Module 2.2 Monitoring activity data for forests remaining forests (incl. forest degradation)

Module developers:

Carlos Souza, Imazon

Sandra Brown, Winrock International

Jukka Miettinen, European Commission (EC)–Joint Research Centre (JRC)

Frédéric Achard, EC–JRC
Martin Herold, Wageningen University

After the course the participants should be able to:

- Describe different types of forest degradation and the approaches to monitor degradation
- Map and analyze various forest degradation processes using ground surveys and the remote sensing tools provided in the module

V1, May 2015

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GOFC-GOLD Global Observation of Forest and Land Cover Dynamics

FOREST CARBON PARTNERSHIP FACILITY

Background material

- GOFC-GOLD. 2014. *Sourcebook*. Section 2.2.
- GFOI. 2014. *Integrating Remote-sensing and Ground-based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests: Methods and Guidance from the Global Forest Observation Initiative* (MGD). Sections 2.2.2 and 3.
- Souza. 2012. “Monitoring of Forest Degradation.” In *Global Forest Monitoring from Earth Observation*.
- Morton, D., et al. 2011. “Historic Emissions from Deforestation and Forest Degradation in Mato Grosso, Brazil: 1) source data uncertainties”
- Simula. 2009. “Towards Defining Forest Degradation: Comparative Analysis Of Existing Definitions.” Working Paper 154, FAO.
- Herold et al. 2011. “Options for Monitoring and Estimating Historical Carbon Emissions from Forest Degradation in the Context of REDD+.” *Carbon Balance and Management.*
- Pearson, Brown, and Casarim. 2014. “Carbon Emissions from Tropical Forest Degradation Caused by Logging.” *Environmental Research Letters.*

Outline of lecture

1. Definition of forest degradation and IPCC GPG* context
2. Types of forest degradation
3. Approaches to assess forest degradation areas:
    i. Monitoring forest degradation from selective logging
    ii. Monitoring forest degradation from fuelwood collection
    iii. Remote sensing approaches:
        a) direct methods
        b) indirect methods
4. Software requirements

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Degradation: Introduction

- Forest degradation (changes in forests remaining forests) leads to a long-term/persistent decline in carbon stock.
- Emission levels per unit area are lower than for deforestation; cumulative and secondary effects can result in significant carbon emissions.
- Monitoring forest degradation is important to avoid displacement of emissions from reduced deforestation.
- More severe degradation (area/intensity) usually results in more distinct indicators for efficient national monitoring.

Defining forest degradation

- Over 50 definitions have been identified in the scientific literature (Simula 2009; Herold 2011).
- Broadly speaking, forest degradation is a type of anthropogenic intervention that leads to changes in forest cover, structure and/or composition, and function of the original forest.
- Changes can be temporary or permanent.
- Changes can affect biodiversity, carbon stocks, hydrological and biogeochemical cycles, soil, and other environmental services.

Example of forest degradation caused by recurrent logging and fires in Sinop region, Mato Grosso state, Brazil.

Earlier IPCC definition of forest degradation

- For the purpose of the UN Convention on Climate Change, IPCC defined forest degradation in 2003 based on removal of forest carbon stocks:

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

  (X, Y, and T have not been defined.)

Definition in terms of REDD+

- General guidance from SBSTA expert meeting (UNFCCC 2008):
  - "Degradation leads to a loss of carbon stock within forests that remain forests"
- Definition of forests directly affects definition of forest degradation (... within remaining forest)
- Several processes lead to forest degradation: logging, fuelwood collection, fire, forest grazing etc.
- From a monitoring perspective it is important to consider what type/process of degradation to be assessed:
  - Different types of degradation may require different methods and data for monitoring

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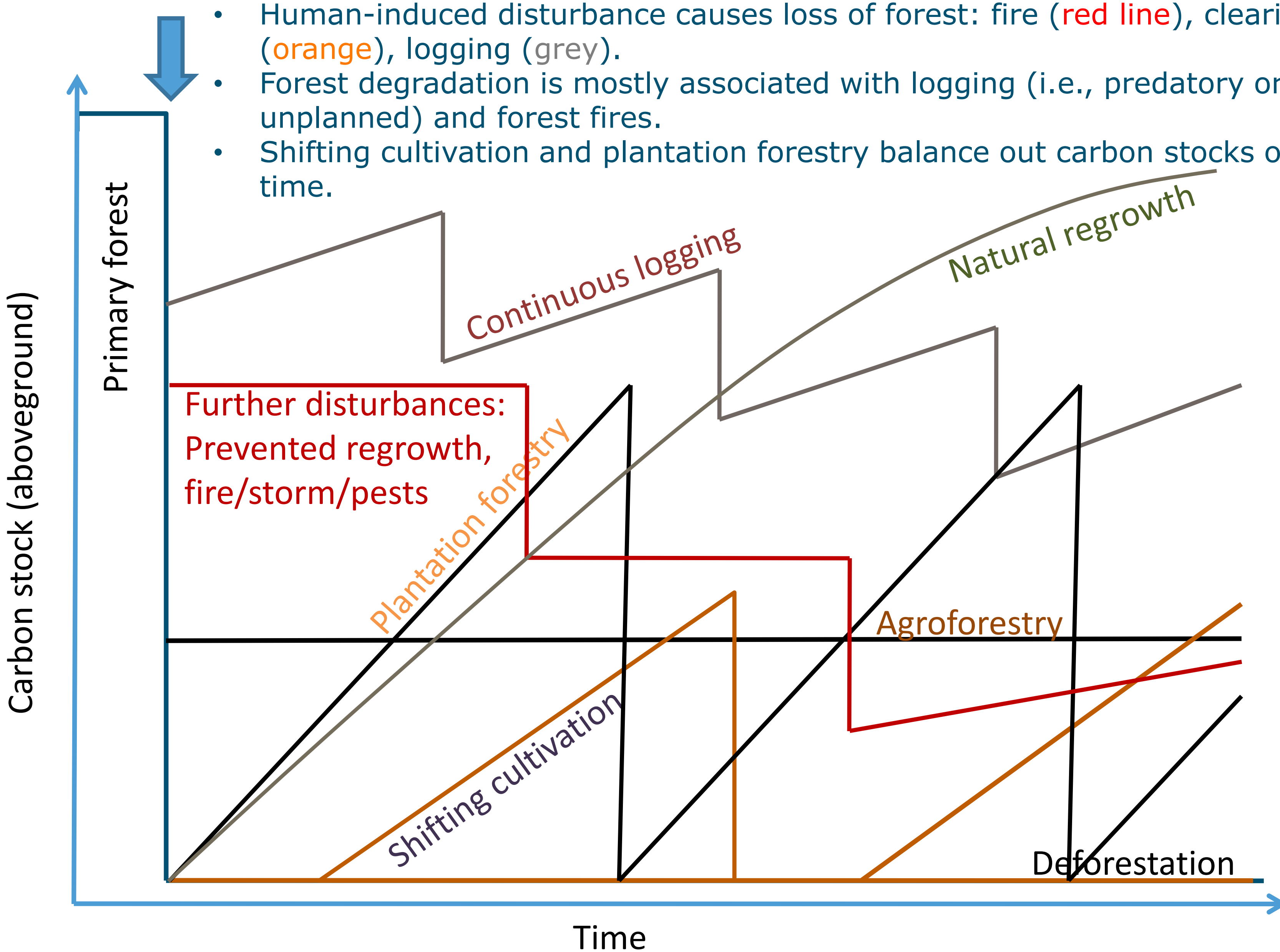
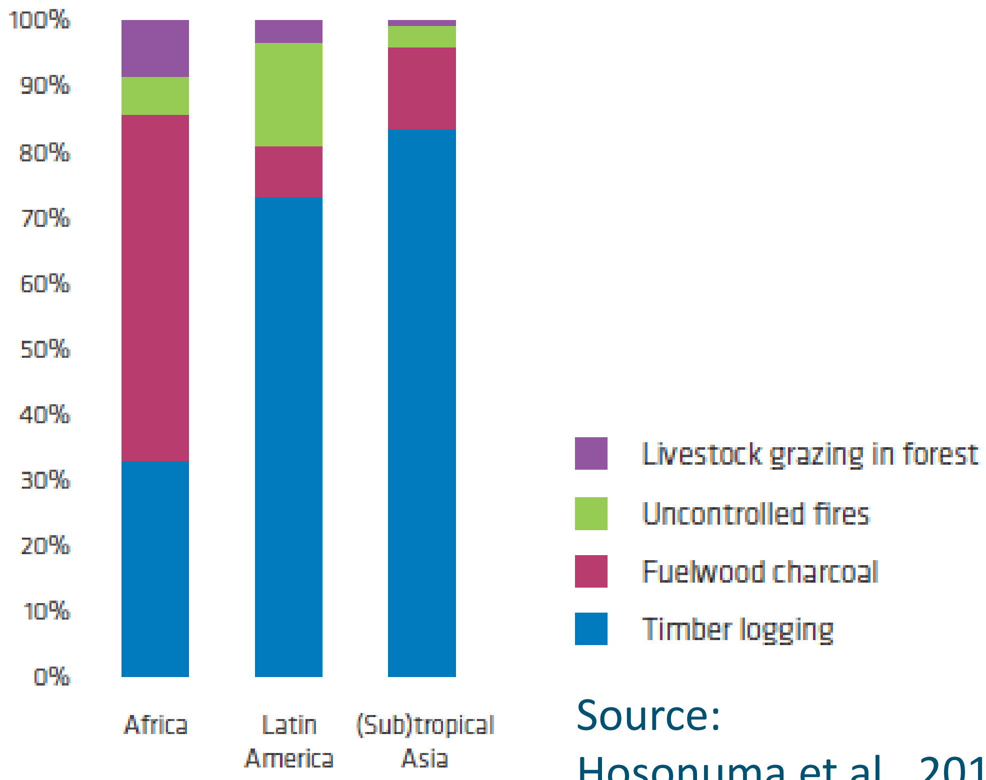
Forest degradation & impact on carbon stocks

- Human-induced disturbance causes loss of forest: fire (red line), clearing (orange), logging (grey).
- Forest degradation is mostly associated with logging (i.e., predatory or unplanned) and forest fires.
- Shifting cultivation and plantation forestry balance out carbon stocks over time.



Important direct drivers of degradation

Proportion of forest degradation drivers



Source:
Hosonuma et al., 2012

- **Latin America and (sub)tropical Asia:** Commercial timber production > 70% of total degradation
- **Africa:** Fuel wood collection, charcoal production, followed by timber production

Detectability of forest degradation

- Forest degradation can be caused by one or a combination of anthropogenic threat(s) and detectability by earth observation systems is not always possible

Detectability of different threats to tropical forests using available medium- resolution remote-sensing techniques

Readily detectable	Marginally detectable	Not detectable
Deforestation	Recent selective logging	Hunting or defaunation
Habitat fragmentation	Surface fires	Harvests of many nontimber forest products
Major forest fires	Effects of climate change on plant phenology	Effects of pathogens
Major highways	Small-scale gold mining	Compositional shifts in plant communities from climate change
	Wider roads (6–20 m width)	Nonrecent selective logging
	Some invasions of exotic plant species	Narrow roads (<6 m width)
		Most secondary effects

Source:
Laurence and Peres 2006.

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Options for monitoring historical forest degradation

Activity/driver of degradation	Activity data (on national level)
Extraction of forest products for subsistence and local markets, such as fuel wood and charcoal	• Limited historical data • Information from local scale studies or using proxies (population density, household consumption, etc.) • Only long-term cumulative changes may be observed from historical satellite data
Industrial/commercial extraction of forest products, such as selective logging	• Harvest data and statistics • Historical satellite data (Landsat time series) analysed within concession areas • Direct approach should be explored for recent years
Other disturbances such as (uncontrolled) wildfires	• Historical satellite-based fire data records (since 2000) to be analysed with Landsat-type data

Source: Herold et al. 2011.

Common sources for activity data for forest degradation

1. **Field observations and surveys** (module section 3i)**:**
   - Inventory-based approaches (national, subnational)
   - Data from targeted field surveys (incl. interviews), research, and permanent sample plots
   - Commercial forestry data (i.e., logging concessions and timber extraction rates)
   - Proxy data for domestic markets and demands (charcoal, fuel wood, subsistence)

2. **Remote sensing** (module section 3ii)**:**
   - Direct detection of degradation processes (forest canopy damage)
   - Indirect approaches (observe human infrastructure)
   - Fire monitoring (active fire and burned area, see also Module 2.6)

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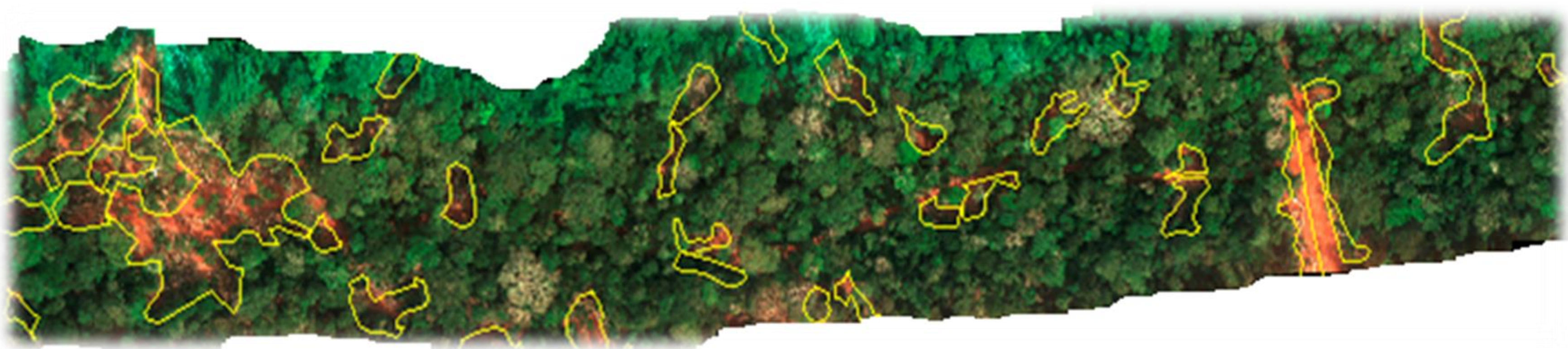
Forest Degradation from Selective Logging

Canopy reduction from:

- Gaps created by felled and collaterally damaged trees
- Clearings for roads, decks, and skid trails

Damage is often not contiguous.



How to estimate emissions from timber harvesting practices

- Two basic methodologies based on IPCC framework:
  - Combination of timber extraction rates, management plans, and high-resolution imagery for activity data (AD) and gain-loss for emission factors (EF) (See also Module 2.3)
  - Remote sensing using medium-resolution imagery for AD and stock-change method for EF (See module section 3.ii)

Example for selective logging

- Emissions due to selective logging are estimated as:

  EF (t C/m3) = ELE + LDF + LIF

Where:

- ELE = extracted log emissions (t C/m^3 extracted)
- LDF = logging damage factor, or dead biomass carbon left behind in gap from felled tree and incidental damage (t C/m^3 extracted)
- LIF = logging infrastructure factor, or dead biomass carbon caused by construction of infrastructure (t C/m^3)

- Field data are collected to quantify the ELE and LDF from multiple logging gaps.
- Activity data for this method is total volume extracted from the forest per year, but to obtain AD one may have to use a combination of field data and very high resolution remote sensing imagery.

Estimating AD for selective logging from harvesting data

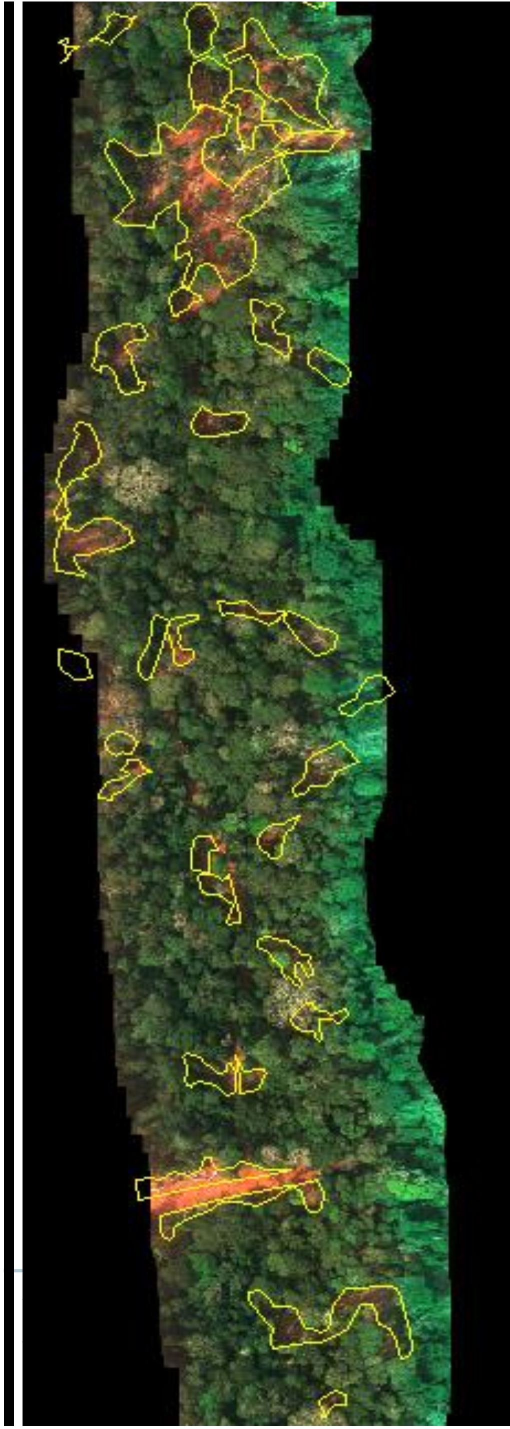
- Selective logging methodology (Module 2.3) requires quantifying the **Logging Infrastructure Factor**:
  - The LIF is the sum of the C impact of: skid-trails + roads + decks
  - The C impact is estimated as the product of C stock estimates of unlogged forest areas and the area of infrastructure
  - The LIF can be normalized to emissions per unit of volume extracted by dividing emissions by harvested volume in m^3



Potential problem: Obtaining reliable amount of timber extracted per unit area per year

- How reliable are national data:
  - Presence of FLEGT program on log tracking?
  - Illegal logging?
  - Extract more than allowable cut?
- Can use an independent method—aerial imagery using a sampling approach produces estimates of area of gaps caused by trees felled and other impacts:
  - Based on field data in logging plots, it can obtain data on m^3 of timber extracted from the gap per m^2 of gap area

Option: Fly aerial transects over concession to monitor logging damage



Strips of aerial imagery showing logging damage

- Image with gaps are delineated automatically with eCognition.
- Uses imagery to estimate area of gaps formed by felled trees and uses relation between volume (m^3) extracted per area of gap (m^2) (from field data).
- Measures area of roads and log landings and length of skid trails.
- Estimates proportion of total sample area covered by gaps, and proportion of total active concession sampled with image strips:
  - Estimates total volume extracted and logging infrastructure area/length

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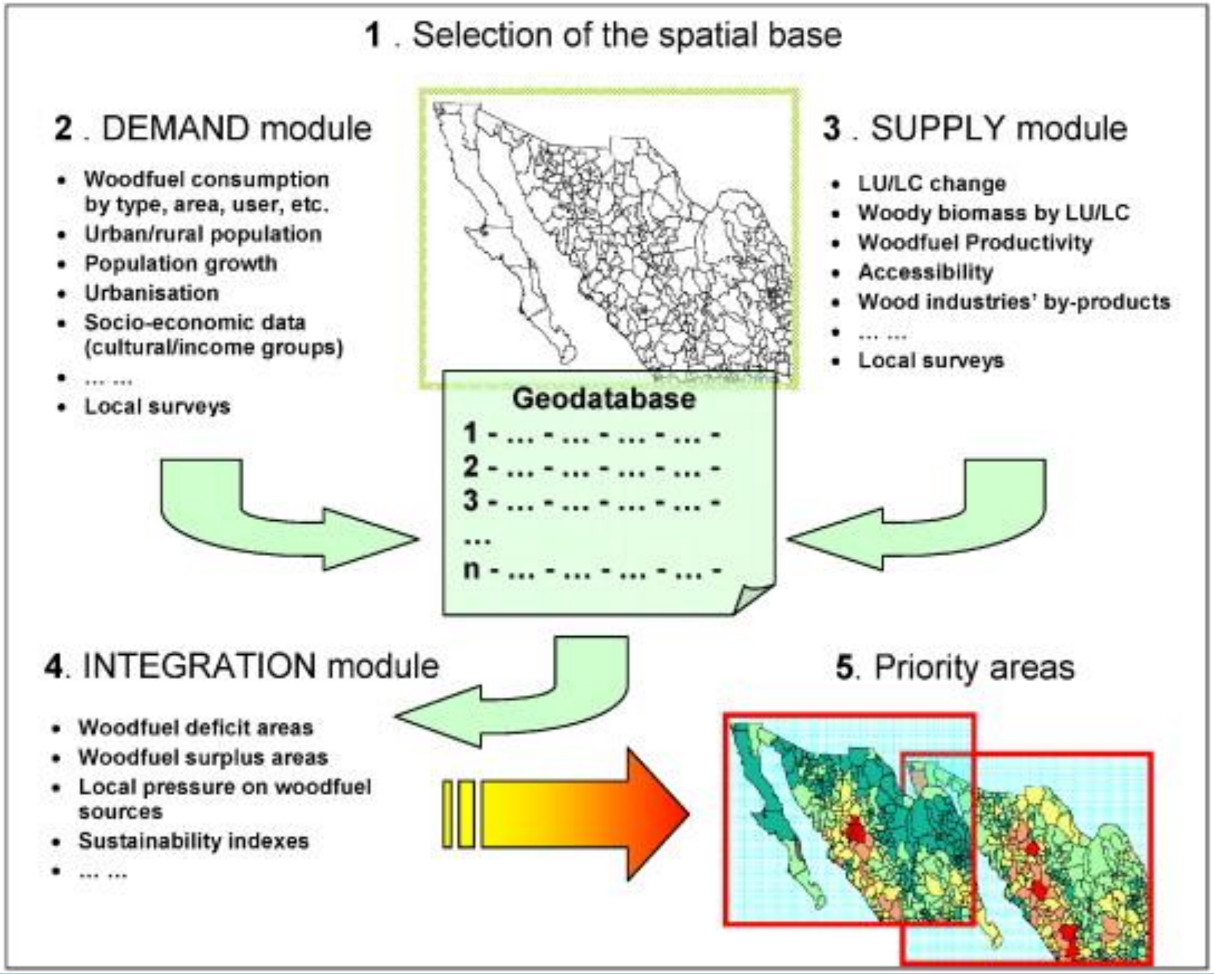
Using spatial analysis to model fuel wood supply and demand



LU/LC = land use / land cover

Source: Ghilardi et al. 2007.

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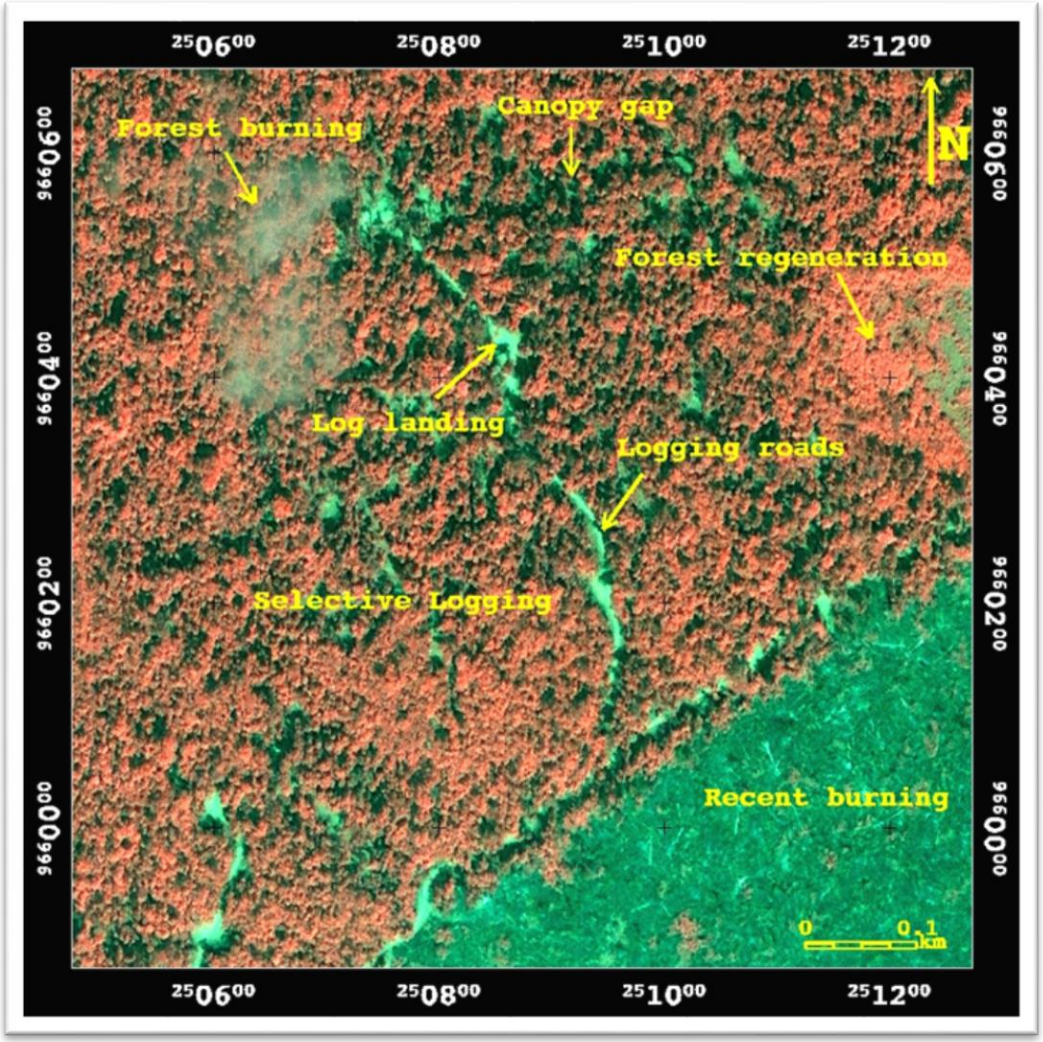
Satellite remote sensing methods

- There are several remote sensing techniques developed to map the main types of forest degradation.
- The choice of remote sensing method depends on:
  - Type and intensity of degradation
  - Spatial and temporal extent of the problem
- Two basic approaches:
  - **Direct Methods** (module section 3iia): Assessing canopy damage using time series data to detect and map degraded forests
  - **Indirect Methods** (3iib): Estimating the forest area affected by forest degradation detecting human infrastructure as proxy (and combine with GIS analysis)

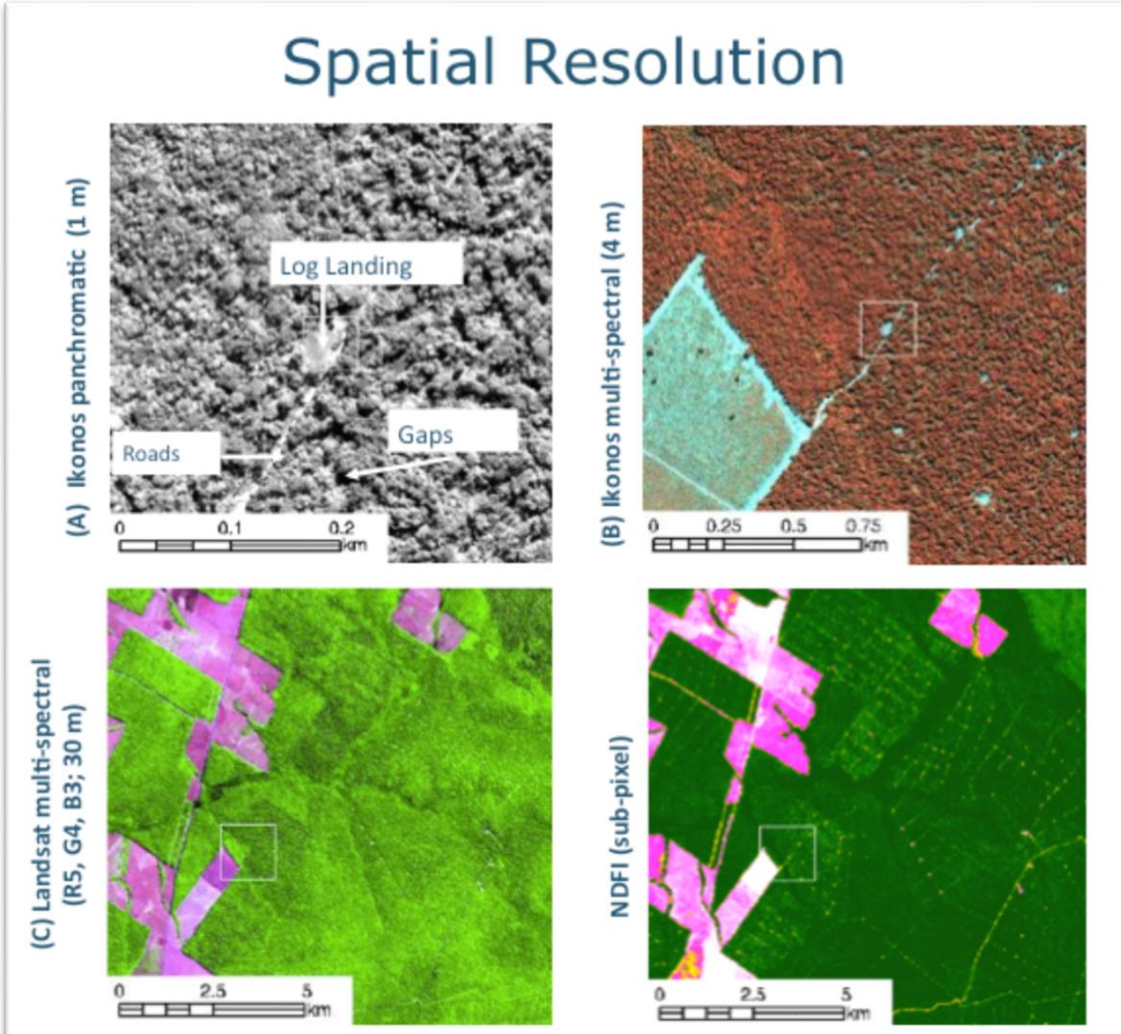
Challenges to defining forest degradation

- Forest degradation can have many effects on the forest canopy.
- Forest degradation creates a mixture of environments, including undisturbed forests, small clearings, and old degraded forests (i.e., forest regeneration) in remote sensing images.



Based on Sourcebook 2014. Figure 2.2.1

Remote sensing methods



- Very high spatial resolution imagery facilitates visual detection of forest degradation.
- Medium spatial resolution imagery with a higher number of spectral bands, such as Landsat, can be useful to map and monitor forest degradation with high temporal coverage.

Based on Sourcebook 2014. Figure 2.2.3

Examples of remote sensing methods to map selective logging and burning in the Brazilian Amazon

Mapping approach	Sensor	Spatial extent	Objective	Advantages	Disadvantages
Visual interpretation	Landsat TM5	Local	Map total logging area	Does not require sophisticated image processing techniques.	Labor intensive for large areas and may be user biased to define the boundaries.
	Landsat TM5	Brazilian Amazon			
Detection of logging landings + buffer	Landsat TM5 e ETM+	Local	Map total logging area (canopy damage, clearings, and undamaged forest).	Relatively simple to implement and satisfactorily estimate the total logging area.	Logging buffers varies across the landscape, and this approach does not reproduce the actual shape of the logged area.
Decision tree	SPOT 4	Local	Map forest canopy damage associated with logging and burning.	Simple and intuitive classification rules.	It has not been tested in very large areas and classification rules may vary across the landscape.

Based on Sourcebook 2014. Table 2.2.1

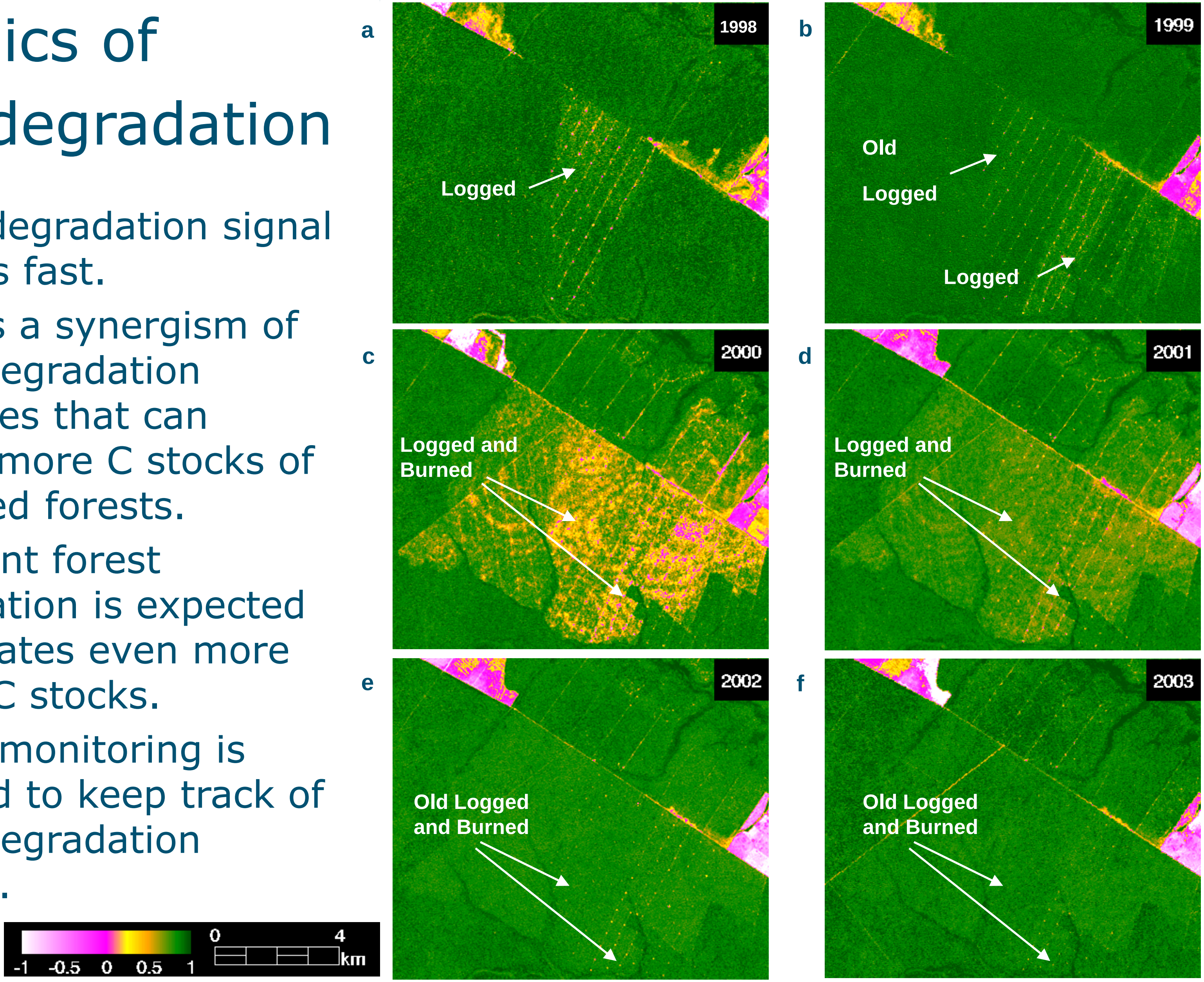
Examples of remote sensing methods (cont.)

Mapping approach	Sensor	Spatial extent	Objective	Advantages	Disadvantages
Change detection	Landsat TM5 e ETM+	Local	Map forest canopy damage associated with logging and burning.	Enhances forest canopy damaged areas.	Requires two pairs of images and does not separate natural and anthropogenic forest changes.
Image segmentation	Landsat TM5	Local	Map total logging area (canopy damage, clearings, and undamaged forest).	Relatively simple to implement and satisfactorily estimate the total logging area. Free software available.	It has not been tested in very large areas, and segmentation rules may vary across the landscape.
Carnegie Landsat Analysis System (CLAS)	Landsat TM5 e ETM+	Three states of the Brazilian Amazon (PA, MT and AC)	Map total logging area (canopy damage, clearings, and undamaged forest).	Fully automated and standardized to very large areas.	Requires very high computation power and pairs of images to forest change detection. Tested only with Landsat ETM+
Normalized Differencing Fraction Index (NDFI)+ Contextual Classification Algorithm (CCA)	Landsat TM5 e ETM+	Local	Map forest canopy damage associated with logging and burning.	Enhances forest canopy damaged areas.	It has not been tested in very large areas and does not separate logging from burning damages.

Based on Sourcebook 2014. Table 2.2.1

Dynamics of forest degradation

- Forest degradation signal changes fast.
- There is a synergism of forest degradation processes that can reduce more C stocks of degraded forests.
- Recurrent forest degradation is expected and creates even more loss of C stocks.
- Annual monitoring is required to keep track of forest degradation process.



Based on Sourcebook 2014. Figure 2.2.6

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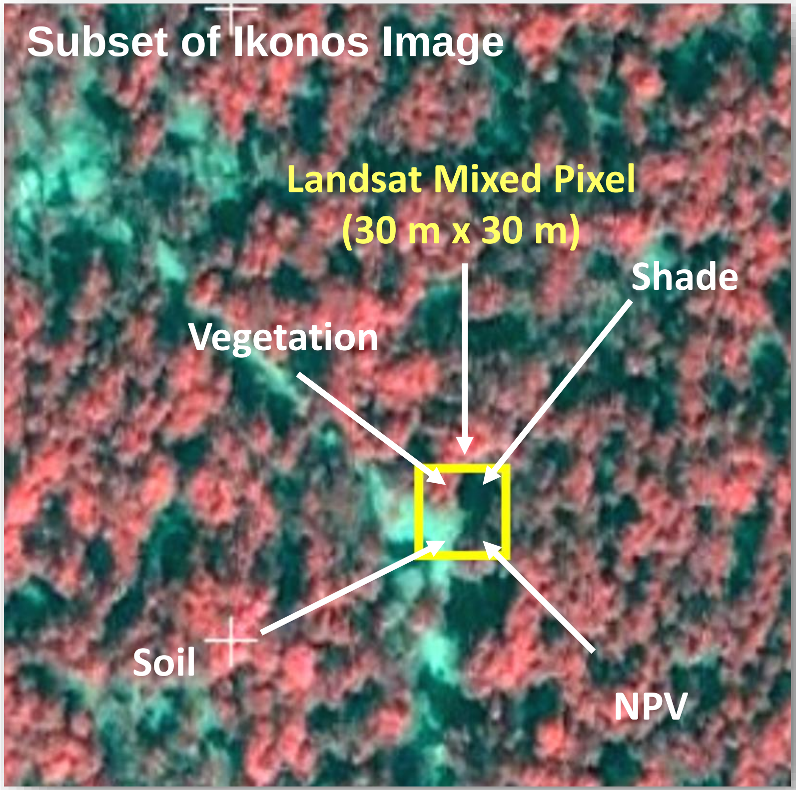
Visual interpretation of forest degradation

Landsat false color composite (R5, G4, B3)

- Examples of selective logging and logged and burned forests in the Sinop region, Mato Grosso, Brazil.
- Defining the boundary between degraded and undisturbed forests is subjective.
- Old forest degradation scars cannot be detected visually.
- Forest degradation signal disappears fast (see slide 31), making visual interpretation challenging.

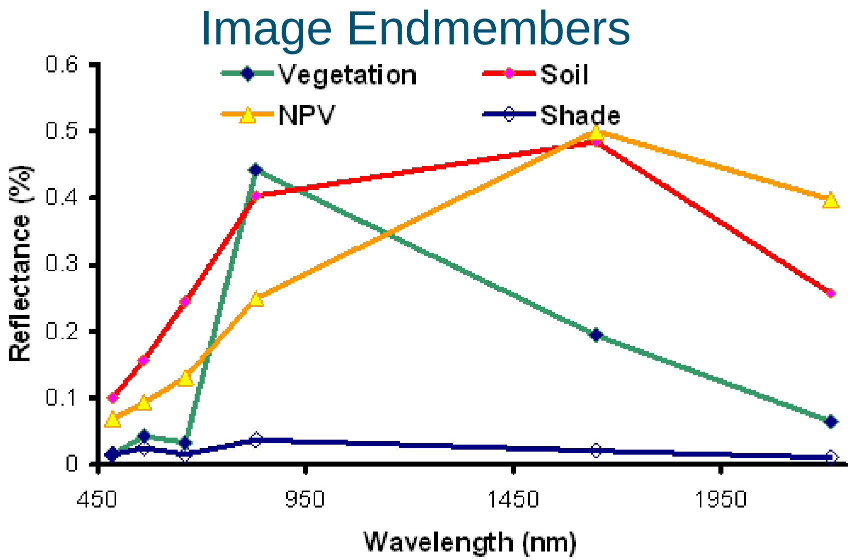
Spectral mixture analysis (SMA)

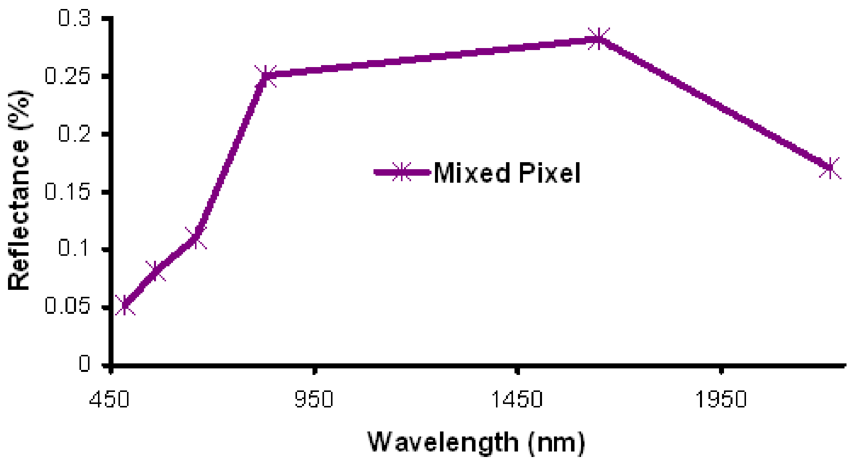


- The most common spectrally pure materials (i.e., endmembers) found in degraded forests are:
  - Green vegetation
  - Soil
  - Nonphotosynthetic vegetation (NPV)
  - Shade
- Mixed pixels predominate in degraded forests.

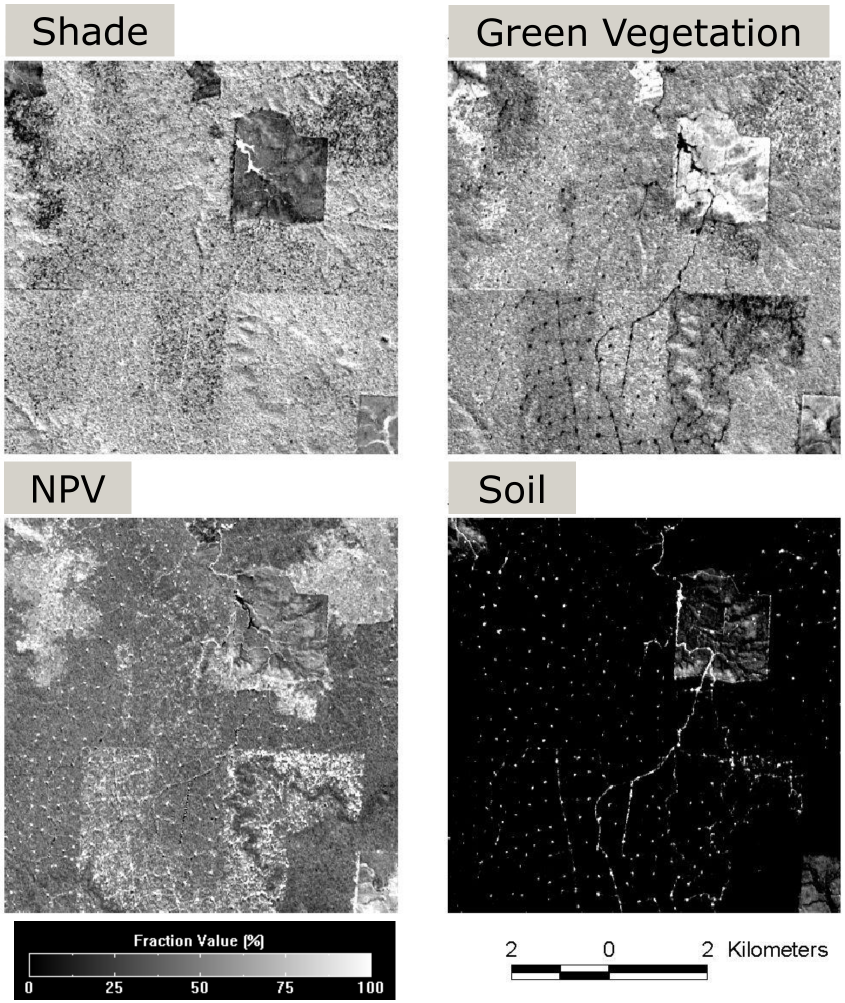
Landsat mixed pixel

- SMA has been proposed to overcome the mixed pixel problem found in degraded forests.
- Mixed pixels can be decomposed into fractions of endmembers.
- The mixed pixel reflectance is the sum of the reflectance of the endmembers' components found in the pixel.





Interpreting endmember fractions



- Shade:
  - Topography and forest canopy roughness and large clearings
- Green vegetation:
  - Canopy gaps, forest regeneration and clearings
- NPV:
  - Canopy damage and burning scars
- Soil:
  - Logging infrastructure (roads and log landings)

Source: Souza Jr. et al. 2003

Combining fraction information to enhance forest degradation detection

Normalized Differencing Fraction Index (NDFI)

$$NDFI = \frac{GV_{Shade} - (NPV + Soil)}{GV_{Shade} + NPV + Soil}$$

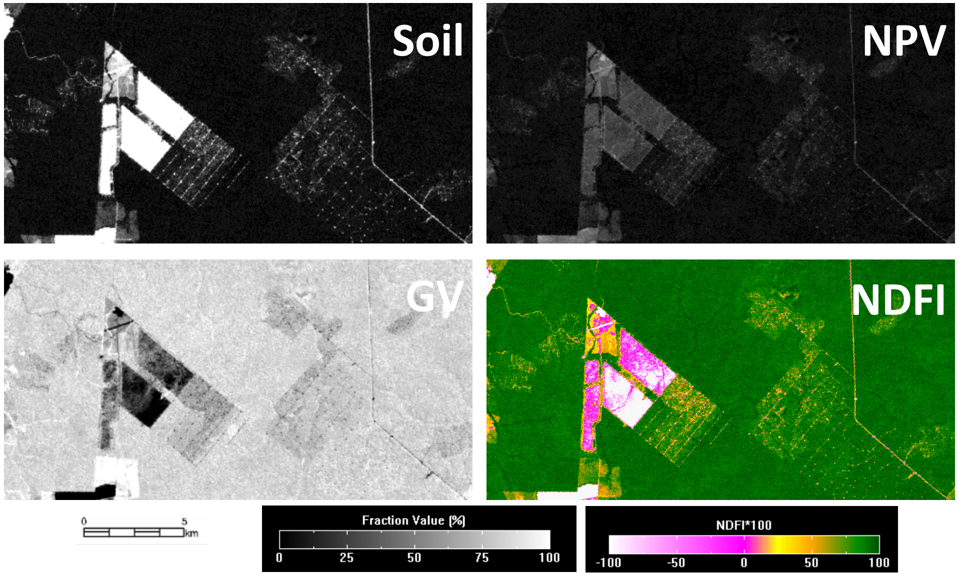
$$GV_{Shade} = \frac{GV}{100 - Shade}$$

Where GV is green vegeation, NPV is the nonphoto synthetic vegetation

$-1 \leq NDFI \leq 1$

NDFI values from 0.70 to 0.85 indicate canopy change that can be associated with forest degradation. NDFI can be rescaled to 0 to 200 to save disk space

Paragominas,Pará State



Source: Souza Jr. 2005

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Indirect approach to monitor forest degradation: Intact/nonintact forest

- Direct remote sensing of forest degradation may not always be possible (e.g., in historical context).
- An indirect method has been proposed, largely adapting the concepts developed to assess the world's intact forest landscape in the framework of the IPCC Guidance and Guidelines for reporting GHG emissions and removals from forest land.

Intact/nonintact forest approach: Basic concepts

- Definitions:
  - Intact forests: fully-stocked (any forest with its natural canopy cover between 10% and 100%)
  - Nonintact forests: not fully-stocked (the forest has undergone some level of timber exploitation or canopy degradation)
- This distinction should be applied in any forest land-use subcategories a country aims to report under UNFCCC.
- Thus a country will also have to collect the corresponding carbon stock data to characterize each forest land subcategory.

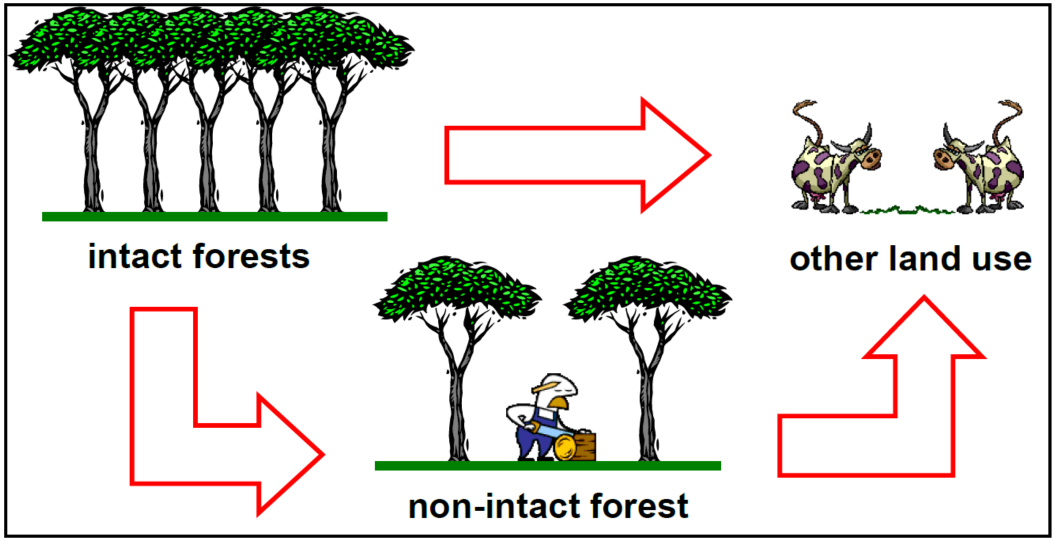
Intact/nonintact forest approach: Definition of intact forest land

- Defined according to parameters based on spatial criteria that could be applied objectively and systematically over all the country.
- Country specific definition could be, e.g.:
    - Situated within the forest land according to UNFCCC definitions and with a buffer zone inside the forest
    - Containing a contiguous mosaic of natural ecosystems
    - Not fragmented by infrastructure (road, navigable river, etc.)
    - Without signs of significant human transformation
    - Without burnt lands and young tree sites adjacent to infrastructure objects

Source: Potapov et al. 2008.

Intact/non-intact forest approach – Application to carbon accounting

- Carbon emission from forest degradation for each forest type consists of two factors: 1) the difference in carbon content between intact and non-intact forests and 2) the area loss of intact forest area during the accounting period
- Forest degradation is included in the conversion from intact to non-intact forest, and thus accounted as carbon stock change in that proportion of forest land remaining as forest land



Source: Mollicone et al. 2007.

Intact/nonintact forest approach: Land use change matrix

From ↓ / To →		Forest land: "Intact (natural) forest"	Forest land: "Non-intact forest"	Other land
Forest land	"Intact (natural) Forest"	Forest conservation	Forest degradation	Deforestation
	"Nonintact forest"	Enhancement of C stocks (forest restoration)	Sustainable management of forests	Deforestation
Other land		-	Enhancement of C stocks (A/R)	

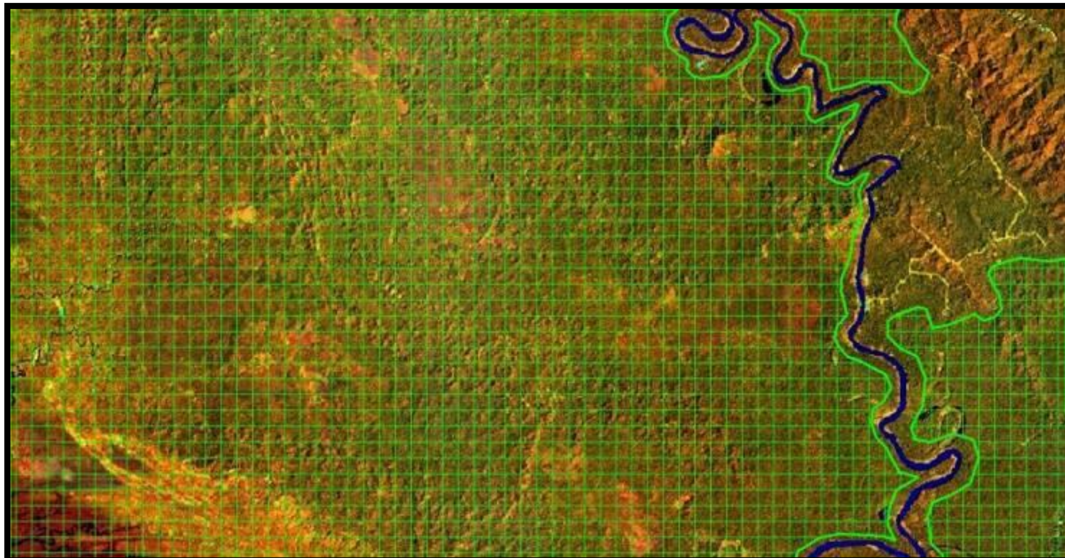
Source: Bucki et al. 2012.

Intact/nonintact forest approach: Delineation of intact forest land

- A two-step procedure could be used to exclude nonintact areas and delineate the remaining intact forest using the "negative approach":

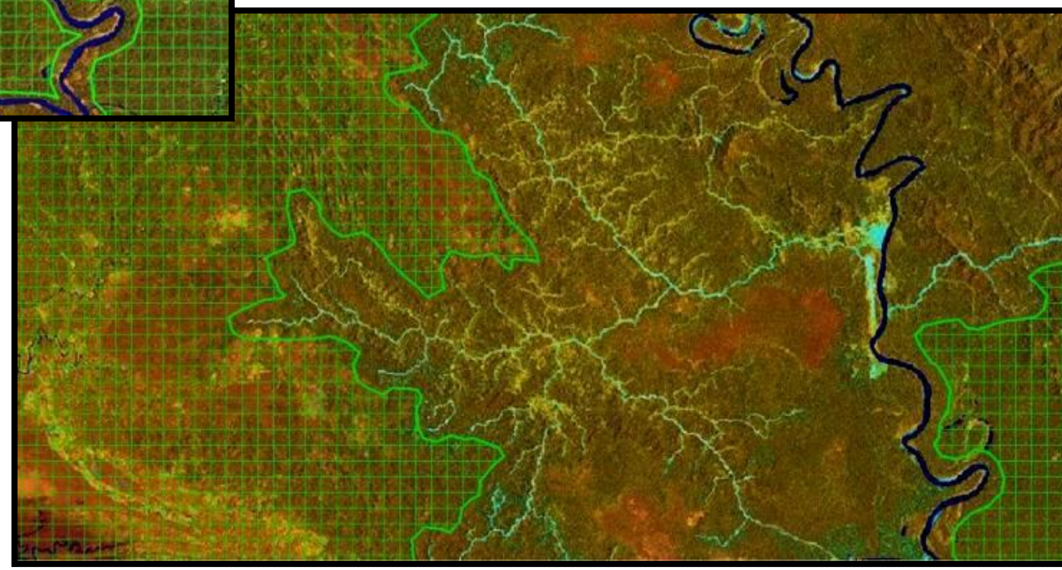
1. Exclusion of areas around human settlements and infrastructure and residual fragments of landscape smaller than 1,000 ha, based on topographic maps, GIS database, thematic maps, etc. This first (potentially fully automated) step would result in a candidate set of landscape fragments with potential intact forest lands
2. Further exclusion of nonintact areas and delineation of intact forest lands is done by fine shaping of boundaries, based on visual or semi-automated interpretation methods of high-resolution satellite images (~ 10-30 m pixel spatial resolution).

Intact/nonintact forest delineation example



(a) Papua New Guinea
December 26, 1988

(b) Papua New Guinea
October 7, 2002

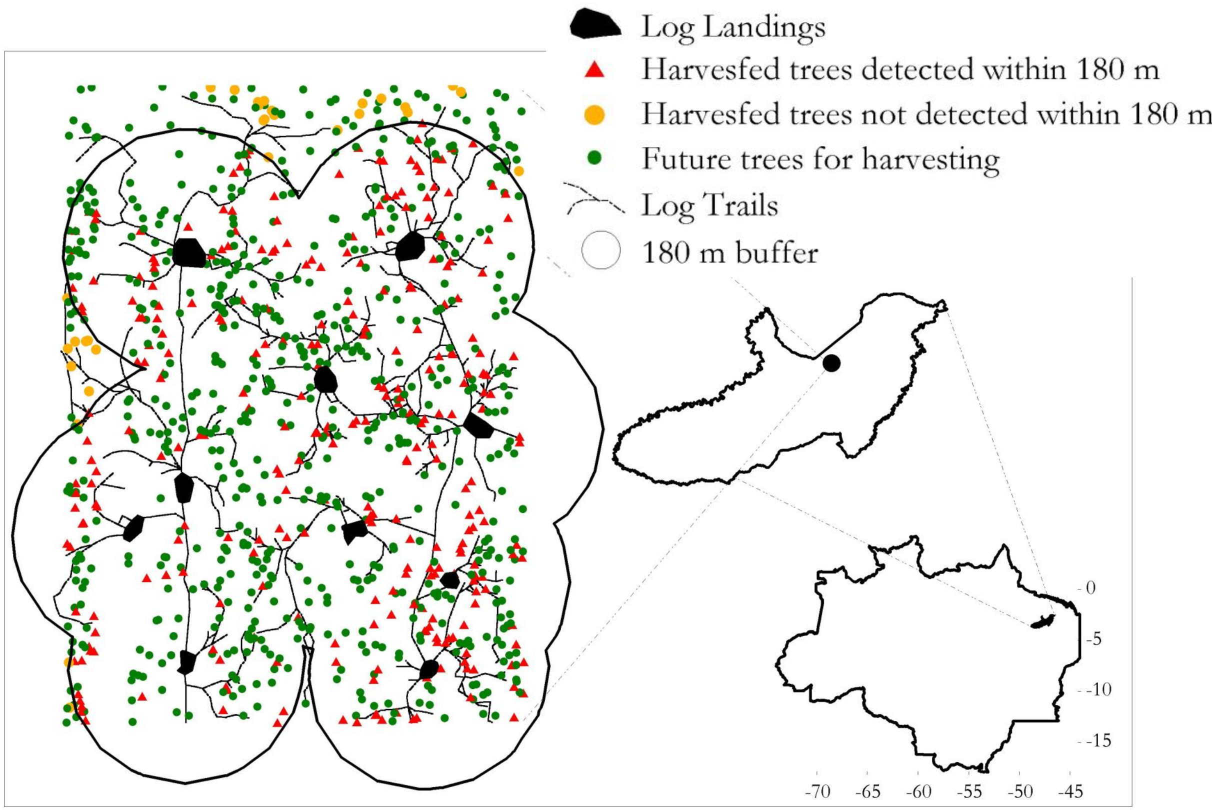


- The hashed areas are considered intact.
- In the sample area, in 14 years, 51% of the existing intact forest land has been converted to nonintact forest land.
- At the same time, deforestation accounts for less than 1% (roads).

Source: Potapov et al. 2008.

Another example of indirect method:

Combining remote sensing detection and GIS to map selective logging



Source: Souza and Barreto 2000.

- Detection of roads and log landing created by logging activity can be done with remote sensing.
- Buffer distances can be applied using GIS to estimate the area affected by logging.

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Software to map forest degradation

- Commercial software such as ENVI, ERDAS, PCI, and ArcGIS can be used to implement most of the methods discussed above.
- Specialized software has been developed to deal specifically with the mapping and monitoring of forest degradation:
  - CLASlite
  - ImgTools (See Exercises)

In Summary

- It is important to clearly define forest degradation and to set a benchmark for measuring carbon stock changes within a forest area.
- Detection of forest degradation by earth observation is not always possible.
- Different methodologies can be used to assess different types of forest degradation:
    - Field observations and surveys
    - Direct remote sensing methods
    - Indirect remote sensing methods
- Diverse commercial and open source software available for mapping forest degradation

Country examples and exercises

Country examples:

- Peru: Monitoring forest degradation using CLASlite
- Cameroon: Monitoring forest degradation using NDFI
- Bolivia: Monitoring forest degradation using a combination of SMA fractions and NDFI

Exercises:

- Monitoring forest degradation processes (logging), using ImgTools:
    - Part 1: Introducing ImgTools
    - Part 2: Forest Change Detection using SMA fractions and NDFI
    - Part 3: Decision Tree Classification using a time-series of SMA and NFDI images
- Intact/nonintact forest mapping using a proxy approach

Recommended modules as follow-up

- Module 2.3 for methods to assess emission factors in order to calculate changes in forest carbon stocks.

- Modules 3.1 to 3.3 to learn more about REDD+ assessment and reporting.

References

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