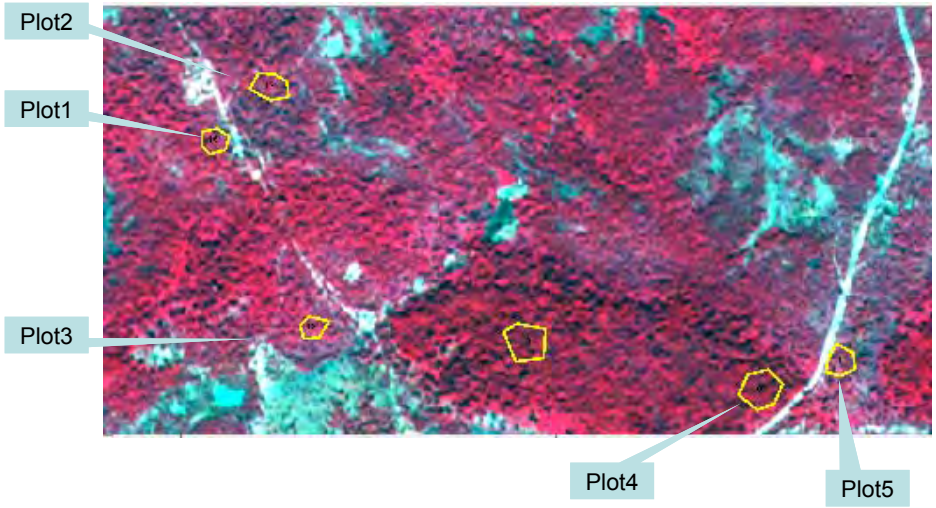
Number of training pixels = 2049, Number of training fields = 1

Channel	1	2	3	4	5
Mean	5646.5	4644.0	3023.6	3778.9	6988.9
Standard Deviation	252.8	313.8	497.4	377.2	583.1

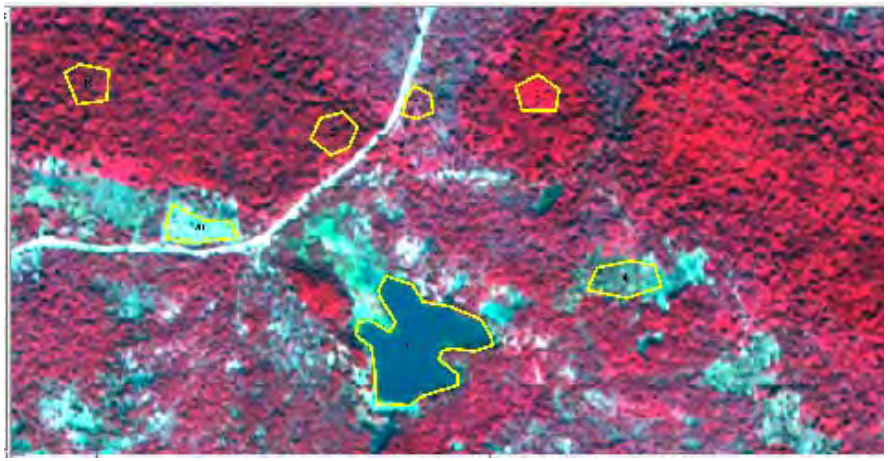
RapidEye Image---2010/11/13



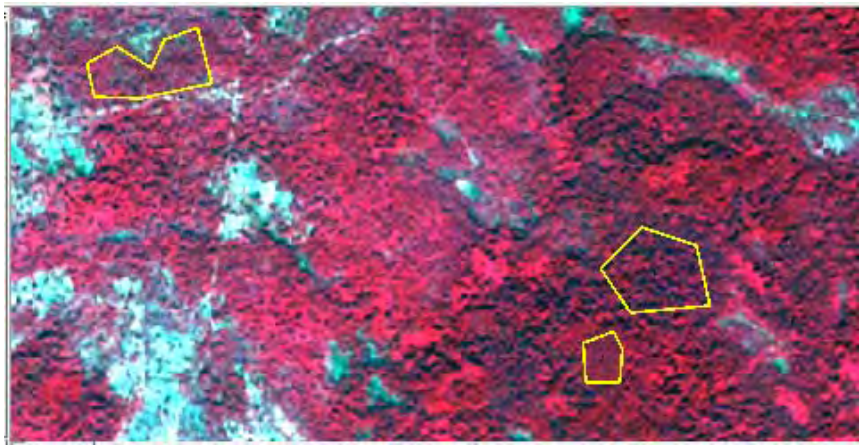
Sites of Plot Surveys

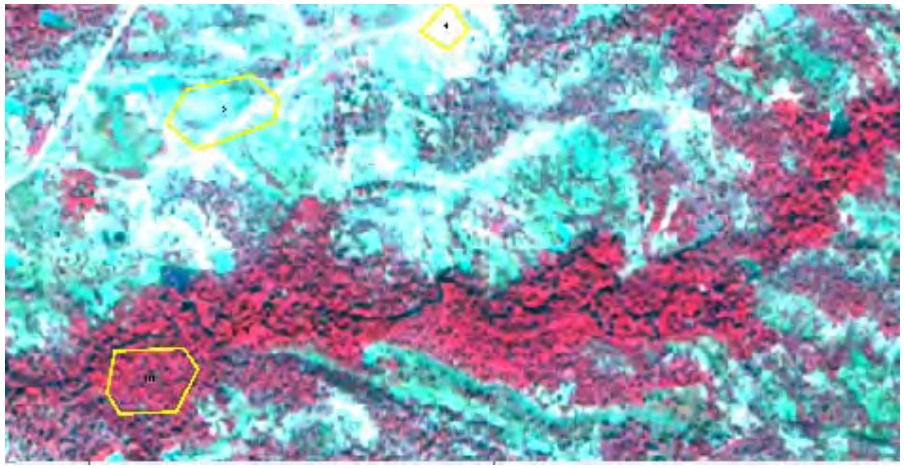


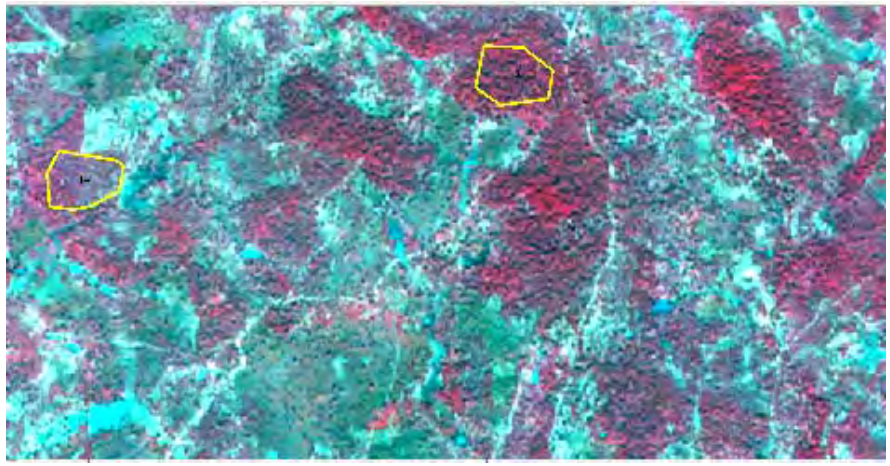
RapidEye Image



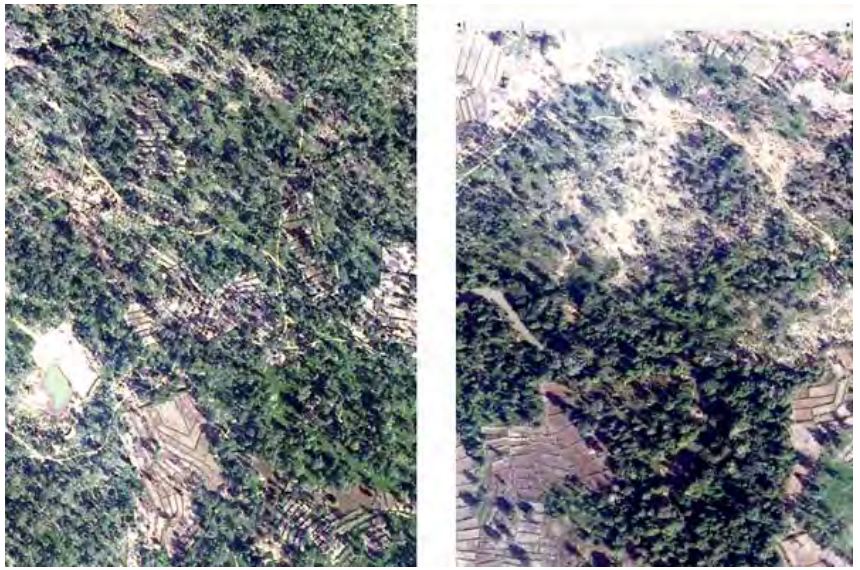
Aerial Views of Survey Plots



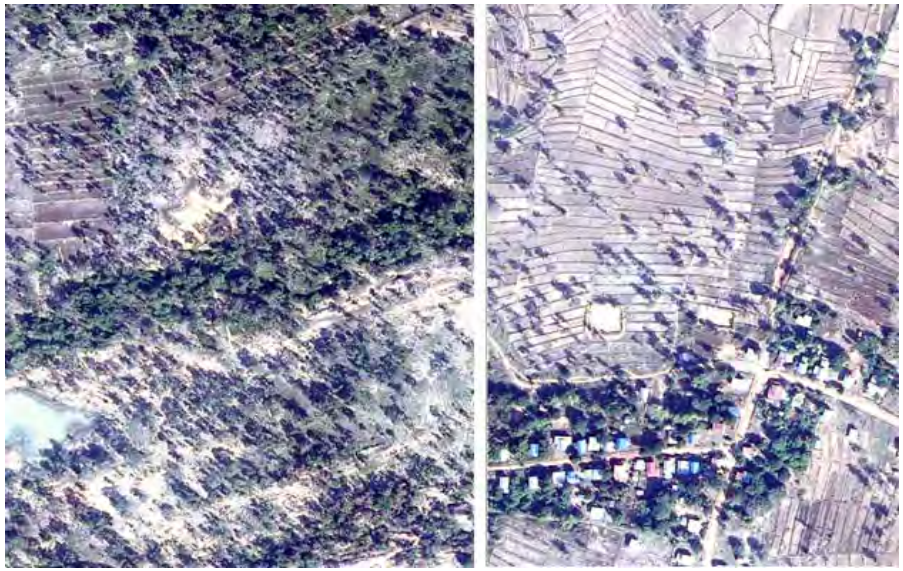




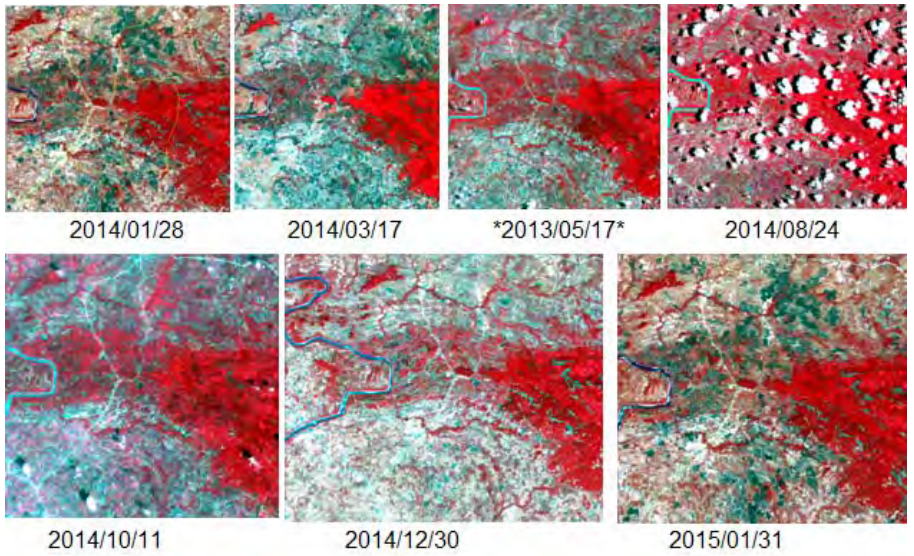
Aerial View of the Area



Aerial View of the Area

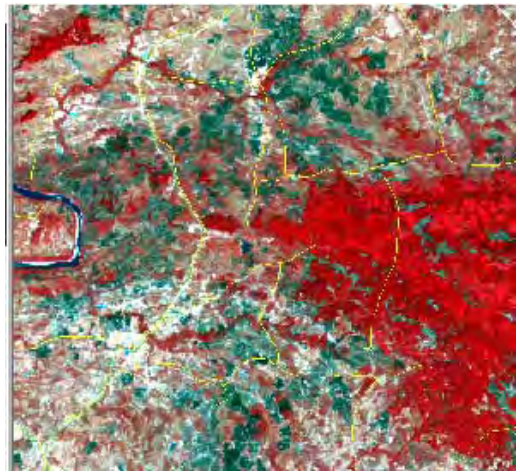


Analysis of Multitemporal Landsat 8 Images (RGB=Band543,Savannakhet)

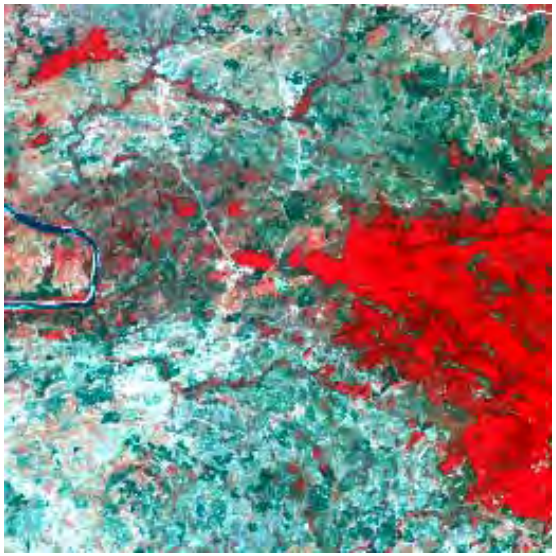


2014/01/28

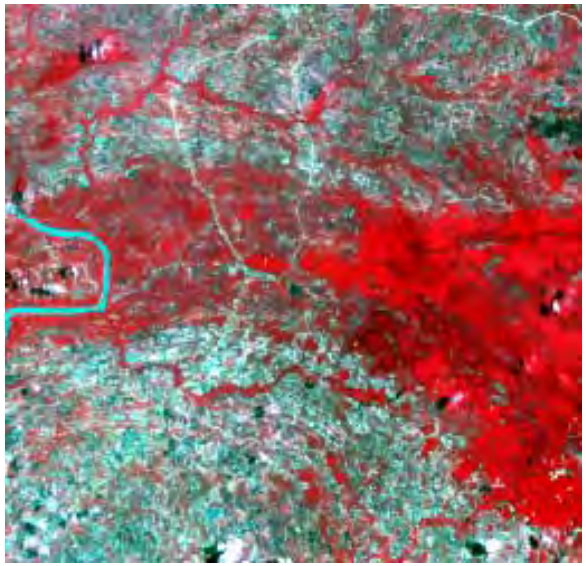
Find and compare the spectral characteristic graphs of various land use/land cover features on the multitemporal images.



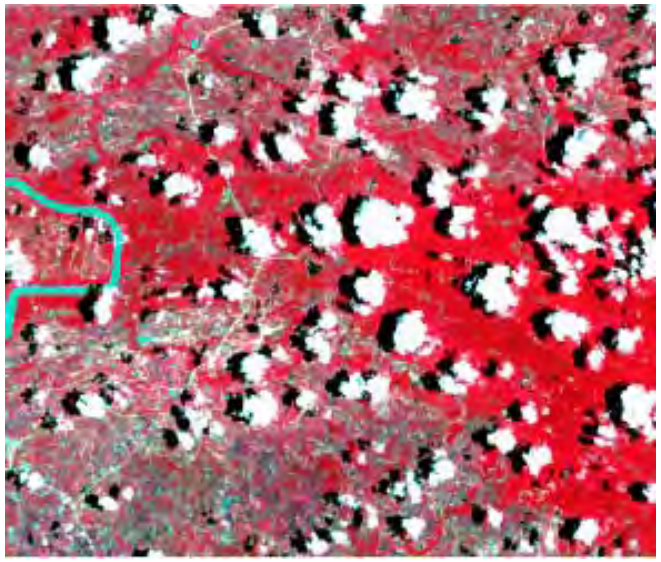
2014/03/17



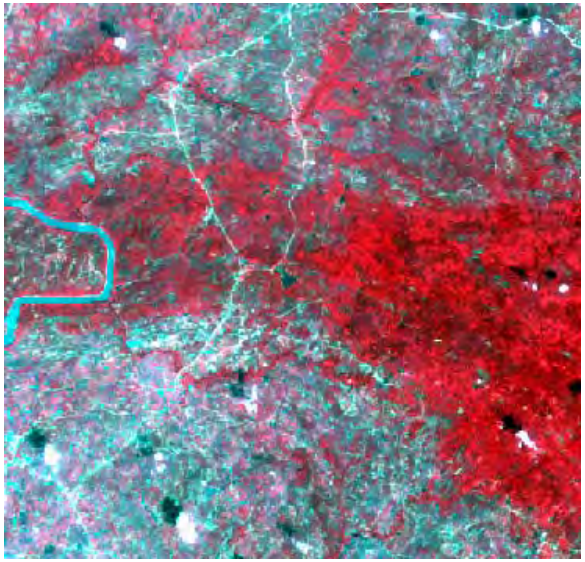
2013/05/17



2014/08/24



2014/10/11



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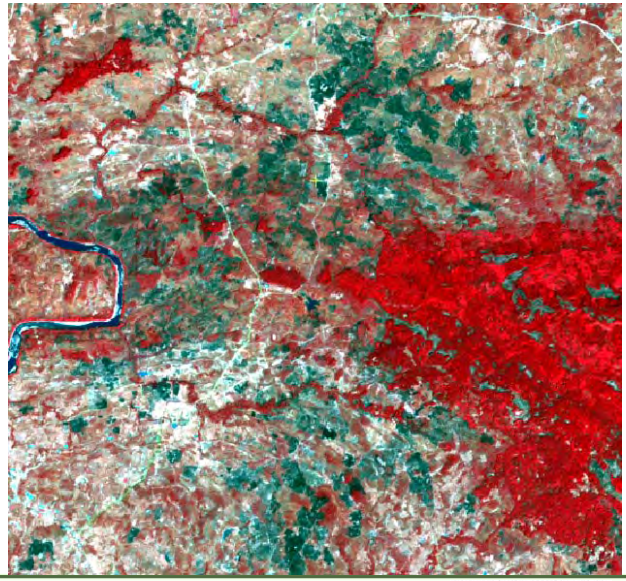
2015/01/31



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Theory of Remote Sensing Part-2

-NDVI and Related Topics-

Technical Training

March 3rd - 16st, 2015

DOF/FIPD KOKUSAI KOGYO CO.,LTD. ASIA AIR SURVEY CO.,LTD.

Mitsuru NASU, Ph.D.

Forest Remote Sensing

7. Understanding Vegetation Indices of Forest and Various Land-Cover Features

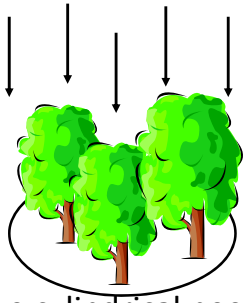
Theme to be studied:

- -Analyses of NDVI and SVI
- -Vegetation Cover and Land Cover vs. NDVI
- -Forest Types vs. NDVI

Leaf Area Index

[Definition of Leaf Area Index]

◇ LAI : The amount of one-side leaf area per unit area of ground



Unit Area
(1 m^2)

◇ For conifers, that have cylindrical needles, one may consider the projected area of the needles or hemi-surface area of the needles.

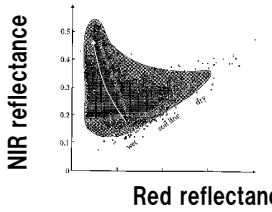
LAI=Technical word in Forestry ⇨ Vegetation Index in RS

Vegetation Transformations (Indices)

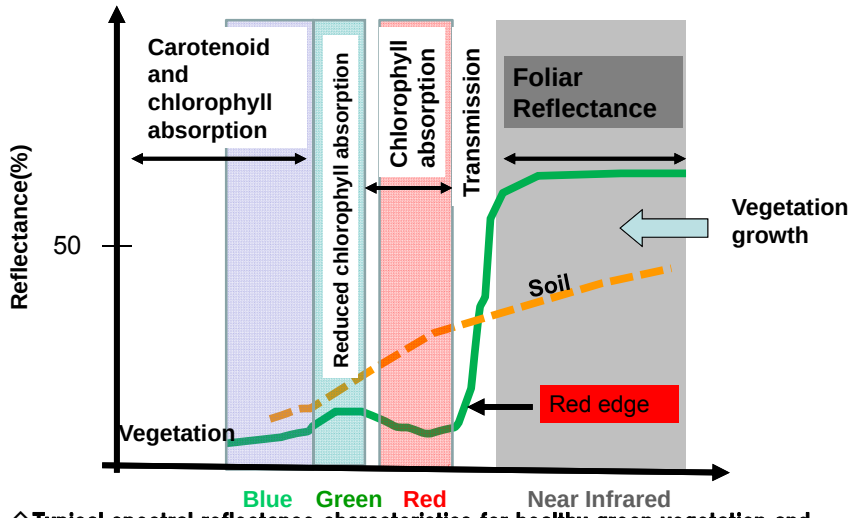
◇Scientists have known since the 1960s that *a direct* relationship exists between response in the near-infrared region and various biomass measurements.

◇There exists an *inverse* relationship between the response in the visible region, particularly red, and plant biomass.

◇The best way to show this is to plot all of the pixels in a typical remote sensing scene in red and near-infrared reflectance space.

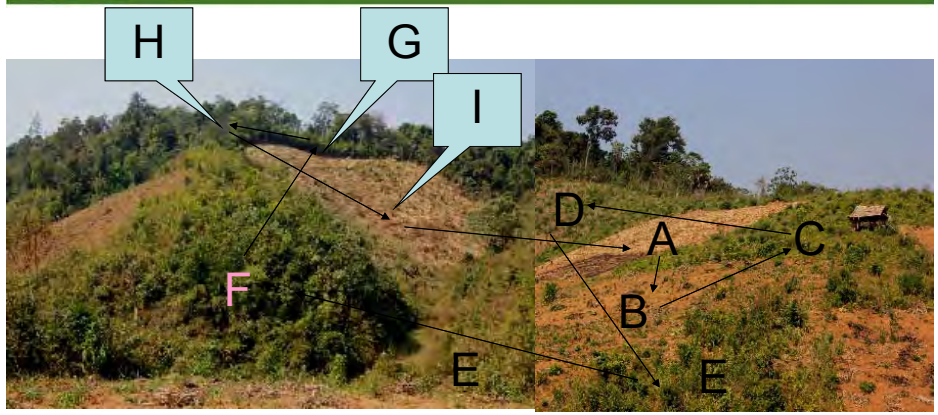


Physiological Basis for NDVI



◇Typical spectral reflectance characteristics for healthy green vegetation and bare dry soil for the wavelength from 0.25 to 1.0 μm(250 – 1000 nm).

Physiological Basis for NDVI



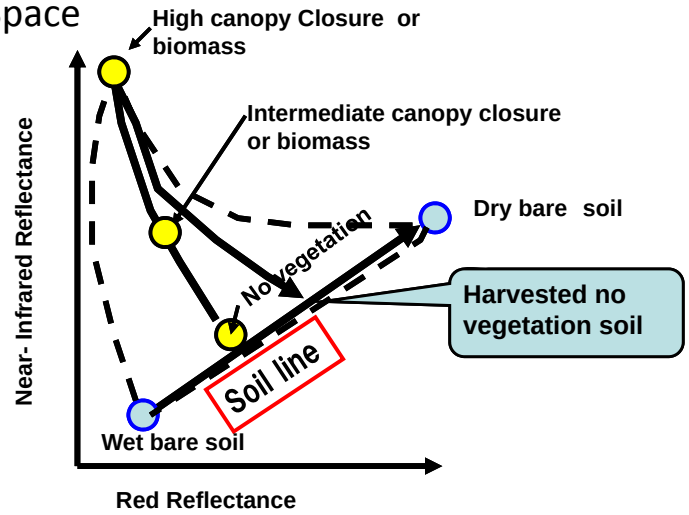
(From GT photos in Oudom Xay Province)

A (bare soil) → B → C → D → E → F → G → H → I (S/B)

Increase of Amount of Biomass

Concept of Vegetation Indices

Distribution of DNs in Red and Near-infrared Spectral Space



Various Vegetation Indices

- Simple Ratio: (Simple Vegetation Index)

$$SVI = \frac{\rho_{red}}{\rho_{nir}}.$$

- Normalized Difference Vegetation Index

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

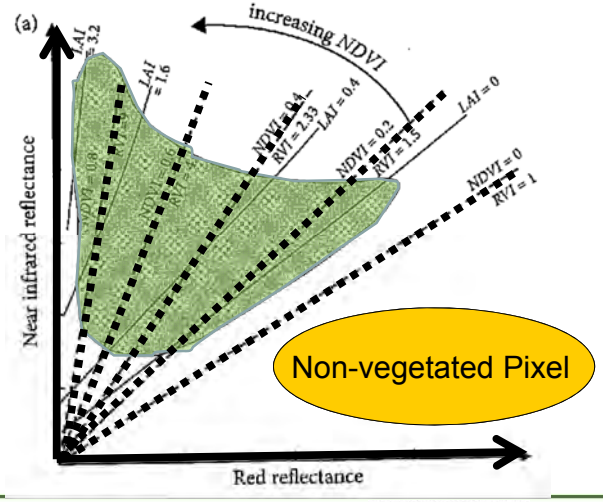
- Enhanced vegetation Index:

$$EVI = G\frac{\rho^*_{nir} - \rho^*_{red}}{\rho^*_{nir} + C_1\rho^*_{red} - C_2\rho^*_{blue} + L}(1+L).$$

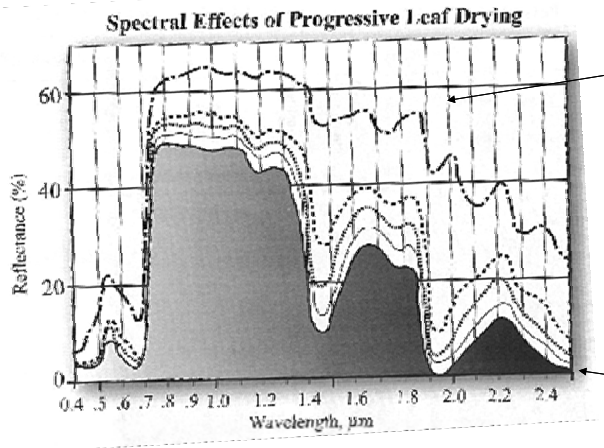
ρ: reflectance of light (DN value of a pixel)

Vegetation Indices

Equal NDVI, equal RVI(=SVI), and equal LAI(Leaf-Area Index) Lines (These are actually very similar figures.)



A Study of Vegetation Indices



◇Reflection response of a single magnolia leaf to decreased relative water content. As moisture content decreased, reflectance increased throughout the 0.4 to 2.5 μm.

LAI and Landsat ETM+ Bands

Investigating relationships between Landsat ETM+ sensor data and leaf area index in a boreal conifer forest (paper on RSE 78)

Lars Eklundh[a,]*, Lars Harrie[b], Andres Kuusk[c]

Remote Sensing of Environment 78 (2001) 239– 251

1) The theoretical reflectance response to LAI changes investigated using a forest canopy reflectance model in order to simulate stand reflectances in the Landsat ETM+ wavelength bands.
2) The response to changes in LAI is strongest in the visible wavelength bands, particularly Red band, whereas only weak response is noted in the NIR band and for some vegetation indices [simple ratio (SR) and NDVI].
3) Modelled reflectances are influenced by various other factors, particularly ground reflectance and leaf biochemical properties.

LAI and Landsat ETM+ Bands

4) Observed reflectances from the Landsat ETM+ sensor have been compared with reflectance modelling results and with field–based LAI estimates.

5) Statistical relationships between LAI and observed ETM+ reflectances are strongest in Mid–IR 2 band.

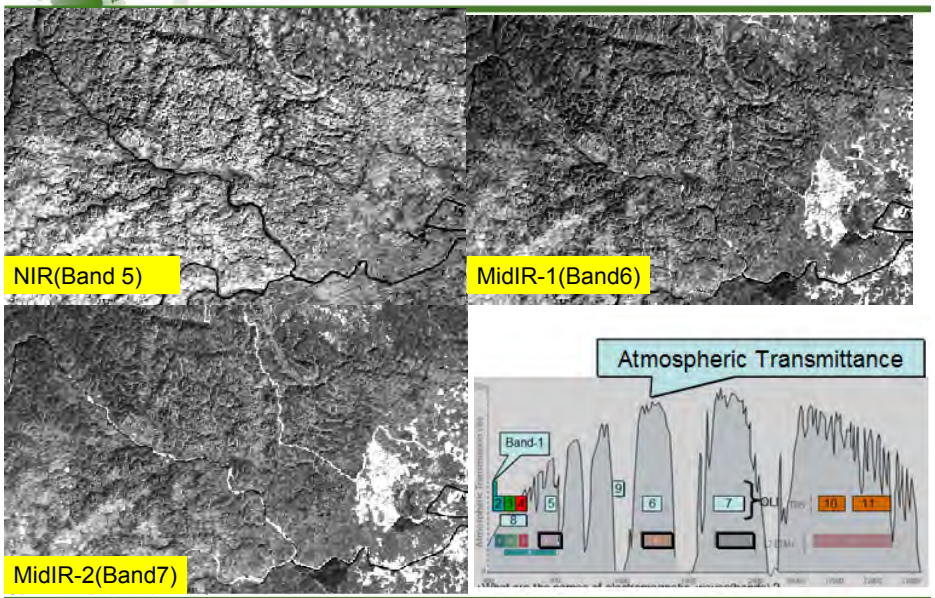
[Landsat ETM+ Spectral Bands]

1	0.45–0.52μm	30m
2	0.52–0.60μm	30m
3	0.63–0.69μm	30m
4	0.76–0.90μm	30m
5	1.55–1.75μm	30m
6	10.4–12.5μm	60m
7	2.08–2.35μm	30m
8	0.50–0.90μm	15m

Mid-IR2

RGB=B432

Landsat Infrared Band Image (Landsat8)



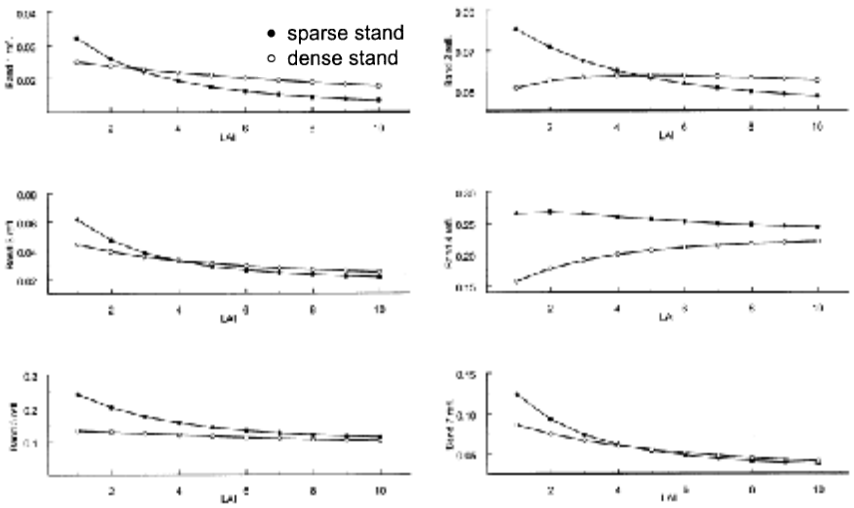
Study Results on LAI

Parameters in the ETM+ optical channels for two different pine stands (sparse and dense) to which the forest canopy reflectance model is most sensitive. (Eklundh, et.al.)

	Blue (B1)	Green (B2)	Red (B3)	Near IR (B4)	Mid-IR1 (B5)	Mid-IR2 (B6)
Stand 1 (sparse)	ground reflectance	ground reflectance	sun angle	ground reflectance	ground reflectance	sun angle
Stand 2 (dense)	Leaf refractive index	chlorophyll	Leaf structure	tree height	leaf water	LAI

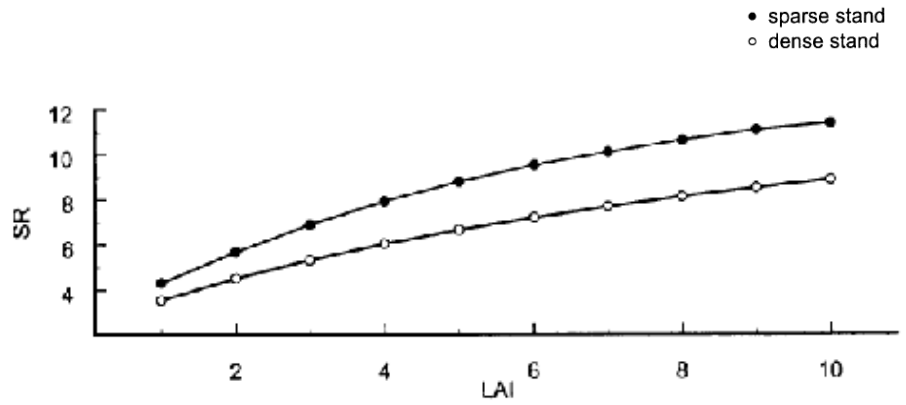
LAI=Leaf Area Index

Correlations among Bands and LAI



(Eklundh)

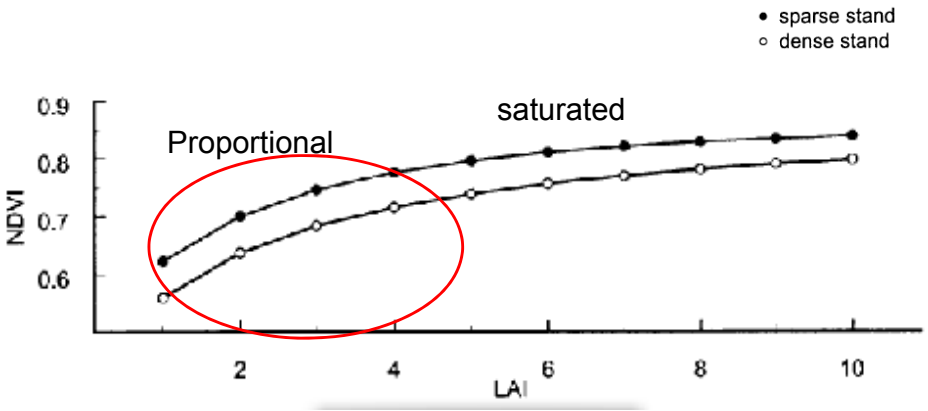
Correlation between SR and LAI



SR=Simple Ratio =R/NIR=SVI

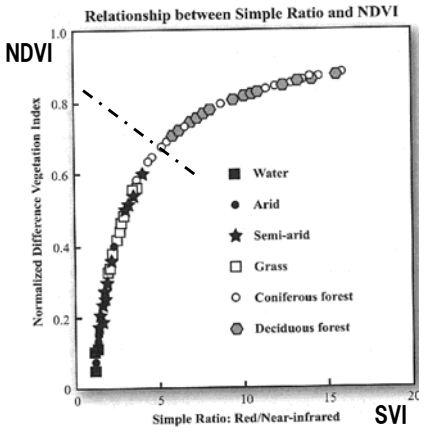
(Eklundh)

Correlation between NDVI and LAI



+Sparse area have better correlation than that's of the dense stand. (Eklundh)

Relationship between SVI and NDVI



$$SVI = \frac{\rho_{red}}{\rho_{nir}}$$

$$NDVI = \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + \rho_{red}}$$

(Jensen)

◇The NDVI is a normalized ratio of the near-infrared and red bands, and functionally equivalent to and is a nonlinear transform of the simple ratio.

Radiative Properties (Summary)

◇Much of the light reflected from a canopy has undergone more than one reflection. Thus, the overall reflectance of a dense canopy is usually substantially less than the reflectance measured for a single leaf. → Dense forest ➔ Darker

◇As leaf-area index decreases, the canopy reflectance tends to that of the underlying soil.

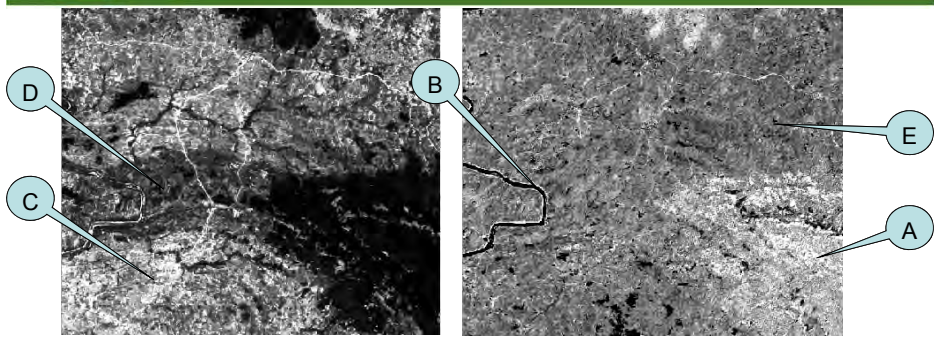
◇Radiation becomes enriched in the near- infrared both as the number of reflections at leaf surfaces increases and with increasing depth in the canopy.

◇Because the canopy albedo depends critically on canopy structure, albedo changes as a function of the solar angle.

◇The strong decrease in soil reflectance as it get wet or burnt can have a substantial effect on overall canopy albedo for sparse canopies.

(Albedo=Total reflectance of light)

Comparison of Red and Near IR Bands

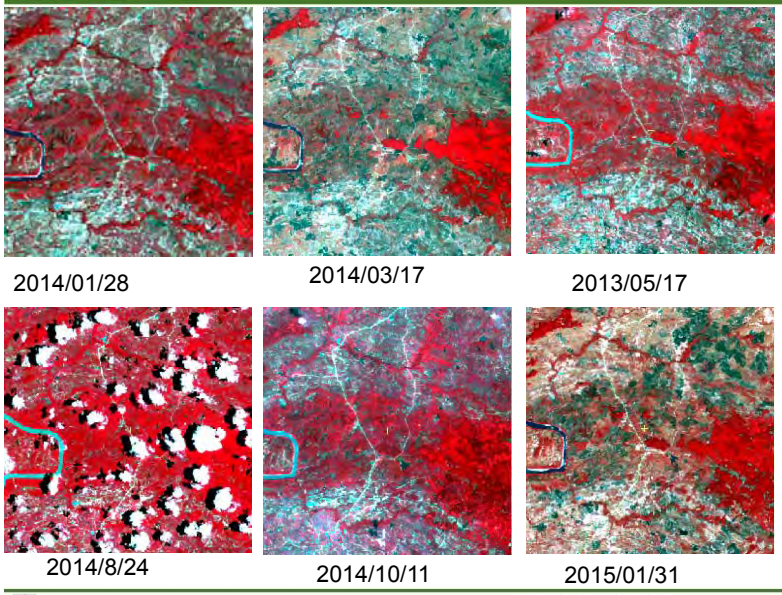


Red Color Band (Band 4) Near Infrared Band (Band 5)

Which features (define) have high, medium and low radiation (reflectance) of red and near LR lights ?

Band	A( )	B( )	C( )	D( )	E( )
4(Red)					
5(NIR)					

Multi-temporal Landsat_8 Images of S. Savannakhet



2014/01/28 2014/03/17 2013/05/17

2014/8/24 2014/10/11 2015/01/31

Landsat_8 Data Analyses of NDVI & SVI

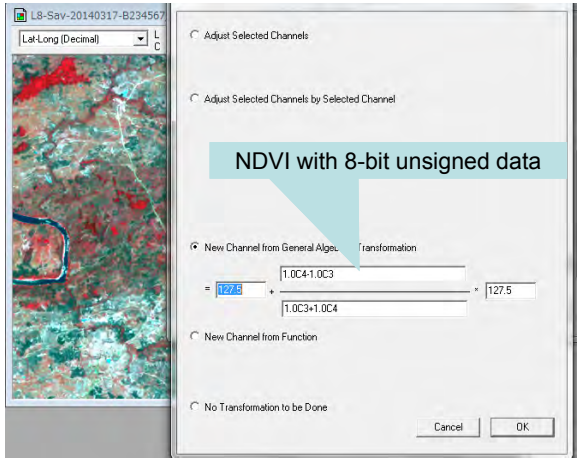
Obtain and Compare NDVI and SVI Data for Savannakhet Landsat_8 Images:

- 2014/03/17⟶ (file:)
- 2013/05/17 (file:)
- 2014/08/24 (file:)
- 2014/10/11 (file:)
- 2015/01/31 (file:)

(Use ArcGIS raster data processing functions)

NDVI and SVI (Simple Vegetation Index)

Computations of NDVI and SVI



NDVI(8bits)=

$$127.5 + \frac{(B4 - B3)}{(B4 + B3)} * 127.5$$

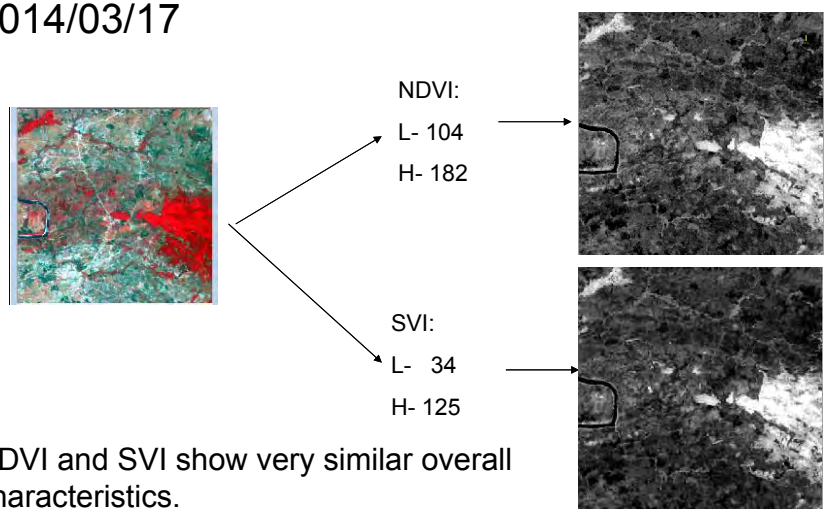
SVI(8bits) =

$$(B4 / B3) * 50$$

(MultiSpec software)

Actual NDVI and SVI (End of Dry Season)

Savannakhet Landsat_8 Images: 2014/03/17

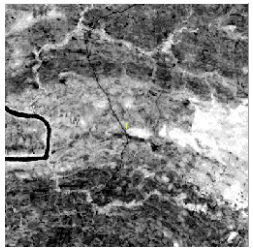


NDVI and SVI show very similar overall characteristics.

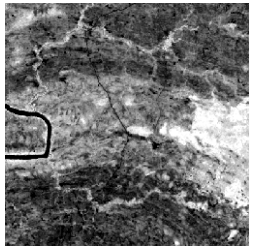
Actual NDVI and SVI (Beginning of Rainy Season)

- Savannakhet Landsat_8 Images:
- 2014/05/17

NDVI:
L- 119
H- 190

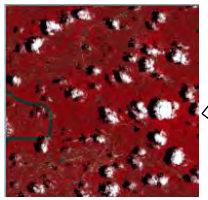


SVI5:
L- 44
H- 148

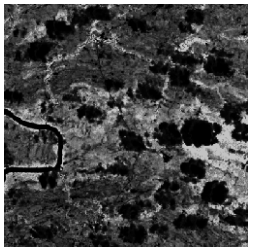


Actual NDVI and SVI (Middle of Rainy Season)

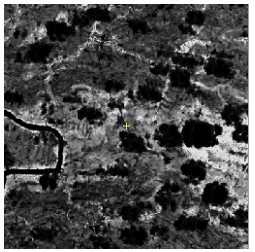
- Savannakhet Landsat_8 Images:
- 2014/08/24



NDVI:
L- 82
H- 205

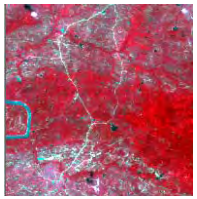


SVI5:
L- 23
H- 206

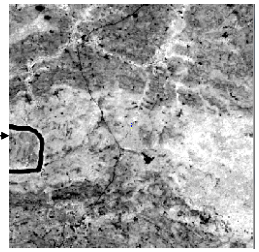


Actual NDVI and SVI (Beginning of Dry Season)

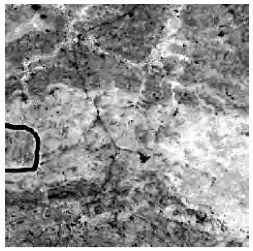
Savannakhet Landsat_8 Images:
2014/10/11



NDVI:
L- 120
H- 191

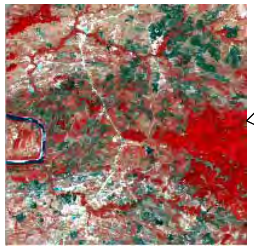


SVI5:
L- 44
H- 152

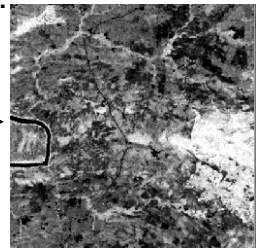


Actual NDVI and SVI (Middle of Dry Season)

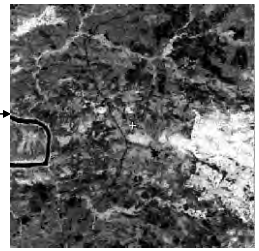
Savannakhet Landsat_8 Images:
2015/01/31



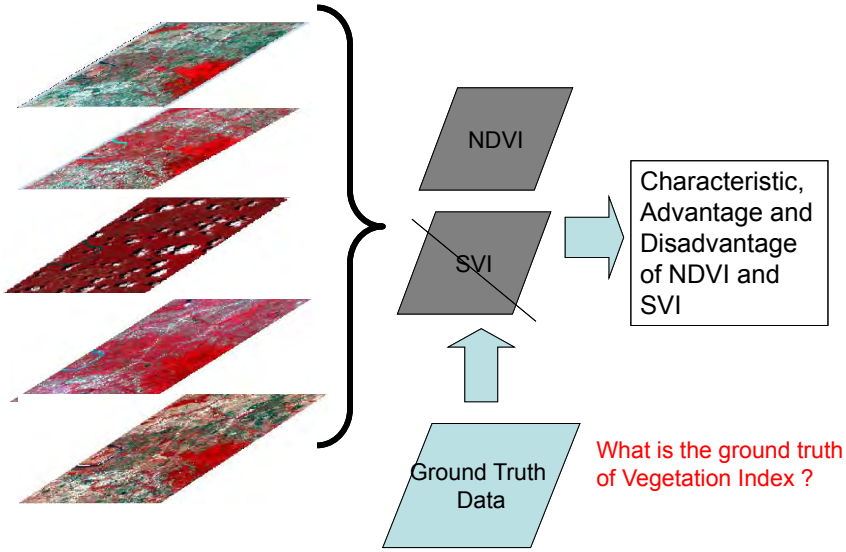
NDVI:
L- 100
H- 188



SVI5:
L- 32
H- 141



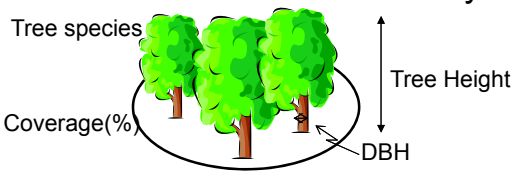
Analyses of NDVI, SVI and GT Data



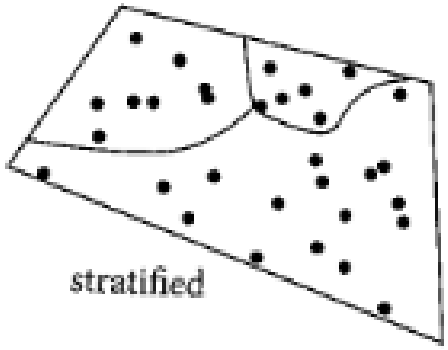
Ground Truth Data for vegetation Indexes

Ground Truth of Vegetation Index

- Biomass/Unit Area → Field Plot Survey
- Tree Density or Crown Density → Field Plot Survey
- Tree Height → Field Plot Survey
- Total Leaf Area → Field Plot Survey ?
- Etc. → Physical measurement ?

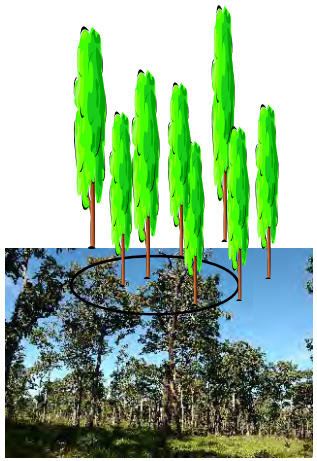


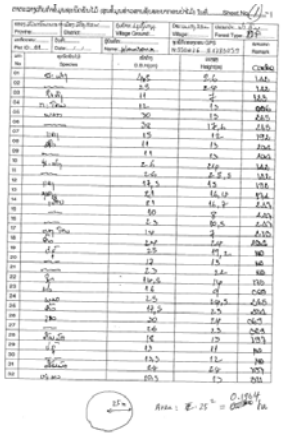
Sampling Survey of Forest Resources



Stratified Sampling Scheme

Sampling Forest Plot Survey





(From Forest Plot Survey in 2013)

(THE STUDY ON THE STRENGTHENING OF METHODOLOGICAL AND TECHNOLOGICAL APPROACHES FOR REDUCING DEFORESTATION AND FOREST DEGRADATION WITHIN THE REDD IMPLEMENTATION FRAMEWORK:APPLICATION IN LAO PDR, April 2012, Asia Air Survey Co.,Ltd.)

Estimation of Biomass

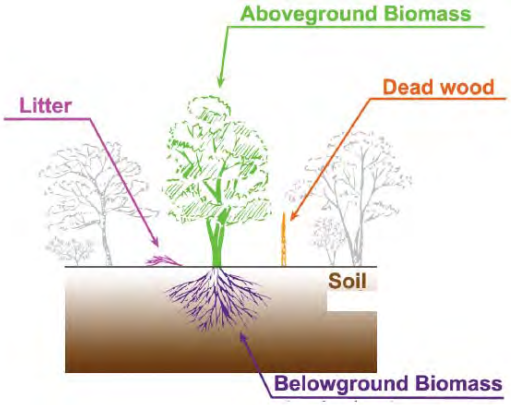
Estimation of Biomass and Carbon

Allometry Model

In general, an allometry equation is used instead of the method of calculation using the stem volume, basic wood density, biomass expansion factor and others based on the forest register and yield table, because the tropical forest is characterized by complicated varieties of tree species and a great variety of tree shapes.

Carbon Estimation

Conceptual View of Five Carbon Pool



(THE STUDY ON THE STRENGTHENING OF METHODOLOGICAL AND TECHNOLOGICAL APPROACHES FOR REDUCING DEFORESTATION AND FOREST DEGRADATION WITHIN THE REDD IMPLEMENTATION FRAMEWORK:APPLICATION IN LAO PDR, April 2012, Asia Air Survey Co.,Ltd.)

Example of the Allometry Equation

Dr. Kiyono's Allometry Equation:

$B = 5.29 \times ba^{1.24} \times D^{1.28}$

B : Living Biomass (kg dry matter / tree)

ba : Basal Area = $\pi \times DBH^2 / 4$ (m^2)

D : Basic Wood Density (oven-dry. kg / moist m^3)

$C = B \times 0.47$

C : Living Biomass Carbon Stock (kg C / tree)

0.47 : Carbon Fraction (kg C / kg d.m.)

Application: All the trees in tropical forest having a diameter of 60 cm or less at breast height

Advantages: Since basic wood density is used, amount of carbon stocks are different according to each tree species even if the DBH is the same. This provides differentiation and reduces errors. This equation provides a basis for calculation in the allometry equation (4.1) for the mean overstory height and the forest stand biomass carbon stock. This ensures consistency in the calculation of carbon stocks.

Disadvantages: In many of the tropical forest of Lao PDR, DBH is more than 60 cm. The tropical forest is characterized by difficult identification of the tree species. Even if the tree species can be identified, basic wood density is not clear in many cases.

(THE STUDY ON THE STRENGTHENING OF METHODOLOGICAL AND TECHNOLOGICAL APPROACHES FOR REDUCING DEFORESTATION AND FOREST DEGRADATION WITHIN THE REDD IMPLEMENTATION FRAMEWORK:APPLICATION IN LAO PDR, April 2012, Asia Air Survey Co.,Ltd.)

Example of the Allometry Equation

IPCC's General Allometry Model for Tropical Forest

$Ya = \exp[-2.289 + 2.649 \times \ln(DBH) - 0.021 \times (\ln(DBH))^2]$

Ya: Aboveground Biomass (kg dry matter / tree)

Application: Tropical trees in general having DBH of 5 to 148 cm in the tropical low land with an annual precipitation of 2,000 to 4,000 mm

$BBD = \exp[-1.0587 + 0.8836 \times \ln(ABD)]$

BBD: Belowground Biomass (t dry matter / ha)

ABD: Aboveground Biomass (t dry matter / ha)

●Method of biomass estimation and allometry model for Lao forest will be studied and developed in the near future.

Estimation of Above Ground Biomass

Estimation of the above ground biomass from the field plot survey data:

DBH ⇒ Basal Area ⇒ B

$Ya = \exp[-2.289 + 2.649 \times \ln(DBH) - 0.021 \times (\ln(DBH))^2]$

Ya: Aboveground Biomass (kg dry matter / tree)

Application: Tropical trees in general having DBH of 5 to 148 cm in the tropical low land with an annual precipitation of 2,000 to 4,000 mm

$BBD = \exp[-1.0587 + 0.8836 \times \ln(ABD)]$

BBD: Belowground Biomass (t dry matter / ha)

ABD: Aboveground Biomass (t dry matter / ha)

(IPCC Allometry Equations)

Computation of Biomass and Carbon

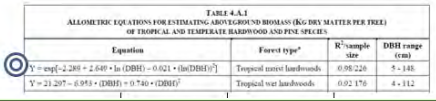
Excel Computation using IPCC Allometry Equation

Tree number

No.	DBH (cm)	IPCC GPG-LULUCF Ya	Allometry Equation LN(DBH)	(LN(DBH))^2	Plot_1 Height(m)	Codes in "Trees of Lao"	Scient Name
01	45.0	1,791.0	3.80666	14.49068	26.0	142	
02	25.0	412.0	3.21888	10.36116	24.0	142	
03	11.0	52.0	2.39790	5.74990	7.0	123	
04	12.0	64.0	2.48491	6.17476	13.0	6	
05	30.0	651.0	3.40120	11.56814	15.0	265	
84	14.0	95.0	2.63906	6.96462	15.0	109	
85	26.5	477.0	3.27714	10.73968	22.5	142	
Average	22.1				19.1		

Total	31,742.0 kg d.m.
ABD	161.70 t d.m. / ha
BBD	31.00 t d.m. / ha
Living Biomass	192.70 t d.m. / ha
Carbon	96.4 t C / ha

r=25 m
(0.1964 ha)



IPCC Good Practice Guidance for LULUCF

Chapter 4: Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol

Annex 4A.2 Examples of allometric equations for estimating aboveground biomass and belowground biomass of trees

TABLE 4.A.1
ALLOMETRIC EQUATIONS FOR ESTIMATING ABOVEGROUND BIOMASS (Kg DRY MATTER PER TREE) OF TROPICAL AND TEMPERATE HARDWOOD AND PINE SPECIES

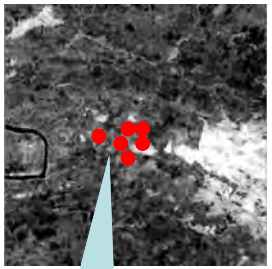
Equation	Forest type*	R^2/sample size	DBH range (cm)
$Y = \exp[-2.289 + 2.649 \cdot \ln(DBH) - 0.021 \cdot (\ln(DBH))^2]$	Tropical moist landwoods	0.98/226	5 - 148
$Y = 21.297 - 6.953 \cdot (DBH) + 0.740 \cdot (DBH)^2$	Tropical wet landwoods	0.92/176	4 - 112

Results of the Biomass Estimation

	Living Biomass	Carbon
Plot 1 :	192.70 tdm/ha	96.4 tC/ha
Plot 2 :	267.10 tdm/ha	133.6 tC/ha
Plot 3:	359.00 tdm/ha	179.5 tC/ha
Plot 4:	260.30 tdm/ha	130.2 tC/ha
Plot 5:	209.70 tdm/ha	104.9 tC/ha
Plot 6:	137.00 tdm/ha	68.5 tC/ha

Analysis of Vegetation Indices and Biomass

+Vegetation Indices ⇔ Above Ground Biomass (from Plot Survey Data)

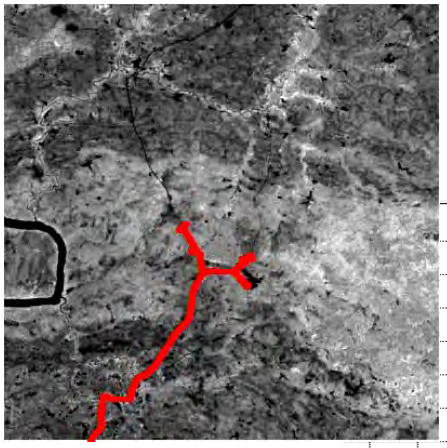


+Crown Cover Rate (from Aerial Photos)

Sample Plots by 2013 field survey

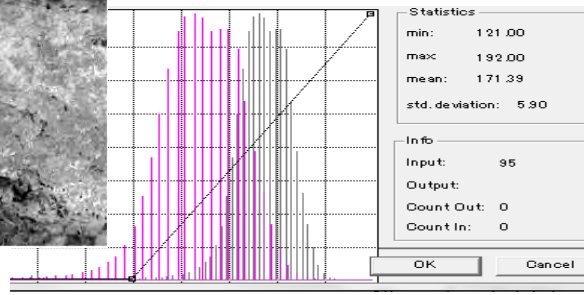
Correlation Analysis

Value of NDVI (2014/10/11)-Savannakhet

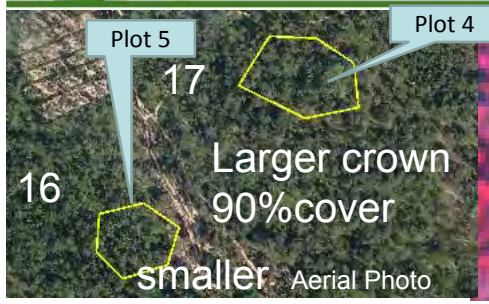


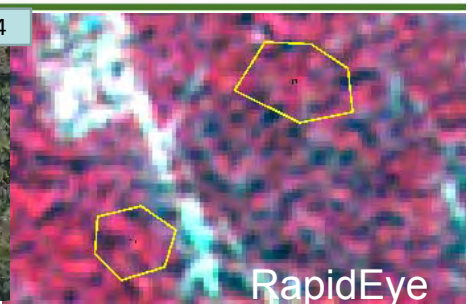
NDVI=121 – 192

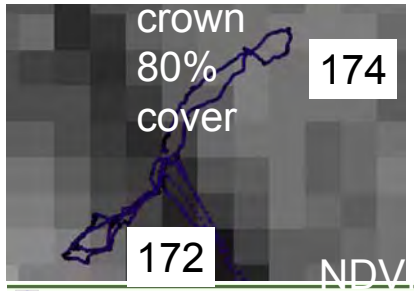
(128<Vegetated Area)

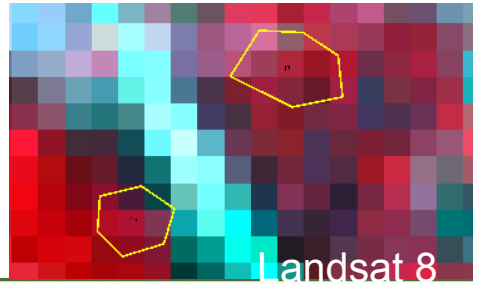


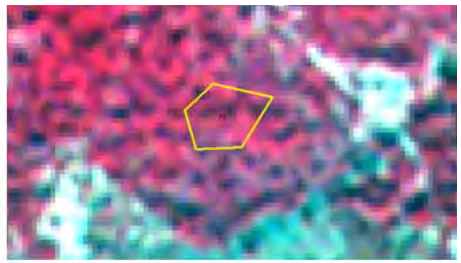
Comparison of Images

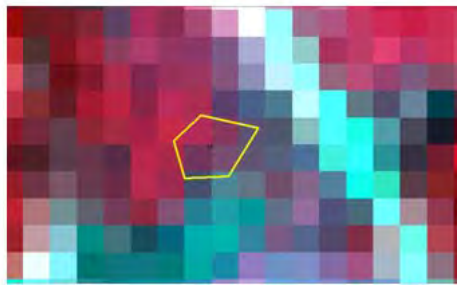


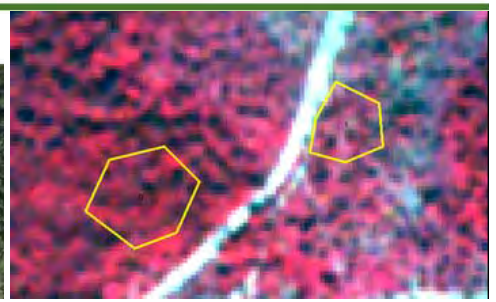


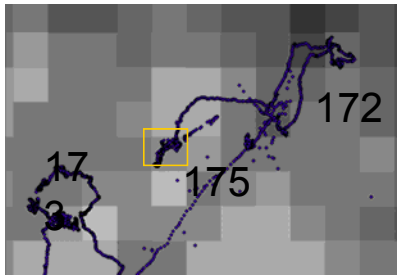


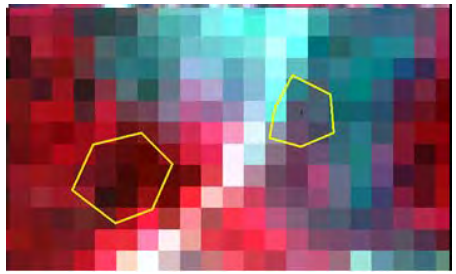


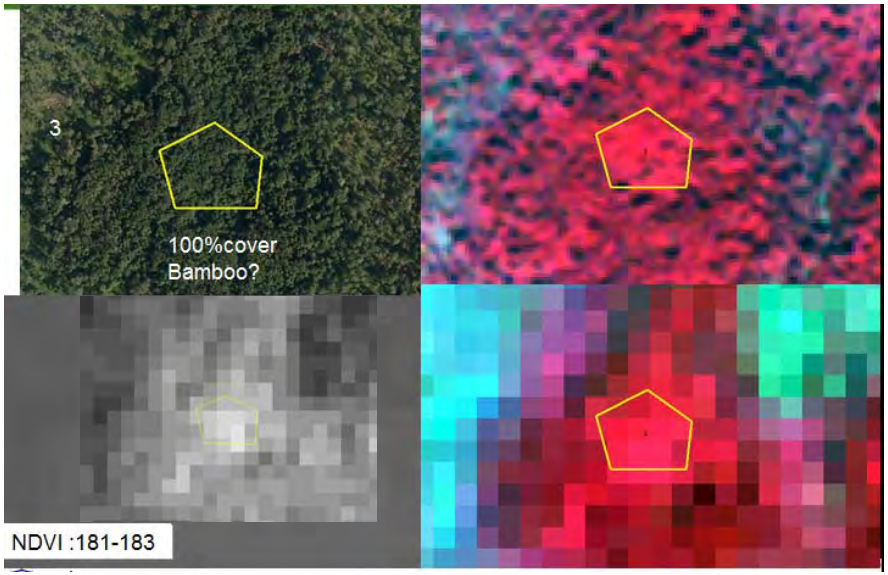






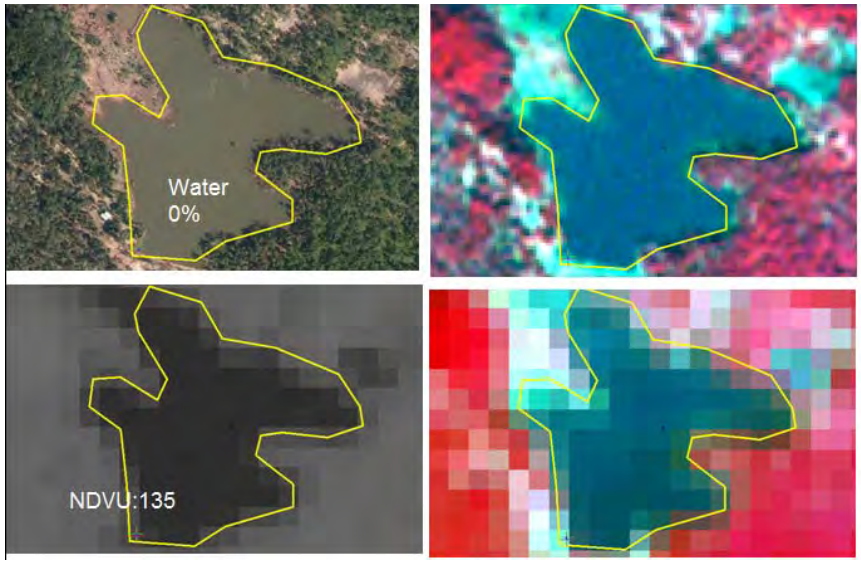




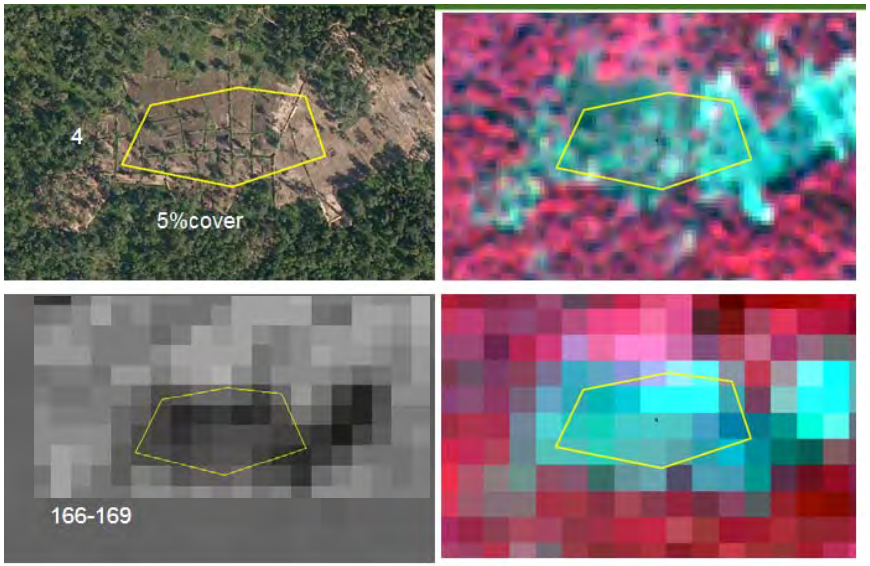


Enlarged aerial photo

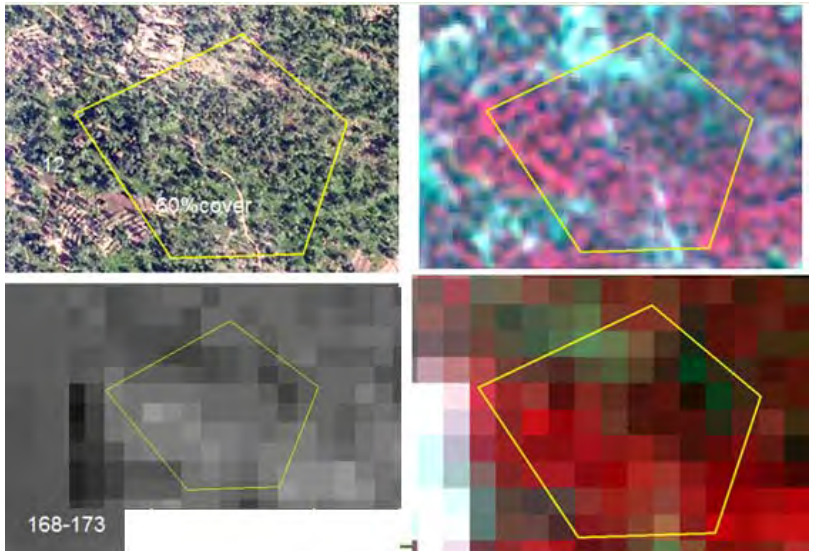
No.5 area (Water)

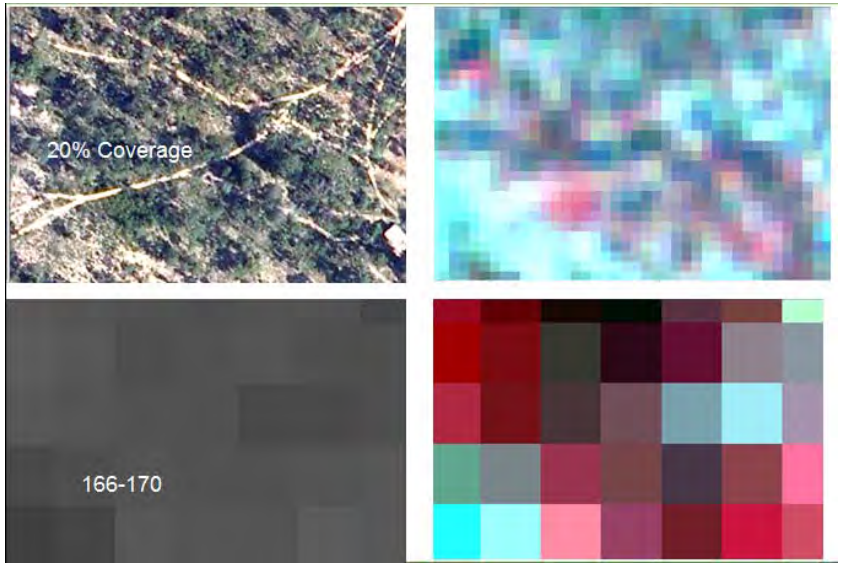


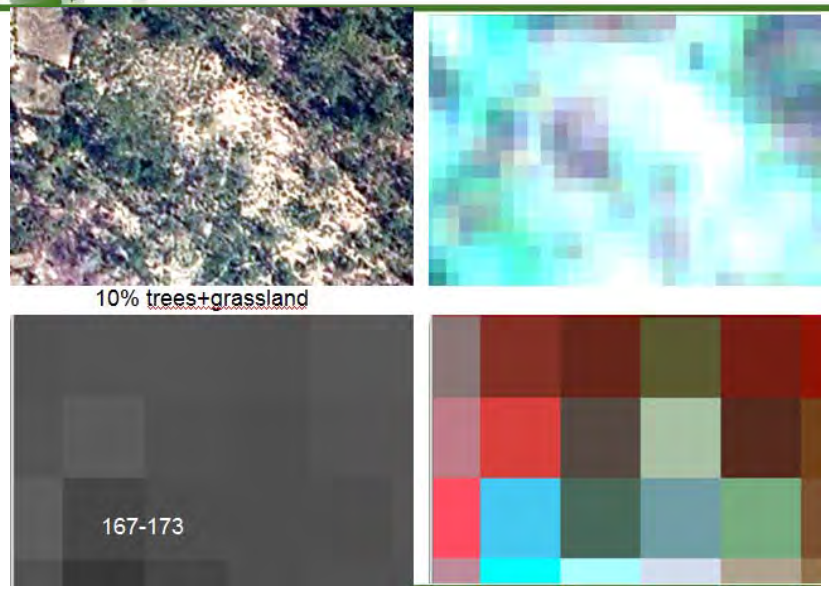
No.4 Area

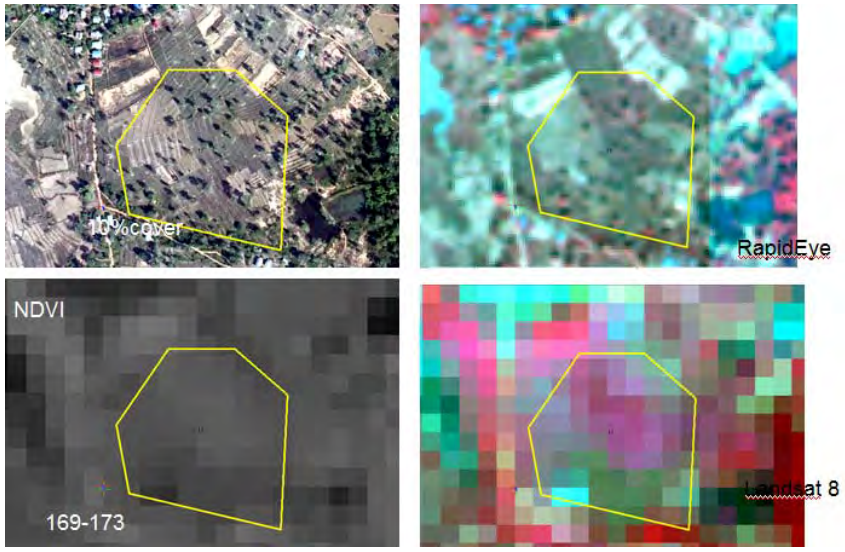


No.12 area

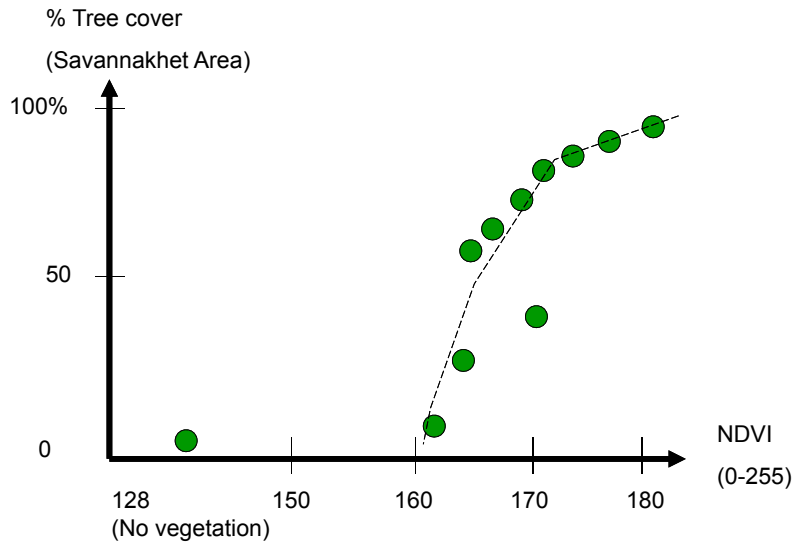

12
80%cover
168-173


20% Coverage
166-170


10% trees+grassland
167-173


10%cover
RapidEye
NDVI
169-173
Landsat 8

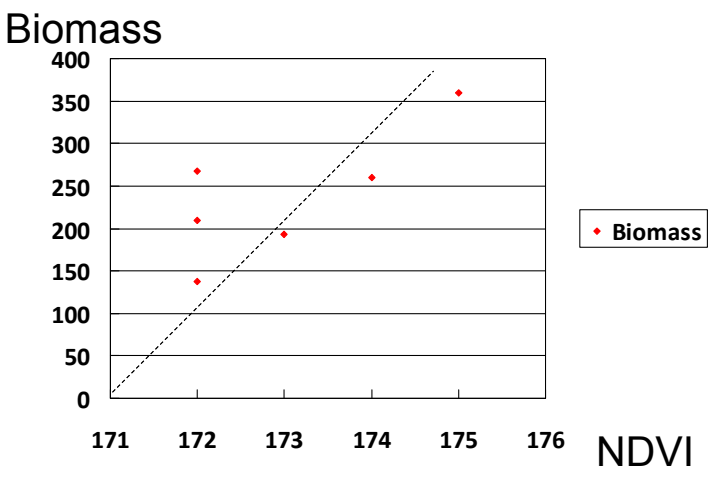
NDVI vs. Tree Coverage



Results of the Biomass Estimation

	Living Biomass	Carbon	NDVI
Plot 1 :	192.70 tdm/ha	96.4 tC/ha	173
Plot 2 :	267.10 tdm/ha	133.6 tC/ha	172
Plot 3:	359.00 tdm/ha	179.5 tC/ha	175
Plot 4:	260.30 tdm/ha	130.2 tC/ha	174
Plot 5:	209.70 tdm/ha	104.9 tC/ha	172
Plot 6:	137.00 tdm/ha	68.5 tC/ha	172

Relationship between NDVI and Biomass



(Biomass Data: From the data obtained from the field survey data carried out by Asia Air

Summary

8. Summary

◇RS practice needs many fundamental knowledge of sciences and technology.

◇The lecture “theory of remote sensing-Part 2” tried to cover very basic topics with some practical example including a field survey.

◇In addition to these basic knowledge, practical study of image interpretation combined with field works would be useful to improve skills for the remote sensing image analysis.

◇Continuous self-studying is expected after this.

Thank you very much !

Khoputyai Rai Rai !

ありがとうございました

ラオス人民民主共和国
ラオス国持続可能な森林経営及びREDD+のための国家森林情報システム構築に係る能力向上プロジェクト
（第2年次）

業務完了報告書

添付資料９：Overview of potential NFI design approaches

Overview of potential NFI design approaches

Background

Through the JICA funded program "Capacity Development Project for Establishing National Forest Information System for Sustainable Forest Management and REDD+", the Department of Forestry is working with Kokusai Kogyo Co and Asia Air Survey to assist in the design of an updated National Forest Inventory.

One of the first steps in this work is to determine the main objectives of the NFI, what general approaches DoF and FIPD are interested in the NFI including, an overview of potential parameters that will be collected, and potential ways the information from such an NFI approach can be used.

Prior to developing our proposed NFI design approach, a more in depth **background document** will be completed. This is currently under development and it is hoped that this document will help inform the design of the NFI. In addition, this document will also point out any additional decision points that need to be made prior to finalizing the NFI design. Once a draft is created this will be shared with key counterparts at DoF and FIPD for comments and feedback. Information expected to be in this background include:

- A review of existing projects and previously collected data. This will also include a summary of what data was collected and how this information may be able to inform the NFI design.
- An overview of what NFIs generally are and a summary of NFIs from select countries
- A review of the existing institutional arrangements within FIPD
- A review of potential ways the NFI will fulfill the requirements under the Forestry Law, MAFF No. 0108/AF.2005, and potential others as identified
- An overview of different options for NFI design and decisions required to move forward
- Summary of NFI piloting

However, to assist in the presentation of different NFI approaches, it will be helpful to receive some initial feedback on the priorities of DoF and FIPD's. Therefore, below we present an initial overview of some specific technical approaches. At the end we have included a list of potential parameters that the NFI could include. This is not a 'suggested' list, but instead a list of types of data that are collected elsewhere in NFIs.

At this time we are asking for initial feedback. Please note – this does not need to be seen as a definitive answer. Instead, it will be used to guide the proposed NFI sampling design. In the coming months this sampling design will be shared with key DoF and FIPD counterparts and stakeholders for comments. However, if there are specific components that are required by DoF and FIPD to be incorporated into the NFI, please be sure to state this explicitly.

What is a National Forest Inventory?

Many countries use the approach of developing a National Forest Inventory (NFI) as a way to understand the current conditions of the forests and other land types. The forest (and sometimes nonforest) lands are sampled by taking field measurements at different locations across the country. These field measurements are combined with land cover mapping and land use information to summarize different aspects of the forest land. Often, NFIs are designed to have a wide array of purposes but often the goal is to have an independent estimate of forest resources such as timber or woodfuel, to examine the forest condition, and to estimate standing carbon stocks. Different countries have developed different NFI approaches. A summary of some examples will be included in the background document currently under development.

Examples of the types of information NFI's produce include:

- Estimates of standing timber volume for each land cover class
- Estimates of carbon stocks in each land cover class
- Other information on trees: number per hectare, basal area, size distribution of trees in forest types, species distribution
- Dominance of shrubs and other non-tree pools
- Degradation state of forest type
- Forest health – disease, drought/water stress, natural disturbances, degradation status, Invasive species
- Habitat
- Land use

Decisions required prior to initiation of an NFI

Before the NFI design can be finalized or the NFI design implemented, there are two main decisions that Lao PDR must make and be finalized. These are:

- Definition of Forest
    - A final decision must be made on the 'definition of a forest'
- Land cover classes to include in national classification system
    - Need a final version of what land cover classes will be used in national maps
    - Must include detailed definition of how to identify the land cover class through remote sensing and when on the ground
    - Class definition must state if this class is considered 'forest'

Therefore, the DoF is highly encouraged to take the necessary steps to see that these decisions are formally made. Without these decisions, the NFI design and implementation will be stalled.

Overview of potential NFI design approaches

Dynamic Conditions - Guiding Principle

When designing the NFI, a key guiding principle is that Lao PDR is diverse and dynamic. The geography and vegetation types along with agricultural and other land use systems vary significantly across the country. The land use, and in particular the land use management, of a particular area of the landscape may change over time.

This dynamic nature also pertains to technology, capacity, resource availability, and key objectives. Although the DoF and FIPD may have strong interest and intentions of conducting certain types of work, the availability of funds and resources to implement such work may limit the final scope and schedule of the NFI and may change over time. In addition, the main interests of DoF and FIPD may also change as local and global needs change. For example, historically the NFI was focused more on timber volume while now there is an interest in carbon stocks. In the future other needs may arise.

Therefore, wherever possible, the NFI will also be designed to be dynamic and adaptive. This will influence the sampling design, the frequency of data collection, and the parameters measured.

Key NFI Objectives

As stated, the NFI can be designed with different purposes in mind. Based on recent discussions, potential priorities include:

- Carbon stocks
- Timber volume
- Forest Condition
- Carbon stock changes over time (only through successive NFIs)
- Timber volume changes over time (only through successive NFIs)
- Forest Condition changes over time (only through successive NFIs)
- Evidence of land use

It is recommended that FIPD and DoF, together with the Ministry of Natural Resources and Environment to identify objectives that are of the highest priority to the Government of Laos (GoL). This will allow the sampling design to be optimized for those objectives. In addition, as additional parameters are added, the total amount of time it takes to complete all measurements in each inventory plot goes up, thus increasing the financial and time resources required to complete such an NFI.

As is well known, under the SUFORD project, extensive data is being collected on timber volumes within the Production Forest Areas (PFAs). The sampling design used for that effort will result in a large number of sampling points and detailed estimates of timber volumes across each PFA. Usually the density of sample points included in an NFI would be much lower than what is currently being implemented in the SUFORD PFA sampling design. Therefore, a timber assessment completed under an NFI would not provide the level of detail that the PFA inventory will create. Instead, it would provide an estimate of average timber volume availability across each land cover mapping class.

Parameters related to the 'Forest Condition' can also be included. These measurements may satisfy some of the requirements of National Assembly Cabinet Office No 273.

Action Requested:

Please add comments on what are the main priority objectives of the NFI. As needed, please add additional objectives.

Potential Objectives (add others as needed)	Priority (Please list as High, Medium, Low. More than one objective can be listed as same priority)
Carbon/biomass stocks of each land cover class (including forest and non-forest classes)	
Timber volumes (PFA only)	
Forest condition	
Other forest resources (e.g. NTFP)	
Carbon stock changes over time (only through successive NFIs)	
Timber volume changes over time (only through successive NFIs)	
Forest Condition changes over time (only through successive NFIs)	
Evidence of land use	
Other	

Land cover types included within NFI

The NFI field measurements can be conducted within a variety of land cover types. This could include:

- Forest classes
- Non-forest natural land cover classes (eg savanna, grassland)
- Agricultural and fallow land

One option that has been discussed is to collect different number of plots within different types of land. The suggestion is that for forest classes, many sample plots will be taken. The exact number of plots will be dependent on the variability found within a particular forest class and specific regulations stated in the Forest Laws of Lao PDR.

For non-forest classes, although field measurements will still be taken, the number will be lower. Depending on the variability within a certain non-forest class, this may result in estimates of carbon (or other land characteristics) to have less precision.

Action Requested:

Please add comments on what mapping classes should be included within the NFI design. As needed, please add additional classes or comments.

Mapping Class	Sample: (Many plots, few plots, No sampling)
All forest classes	
All 'Other wooded area' classes	
All 'Permanent Agric' classes	
All 'Potential Forest' classes	
Grassland + Swamp class	
Settlements	
Urban	
Other	

Sample Distribution Design

Many NFIs in other countries were developed prior to the technological advances in GIS and Remote Sensing and therefore use a very systematic sampling approach and are not optimized for any particular goal. However, now a variety of sampling designs are easy to create within a GIS environment.

For many NFIs using systematic sampling approaches, plots are laid out across the country (sometimes systematic, sometimes combination of systematic and random) irrespective of the land cover. Instead, during data analysis, each plot is placed in a certain strata depending on what type of land cover was actually in the plot. This is called 'post-stratification'. When the total number of plots is large, it will generally be sufficient to estimate any forest characteristic with good precision at a national level. Generally, the location of each sample point is fixed over time and permanent sample plots are installed.

However, if a very large number of plots are not taken, then there is a chance some forest types may be under-sampled. This will mean that for some forest classes there will be an insufficient number of data points resulting in low precision estimates.

Alternatively, the sampling design can be 'pre-stratified' by land cover mapping class. The number of sample points can be based on the variability of that land cover class and a precision target. This would mean that the number of sample points would not be the same for all land cover classes. This is also an acceptable and standard approach to sampling. However, one important consideration in following this approach is that due to a dynamically changing landscape in Lao PDR, land cover will likely change over time. Thus, for each successive forest inventory, a new nation-wide land cover map and the location of sample points would also need to be updated.

Given the dynamic land cover change in Lao PDR and the number of sample points resources will allow, it may be most efficient to have the sampling design be 'pre-stratified' by land cover mapping class.

Another potential recommendation is that only a sub-set of the sample points be installed as permanent sample points while the majority of sample points will be temporary. This will allow some understanding of how various aspects of the forests change over time, such as the growth rates of trees, while not devoting significant resources toward installing permanent plots in locations where there is a high probability of land cover/use change.

Action Requested:

Please state if there are particular requirements or recommendations you have about the sampling design. In addition, please add comments on potential sample distribution options and sample point types:

Sample Distribution Options	Comments
Systematic, post-stratification (similar to Vietnam)	
Systematic random, pre-stratification (similar to Houaphan CliPAD sampling)	
Other	
Other	

Sampling type	Comments
All temporary plots	
All permanent plots	
Combination of temp. and permanent plots	
Other	

Potential Institutional Arrangements

Under the previous NFI, field data collection was the responsibility of the National FIPD staff. However for the upcoming NFI, it has been proposed that the NFI could be conducted by national, provincial (PAFO and PONRE) and district (DAFO and DONRE) staff working together. This would allow more data to be collected more rapidly. However, this approach would also require a large amount of training. Thus, the sampling design and field measurement collection procedures must be very easy to learn and limit subjective decision-making.

An example of a delineation of arrangements could include:

- National level FIPD:
  - Sampling design
  - Field SOP manual
  - Training materials
  - Train provincial level staff on field methods
  - Data analysis
- Provincial and District Staff
  - Provincial-level coordination and facilitation of NFI
  - Conduct field inventory
  - Enter data from datasheets/tablet into database, but no analysis

Action Requested:

To guide this process it will be helpful to know what institution/agency should be responsibly for **leading**, **supporting** and/or **not involved (N/A)** for each of the main tasks of the NFI. In the table below, please describe any specific recommendations on institutional arrangements.

	National	**Provincial**	**District**	**Local**
Key Task	(Indicate: *Lead*, *Support*, or *Not Applicable in boxes below*)			
Sampling design				
Field SOP manual				
Training materials				
Conduct Training				
Conduct field inventory				
Reporting on field inventory				
Enter data into database				
Data analysis				
Summary Reporting				
other				
other				
other				
other				

Frequency and Timeline

National Forest Inventories are implemented in a number of different ways globally. In some countries the NFI is a permanent component of the government and role of the national Department of Forestry. Permanent fulltime staff are assigned to designing the sampling, conducting the fieldwork, and analyzing the results.

Alternatively, field sampling can take place within a shorter period of time, for example within 1-2 years and then repeated again after a set number of years.

Ultimately, the final approach to be used may need to be largely determined based on the availability of financial resources to complete the NFI. Therefore, as much as possible, the initial sampling strategy will be suitable for both approaches. As additional information is known about potential options for implementing, a decision will be made by DoF and FIPD.

If sampling will take place over more than one year, there must be an approach selected for how to order sampling. One approach that is used in other countries is for a subset of all plots to be measured within a given year throughout the country. One cycle is often 5-10 years. Below is a simplified example of a 5-year cycle. All sample points are assigned one group (A, B, C, D, E). In a given year, all sample points from one group are measured. For example, in year 1 all sample points in "group A" are measured.

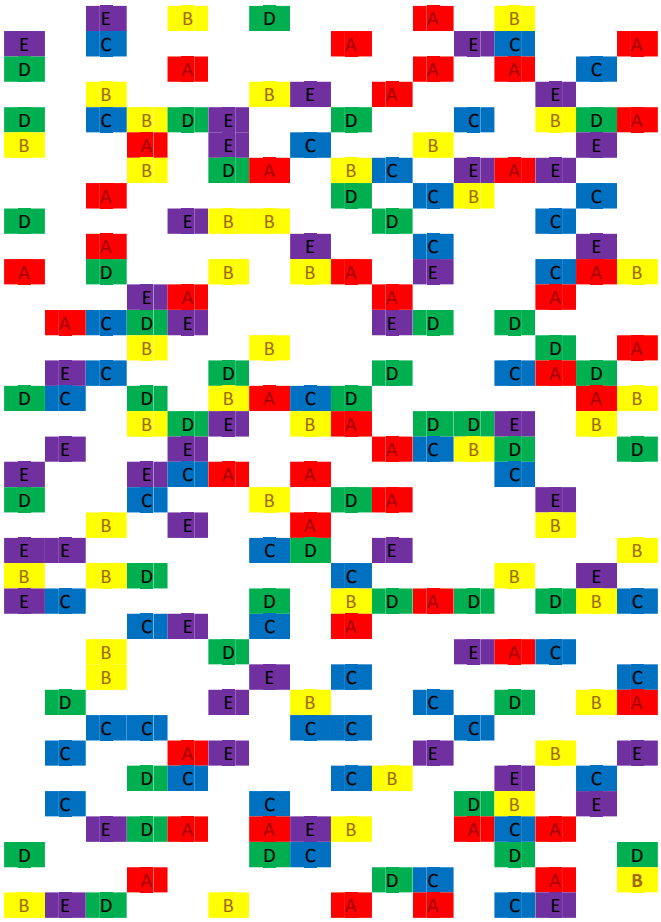


Figure 1: Example of a nation-wide inventory spaced out over 5-years.

Another approach that could be included would be to divide the country into groups geographically – e.g. North, Central, South. With sampling taking place in one group per year. Below is a simplified example.

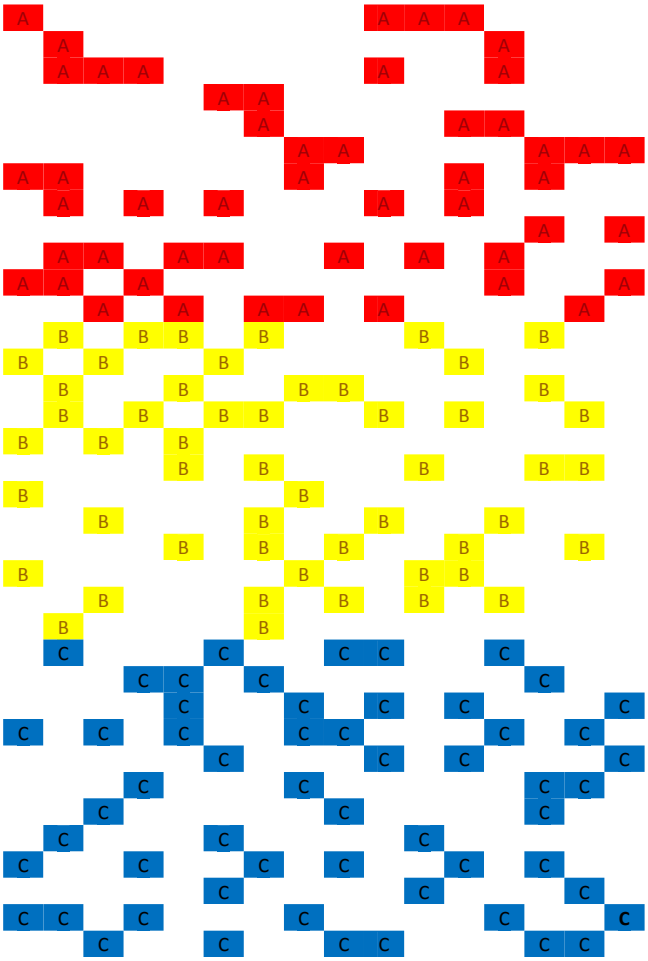


Figure 2: Example of a region-based inventory spaced out over 3 regions and 3-years.

There are many positives and negatives to the different approaches. These can be laid out if desired. However, if there are specific needs and opinions now about this idea, please summarize them for us.

Action Requested:

Please describe any initial opinions on the frequency and time distribution of sample points.

Information NFI Will NOT provide

Although the NFI can be designed to collect a wide array of information, there is some information that would not be efficiently measured using an NFI approach. If desired, a more in-depth description of what specific factors the NFI will and not provide for REDD+ and UNFCCC National Communications can be provided.

REDD+: Although the NFI will provide information to create deforestation emission factors (EF), the NFI will unlikely provide direct emission factors for forest degradation (logging, fuelwood, fire) or emission factors for enhancements due to tree planting. In addition, the NFI alone will not provide any 'activity data' (AD) (Table 1). Instead, Lao PDR will need to set up a system to monitor activities. This will include creating successive land cover maps and monitoring the quantity of other activities such as degradation.

UNFCCC National Communications: There are only a selection of parameters that the NFI will need to provide for UNFCCC National Communications (NFI). Again, it will not be sufficient for EF from degradation or generate estimates of land areas in different categories (AD).

Table 1 Information on whether the NFI will provide data needed for REDD+ and National Communications

	Activity Data (e.g. area change per year)		Emission Factors (t CO2e/ha)	
	Historical	2015-2020	Historical	2015-2020
Forest – Nonforest / Deforestation				
--> Non forest	no	No	Yes	Yes
--> Slash and burn	no	No	maybe	maybe
--> Rice paddy	no	No	maybe	maybe
--> Agri plantation	no	No	maybe	maybe
Forest-Forest / Degradation				
Nat forest to Plantation	no	no	maybe	maybe
Fuelwood	no	no	No	No
Legal logging	no	no	No	No
Illegal logging	no	no	No	No
Fire	no	no	No	No
Enhancement				
Forest growth	no	no	No	No
Afforestation	no	no	No	maybe

Timber volume: Although and NFI can be used to provide a general understanding of the timber availability in the country, the density of sample points will NOT allow estimates of timber volume at a local level. It will also not be suitable for monitoring overall degradation from logging through time.

Biodiversity: Although the main tree species composition will be known from the NFI, the NFI is not designed to find rare species. In addition, it will not provide information on non-tree species (eg other plants, birds, animals, insects) or define the 'High Conservation Value'.

List of potential parameters

Below is a list of the types of parameters that an NFI can collect along with the potential use of such a parameter. Please note – this table is a work in progress. Some parameters collected in existing studies may have been accidentally not included.

Please indicate which parameters you feel are high (H), medium (M), low (L) priority, or unnecessary (U) for inclusion in the NFI. If there are additional parameters should be included please add at the end.

Table 2: Types of parameters to be collected under different NFI purposes and a list of parameters used in a selection of past forest inventory projects. "X" Indicates that the parameter was included. Numbers Indicate the

Priority Parameter? (H,M,L,U)	Parameter	Purpose						Other Studies			
		Carbon	Timber Volume	NTFP resources	Land Degradation / Forest health	Forest Composition	Tree Growth Rate	1st NFI	FIM	CLIPAD	Production Forest Area Inventory
	<u>Sample point distribution</u>										
	Systematic							X			
	Random								X		X
	Two-stage systematic random									X	
	Post-stratification							X			X
	Pre-stratification								X	X	
	Permanent plots										
	Temporary plots							X	X	X	
	<u>Sample point type</u>										
	Single plots										
	Cluster plots, nested							X	X	X	
	Transect of plots, nested										X
	Circular plots								X	X	
	Rectangular plots							X			X
	<u>Sampling Information</u>										
	# Team members							8	6	3	X
	Time to walk to plot							40 hrs	1 day	1 day	
	Time to complete each carbon pool										

Priority Parameter? (H,M,L,U)	Parameter	Purpose						Other Studies			
		Carbon	Timber Volume	NTFP resources	Land Degradation / Forest health	Forest Composition	Tree Growth Rate	1st NFI	FIM	CLIPAD	Production Forest Area Inventory
	Costs of transport										
	Costs of fieldwork										
	Equipment used										
	Sample point information										
	Land Cover	X	X		X	X	X			X	X
	Land Use	X			X	X	X			X	X
	Photographs							X	X	X	
	Slope	X	X		X						X
	Slope Aspect				X						X
	Topographic position of plot							X			
	Surface topography class							X			
	LU evidence				X						
	Grazing				X						
	Fire				X						
	Logging				X						
	Logging evidence class							X			
	NTFP collection				X						X
	Stand Damage evidence class		X		X	X		X			
	Erosion, soil conditions				X						
	Canopy density				X	X		X	X	X	X
	Deciduousness				X	X				X	
	Leaf fall index				X	X				X	
	Forest Structure							X	X	X	
	Hauling distance from road		X					X			
	Hauling route		X					X			
	Epiphytes										
	main species				X	X					X
	Prevalence				X	X					X
	Evidence of wildlife class				X	X					X
	Evidence of 'Indicator' Species				X	X					

Priority Parameter? (H,M,L,U)	Parameter	Purpose						Other Studies			
		Carbon	Timber Volume	NTFP resources	Land Degradation / Forest health	Forest Composition	Tree Growth Rate	1st NFI	FIM	CLIPAD	Production Forest Area Inventory
	Trees										
	Species	X	X			X		X	X	X	X
	DBH	X	X				X	X	X	X	X
	H		X					X	X		X
	Buttress H	X	X					X			
	Bole H		X								X
	Bole length		X								
	Bole condition		X		X	X					
	Crown condition				X	X					
	Disease				X	X	X				
	Tree quality class		X					X	X		X
	Palms										
	Species	X		X	X			X	X	X	
	Height	X		X	X	X		X	X	X	
	Saplings										
	Number	X	X				X	X	X	X	X
	Species					X					
	Seedlings										
	Number	X	X				X				X
	Species					X					
	Bamboo										
	# culms, by age			X	X	X		X		X	X
	Species			X	X	X		X		X	X
	Rattan										
	# clumps			X	X	X		X			X
	# solitary			X	X	X		X			X
	estimate of natural regeneration potential			X							X
	Berberine, Kheua Haem										

Priority Parameter? (H,M,L,U)	Parameter	Purpose						Other Studies			
		Carbon	Timber Volume	NTFP resources	Land Degradation / Forest health	Forest Composition	Tree Growth Rate	1st NFI	FIM	CLIPAD	Production Forest Area Inventory
	# plants			X							X
	estimate of kg			X							X
	Cardamom, Mak Naeng										X
	# young plants			X							
	# mature plants			X							
	Malva Nut, Mak Chong										
	# trees			X							X
	fruit production category			X							X
	Lianas										
	species composition				X	X					X
	DBH	X									X
	Shrubs										
	prevalence class				X	X		X			
	species comp?				X	X					
	wet mass	X									
	sub-sample for dry mass										
	Non-woody veg										
	species comp?				X	X				X	
	wet mass									X	
	sub-sample for dry mass									X	
	Standing deadwood (including stumps)	X			X						
	DBH									X	
	Top diameter							X		X	
	Height							X		X	
	Lying Deadwood	X			X					X	
	Litter	X			X						
	wet mass									X	
	sub-sample for dry mass									X	
	Soil										
	bulk density	X			X						
	Carbon	X			X						

Priority Parameter? (H,M,L,U)	Parameter	Purpose							Other Studies			
		Carbon	Timber Volume	NTFP resources	Land Degradation / Forest health	Forest Composition	Tree Growth Rate		1st NFI	FIM	CLIPAD	Production Forest Area Inventory
	Type				X				X			X