Module 2.3 Estimating emission factors for forest cover change: Deforestation and forest degradation

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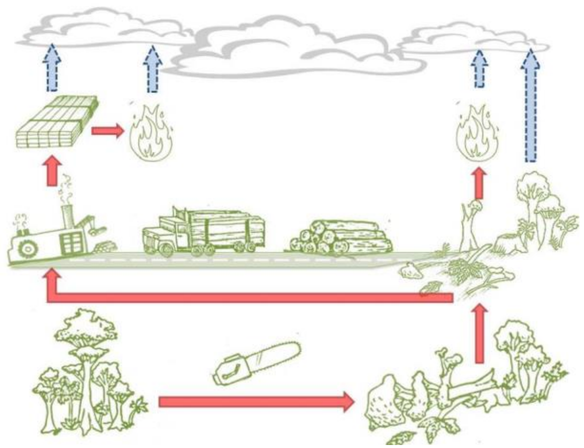

After the course the participants should be able to:

- Describe the procedures and methods to develop estimates of emission factors for **deforestation** and for **forest degradation by selective logging** within a national forest monitoring system at a Tier 2–3 level.
- Estimate emission factors including all pools for deforestation for a selected forest region within a country and estimate emission factors for forest degradation by selective logging.

V1, May 2015

WAGENINGEN UR For quality of life

GOFC-GOLD Global Observation of Forest and Land Cover Dynamics

FOREST CARBON PARTNERSHIP FACILITY

Background material

- GOFC-GOLD. 2014. *Sourcebook*. Section 2.3.
- UNFCCC Decisions:
  - Decisions of the Conference of the Parties (COP). http://unfccc.int/documentation/decisions/items/3597.php#beg
  - UNFCCC. 2009. Methodological guidance for REDD+. http://unfccc.int/resource/docs/2009/cop15/eng/11a01.pdf#page=11
  - UNFCCC. 2012. Decision 12/CP17. http://unfccc.int/resource/docs/2011/cop17/eng/09a02.pdf#page=16
  - UNFCCC. 2013. Decision 1/CP18. http://unfccc.int/resource/docs/2012/cop18/eng/08a01.pdf#page=6
- 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).

Outline of lecture

1. Changes in C stocks from deforestation and forest degradation by selective logging
2. IPCC Tiers for estimating emission factors (EFs)
3. Emission factors using stock-difference and gain-loss methods
4. Estimating emission factors for deforestation
    i. Strategies
    ii. Stratification of lands
    iii. Carbon pools
    iv. Collecting data for estimating C stocks: field measurements
    v. Estimating C stocks and developing EFs
    vi. Sources of error and quality assurance/quality control
5. Estimating emission factors for forest degradation by selective logging
    i. Strategies
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    iii. Estimating EFs and total emissions
    iv. How to estimate gains through regrowth of logged areas

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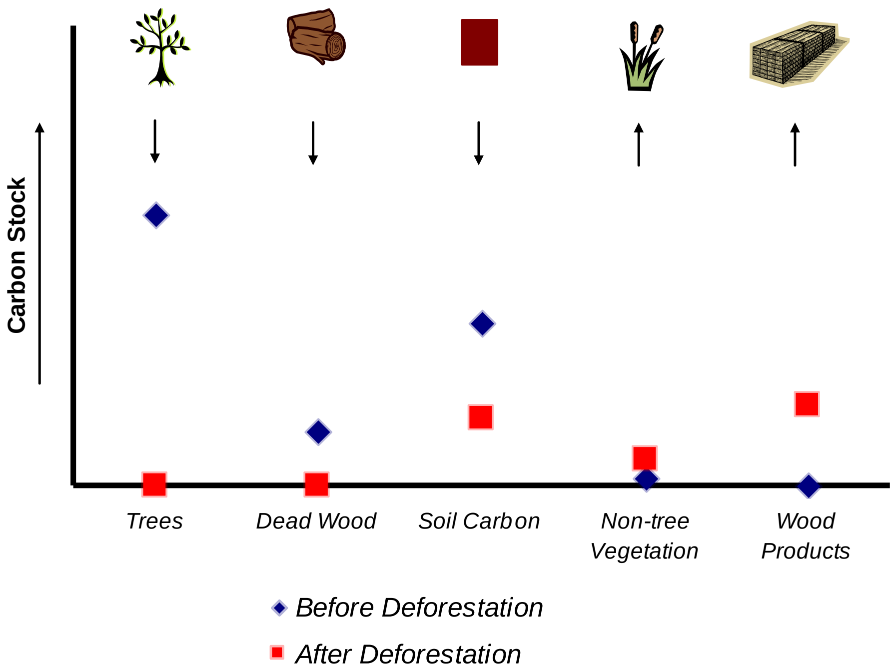
Changes in C stocks from deforestation (1/2)

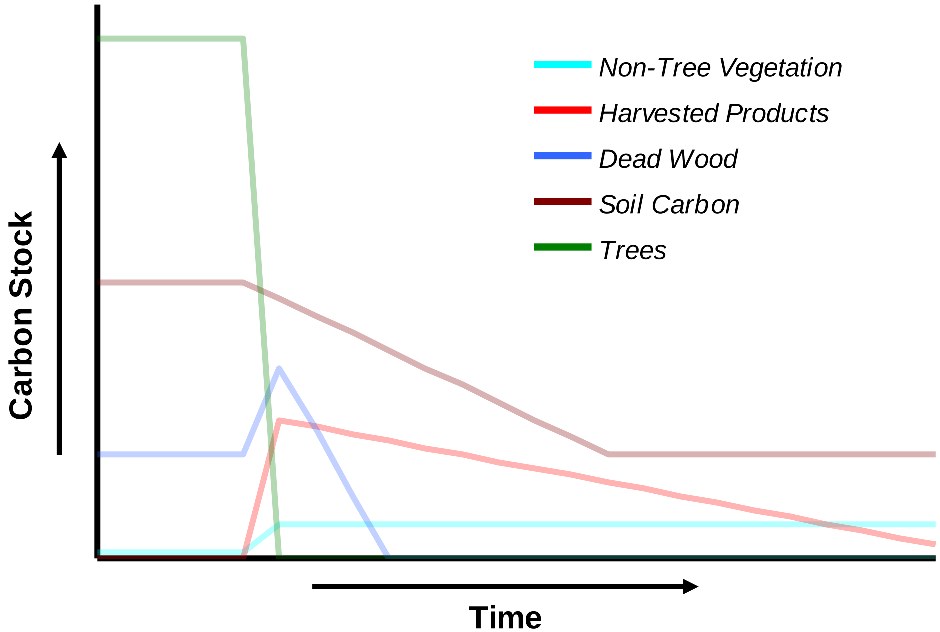
Potential C storage in wood products

CO_2 and non-CO_2 emissions from combustion and decomposition of dead biomass and soil

Changes in C stocks from deforestation (2/2)

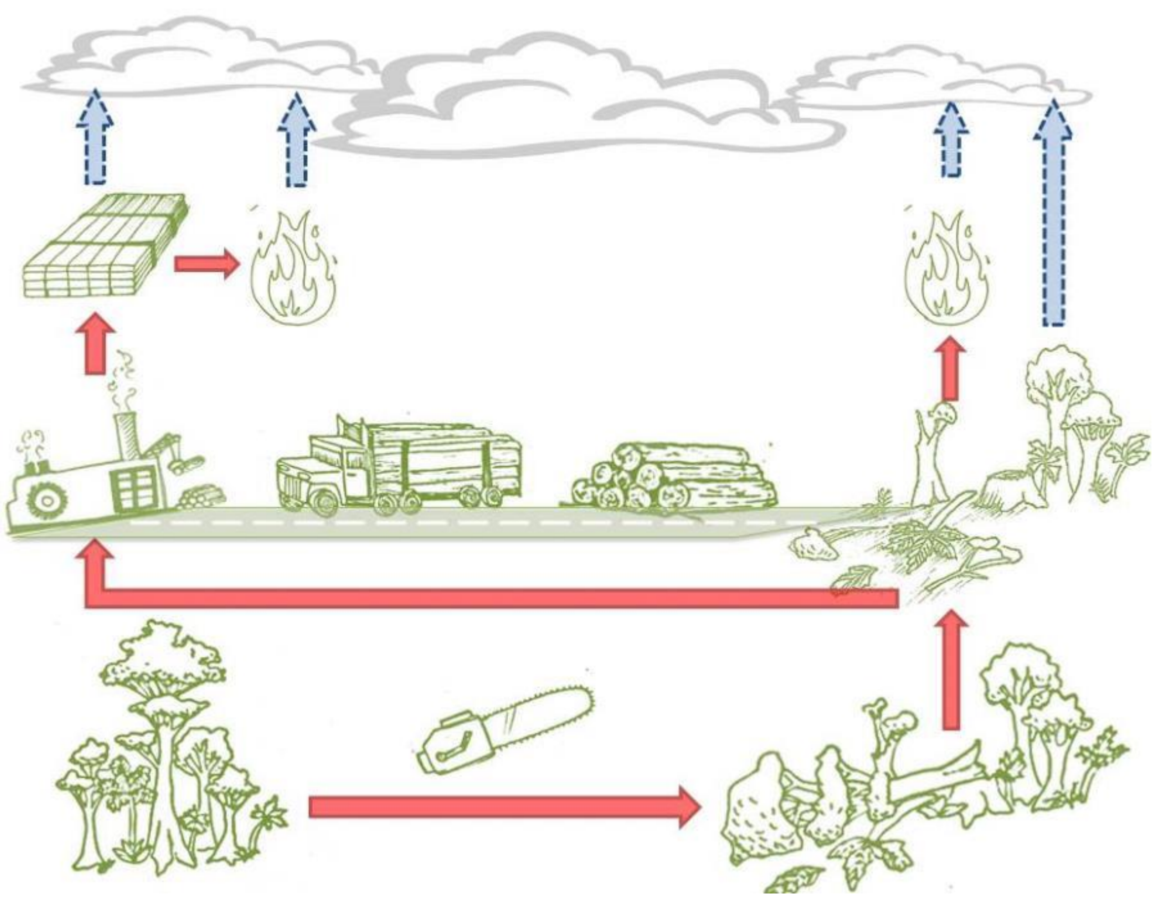


- Magnitude of change varies by pool
- Need to know initial C stocks of all selected pools of forest and postdeforestation land cover/use
- Changes occur over different time frames for different pools



C emissions in selective logging (degradation)

- Selective logging is diffuse across the forest area—only a few trees are felled.
    - Difficult to capture C stock changes with biomass assessments
- It can cause significant emissions because it covers large areas.



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IPCC Tiers for estimating emission factors (EFs)

- The Intergovernmental Panel on Climate Change (IPCC) refers to three general tiers for estimating emissions/removals of GHGs.
- The tiers represent different levels of methodological complexity:
  - Tier 1 is the basic method
  - Tier 2 uses country-specific data
  - Tier 3 is the most demanding in terms of complexity and data requirements
- Nations are encouraged to use higher tiers for the measurement of significant C sinks / emission sources:
  - Assess significance of selective logging activities

Characteristics of different IPCC Tiers

	Tier 1	Tier 2	Tier 3
Data granularity	Default values for broad continental forest types	Country-specific	Region/forest specific
Data Sources	IPCC Emission Factor Data Base (EFDB)	Country-specific data for key factors (e.g. from field measurements)	Comprehensive field sampling repeated at regular time intervals, soils data, and use of locally calibrated models
Cost & Uncertainty	Low cost and High uncertainty	Medium to low cost and uncertainty	High cost and Low uncertainty
Fate of pools post deforestation	Assume immediate emissions at time of event—i.e. committed emissions	Can use disturbance matrices to model retention, transfers, and releases	Model transfers and releases among pools to reflect emissions through time

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Estimating emission factors: stock-difference

→ Most commonly applied for estimating emissions from deforestation

$$EF = \left(C_{bio,pre} - C_{bio,post} - C_{wp} + \{[CS_0 - CS_D]/D\}\right) \times \frac{44}{12} + E_{Oth}$$

Where:

EF	= Emission factor, t CO_2-e ha^{-1}
$C_{bio,pre}$	= C stock in biomass prior to forest change, t C ha^{-1}
$C_{bio,post}$	= C stock in biomass post-deforestation, t C ha^{-1}
CS_O	= Initial or reference soil organic carbon,
CS_D	= Soil organic carbon at default time D, t C ha-1
D	=Default time period to transition to a new equilibrium value (20 year)
C_{wp}	= Carbon stored in long term wood products, t C ha^{-1}
44/12	= Conversion factor for C to CO_2
E_{oth}	= Emissions of non-CO_2 gases, such as CH_4 & N_2O released during burning, t CO_2-e ha^{-1}

Estimating emission factors: gain-loss

→ Particularly useful for estimating emissions from forest degradation

$$EF = (\Delta C_G - \Delta C_L) \times \frac{44}{12} + E_{Oth}$$

Where:

EF	= Emission factor (t CO_2-e ha^{-1})
ΔC_G	= Carbon stock gains in all pools (t C ha^{-1})
ΔC_L	= Carbon stock losses in all pools (t C ha^{-1})
44/12	= Conversion factor for C to CO_2
E_{oth}	= Emissions of non-CO_2 gases, such as CH_4 & N_2O released during burning, t CO_2-e ha^{-1}

Comparison of stock-difference and gain-loss

	Stock-Difference	Gain-Loss
Description	Difference in C stocks in a particular pool in pre- and post–forest cover change	Net balance of additions to and removals from a carbon pool
Data requirements	Data needed on forest carbon stocks in key pools before and after conversion	Annual data needed on C losses and gains, e.g., annual tree harvest volume and annual rates of forest growth post–tree removals
Applications	Appropriate for deforestation and afforestation and for reforestation	Appropriate for forest degradation caused by tree harvest and the regrowth of carbon stocks postdisturbance

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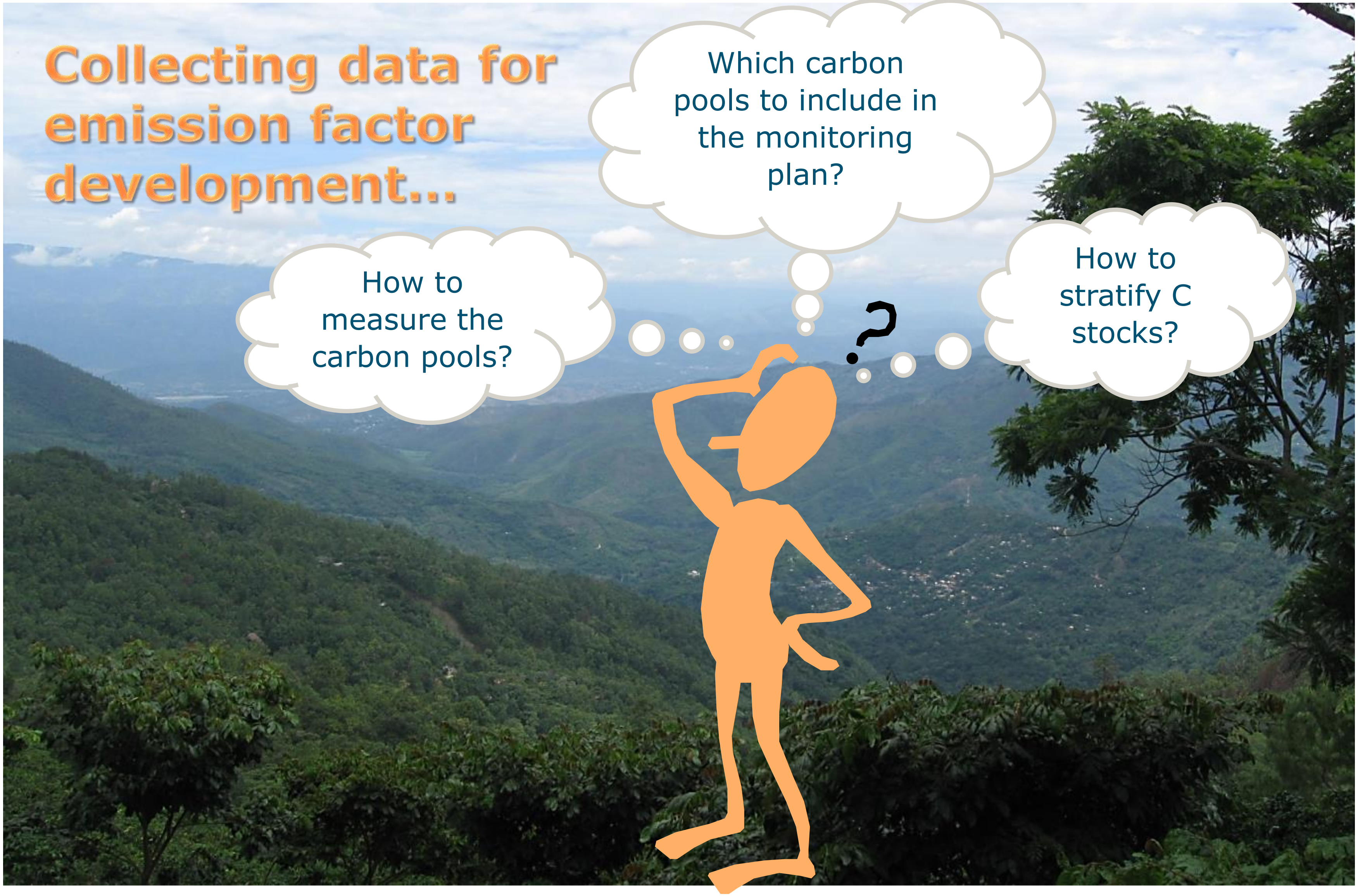
Collecting data for emission factor development...
Which carbon pools to include in the monitoring plan?
How to measure the carbon pools?
How to stratify C stocks?
?

Strategies for estimating emission factors

- Strategies for estimating stocks in forest carbon pools must be planned based on an assessment of the quality, quantity, and availability of existing data and whether new data need to be collected
- Criteria that existing data need to meet are:
    - The data are less than 10 years old
    - The data are derived from multiple measurement plots
    - All species must be included in inventories
    - Minimum diameter at breast height (DBH) is 20 cm or less
    - Data are sampled from a good coverage of strata

Stratification and sampling approach

- Plans should be designed to stratify the forest lands to ensure sampling is cost-effective while producing results with low uncertainty.
- One needs to select pools to include and sampling methods.
- Sampling plans should be designed to meet a targeted or required level of certainty for newly collected data and to meet international standards. Common sampling designs are:
  - Cluster sampling—can reduce sampling costs
  - Stratified sampling—allows for specification of sample size for specific strata
  - Systematic sampling—long history of use in forestry
- Consult a biometrician with experience in forestry.

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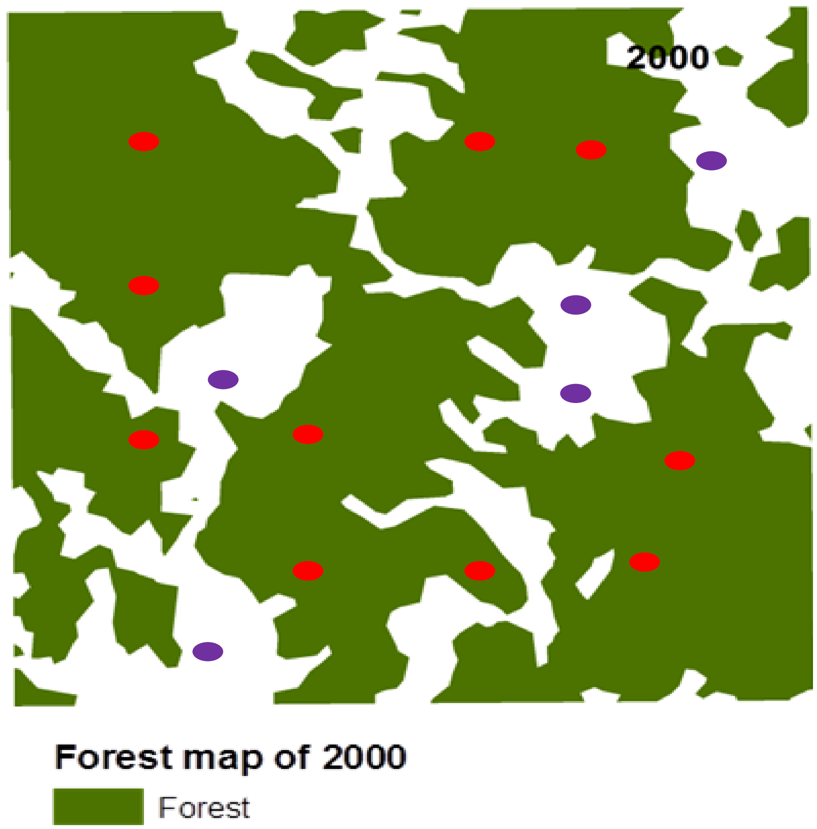
Purpose of stratification

- The purpose of stratification is to organize a *heterogeneous* area into subpopulations or "strata" that form relatively *homogenous* units.
- If stratum sample sizes are chosen properly, the estimated mean is more precise than simple random sample.



Stratification plan

1. Develop initial stratification plan based on biophysical or human factors that influence the distribution of carbon stocks, such as:
    - Land use
    - Vegetation/forest Type
    - Elevation/slope
    - Drainage
    - Proximity to human infrastructure
2. Collect preliminary data on carbon stocks.

    (~10 plots per stratum)

Stratification of lands

Stratification by carbon stocks:

- Stratifying by carbon stock reduces sampling effort required to achieve targeted precision level

Stratification by threat:

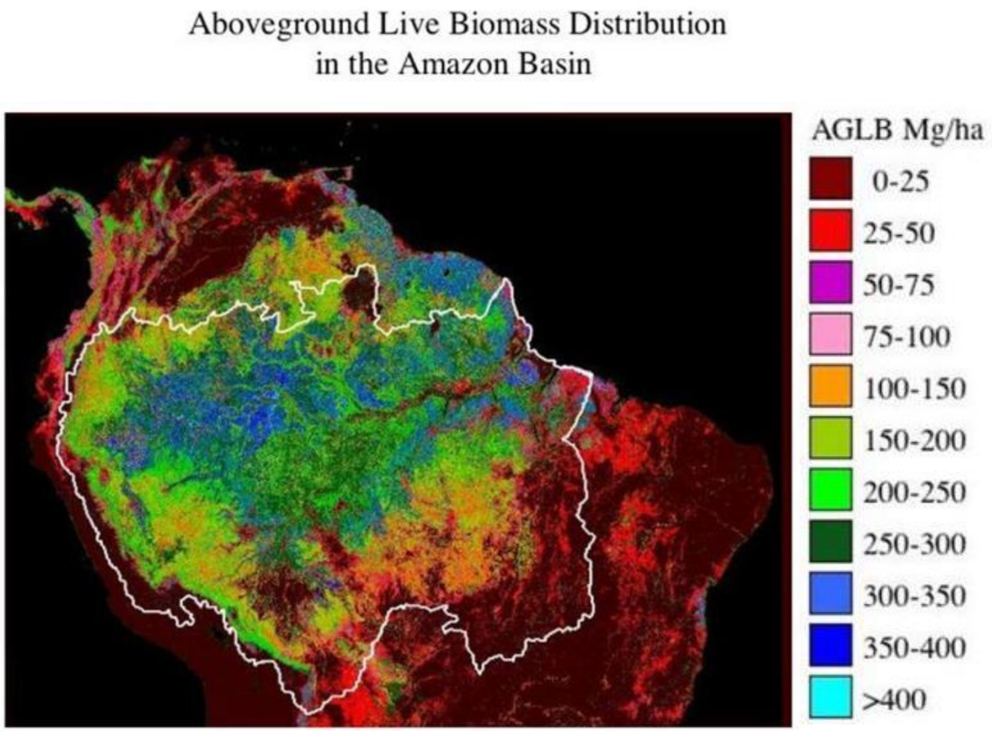
- Stratifying by threat focuses on measuring and monitoring in areas where changes are most likely to occur

Stratification by C stocks (1/2)

- C stocks vary by land use and forest type.
- Differences in C stocks are affected by elevation, climate, soil type, and disturbance.

Stratification by C stocks (2/2)

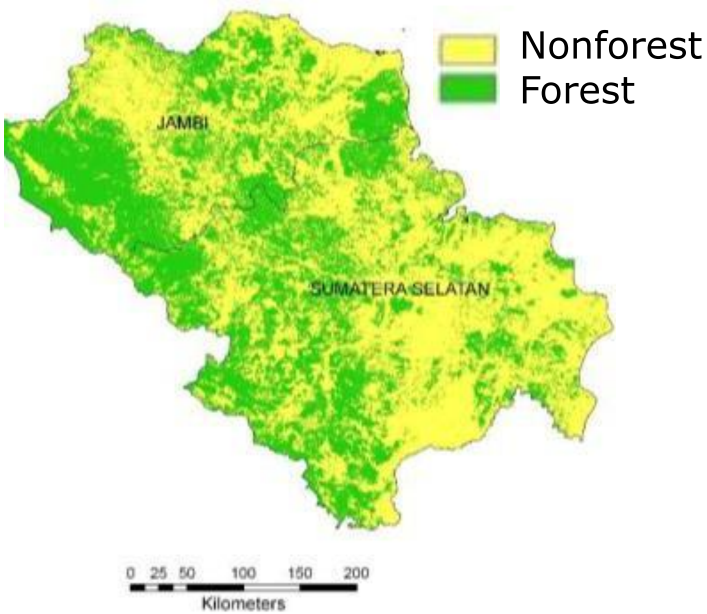
- Grouping forest and other land covers with similar carbon stocks is a cost-effective and good practice to estimate emission factors.



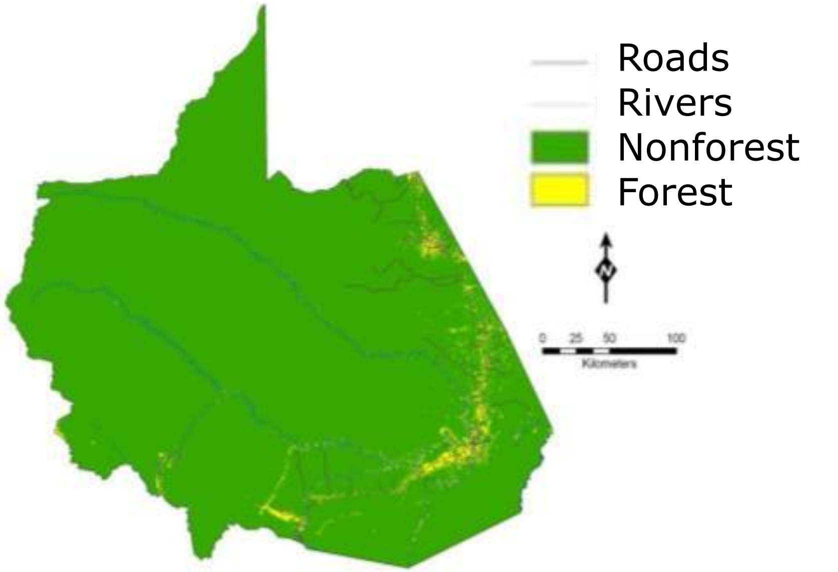
Stratification by threat (1/4)

Not all forests are under immediate threat of conversion.

Sumatra, Indonesia



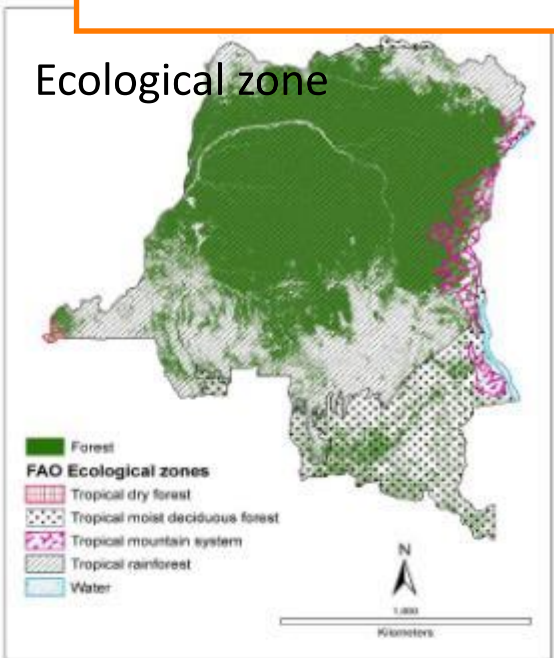
Madre de Dios, Peru

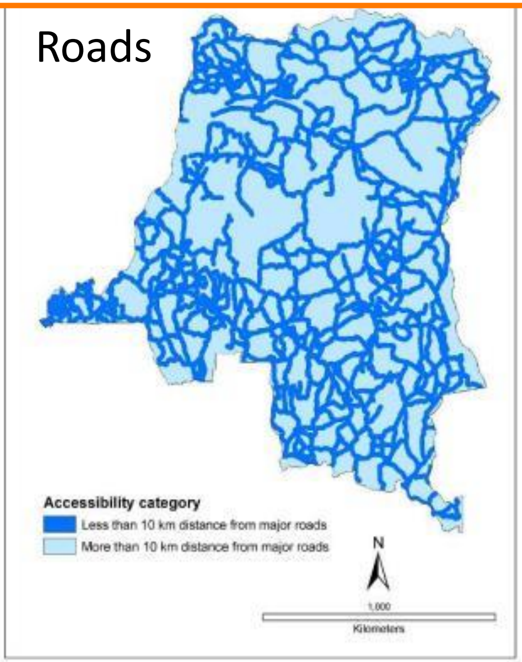


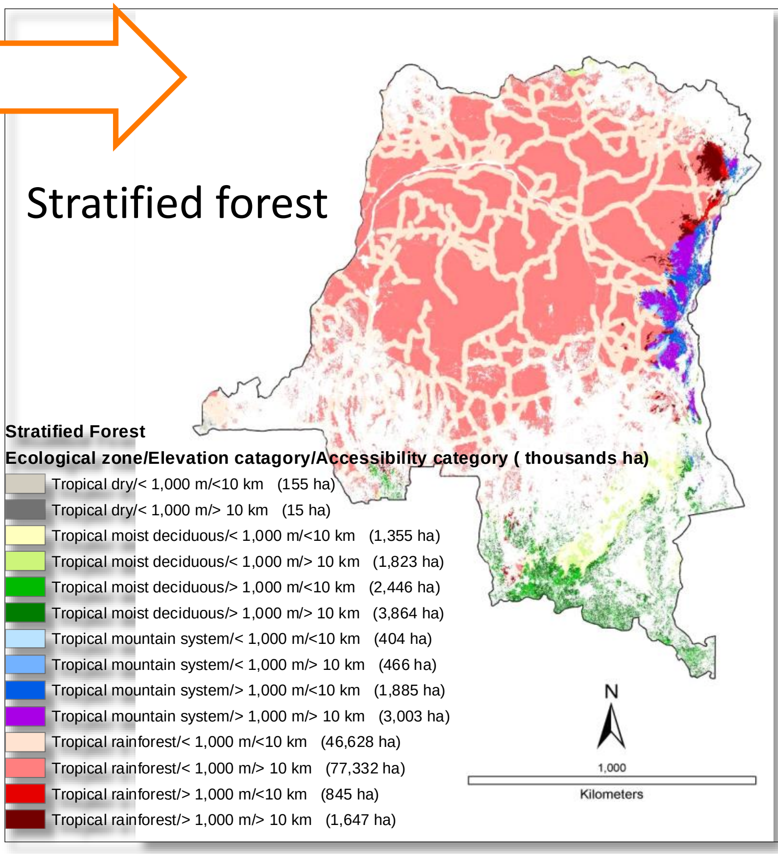
Stratification by threat (2/4)

- Can be a practical, more cost-effective option.
- Provides advantages if forest accessibility is limited in regions and thus likely the forest is likely under no threat.
- Can serve as the first phase in the creation of a national forest monitoring system.
- Uses information such as:
  - Roads, rivers, towns/settlements, proximity to cleared areas
  - Logging concessions, protected areas
  - Post land-use change
  - Patterns of historical deforestation

Stratification by threat (3/4)







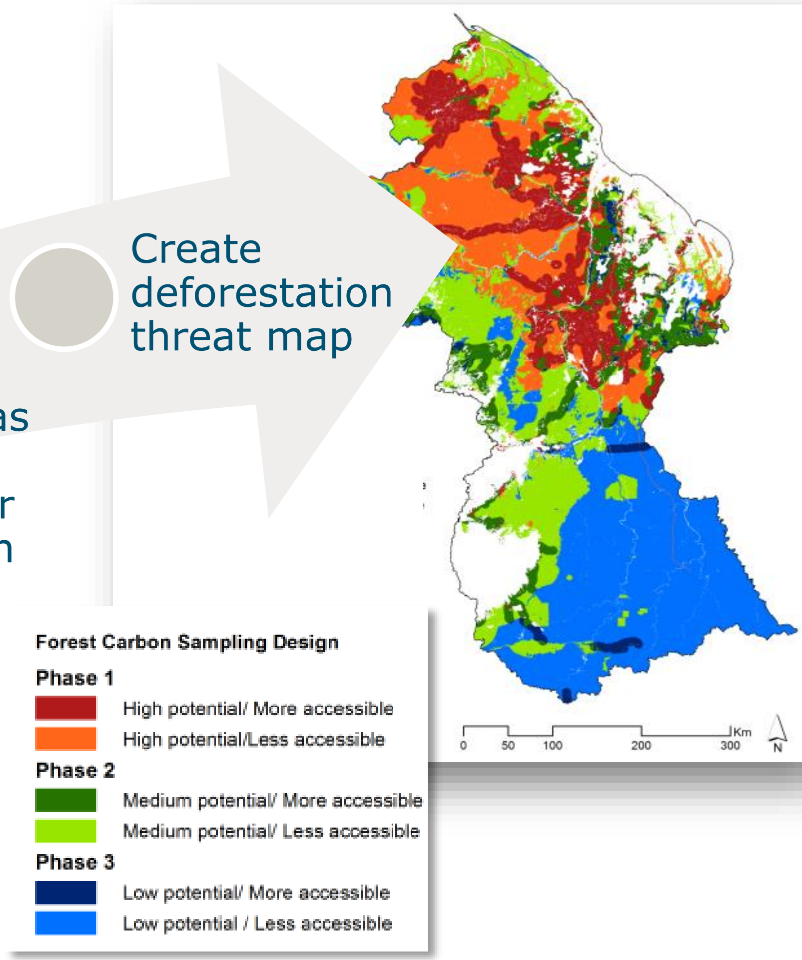
Stratification by threat (4/4)

Use spatially explicit land-use change model

Identify key factors impacting historical deforestation patterns

Identify areas with high suitability for deforestation

Create deforestation threat map



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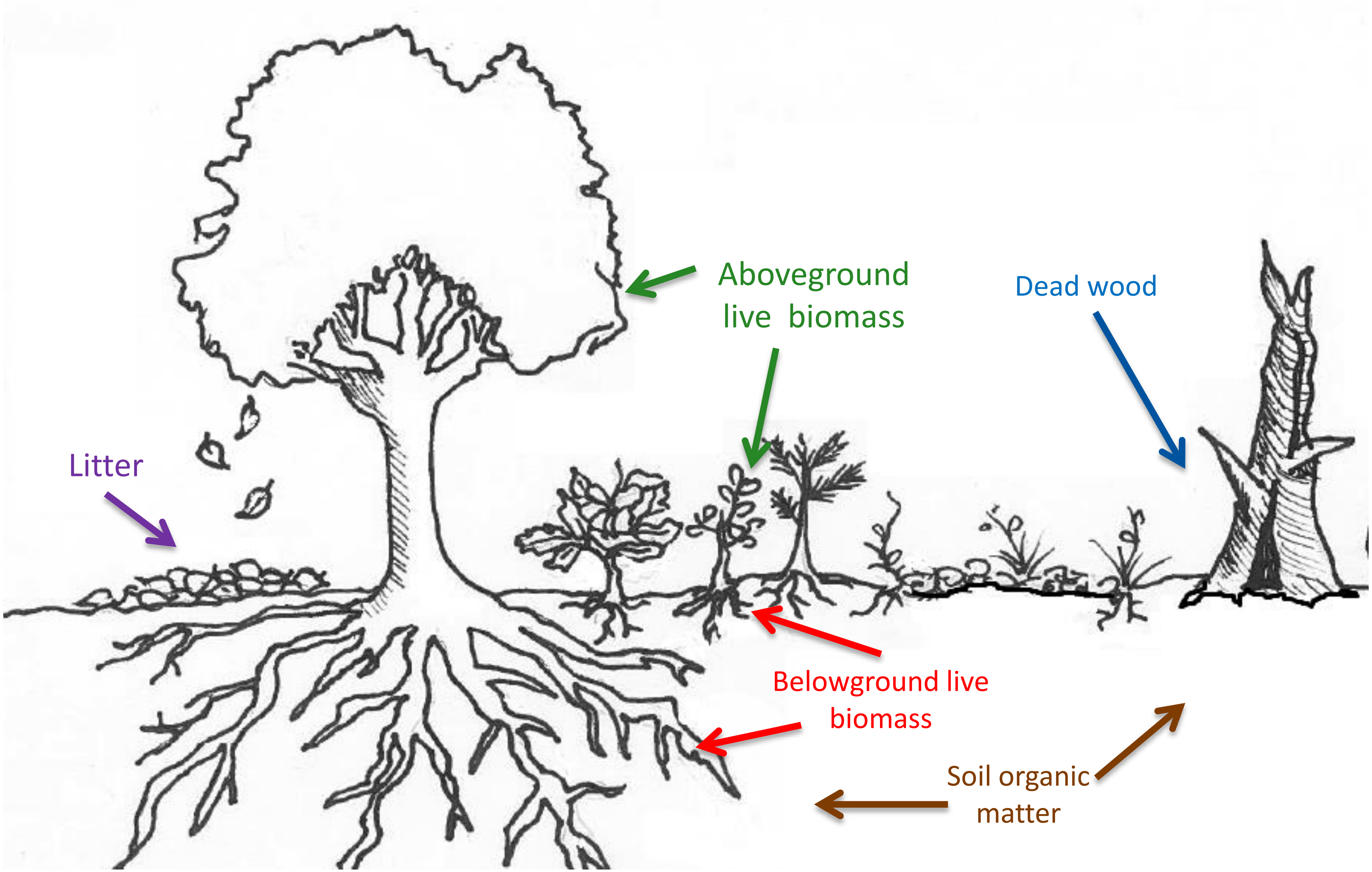
Five forest carbon pools



Which carbon pools to monitor (1/2)

Choosing which C pools to monitor depends on:

- What EF you are developing (e.g., deforestation or degradation)
- Magnitude of pool
- Rate of change of pools in response to human disturbance
- Expected direction of change
- Costs to measure
- Methods available to measure
- Attainable accuracy and precision

Which Carbon Pools to monitor (2/2)

Which C pools should be selected? In general, all those pools representing 5% or more of total should be included:

- The aboveground and below ground tree carbon pool
- Standing and lying dead wood, because it can represent up to 10% of the total carbon pool
- Understory in a mature forest is often negligible—less than 2–3% of the total; in a secondary forest this can be a larger proportion—up to 5% of the total
- The soil carbon pool should be included if the forest conversion is to agriculture or roads or other land uses with high soil disturbance (e.g., mining); if converted to pasture soil, C pool can be ignored
- The soil C pool should be included if deforestation occurs on peat swamp forests

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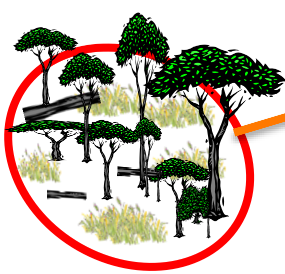
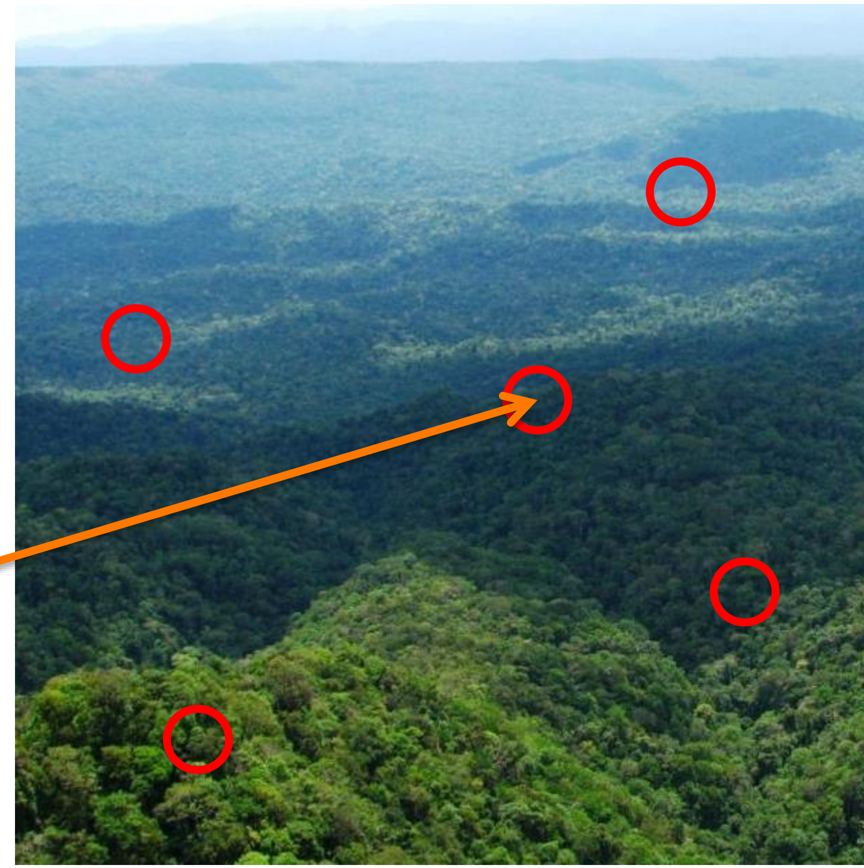
Traditional field measurements

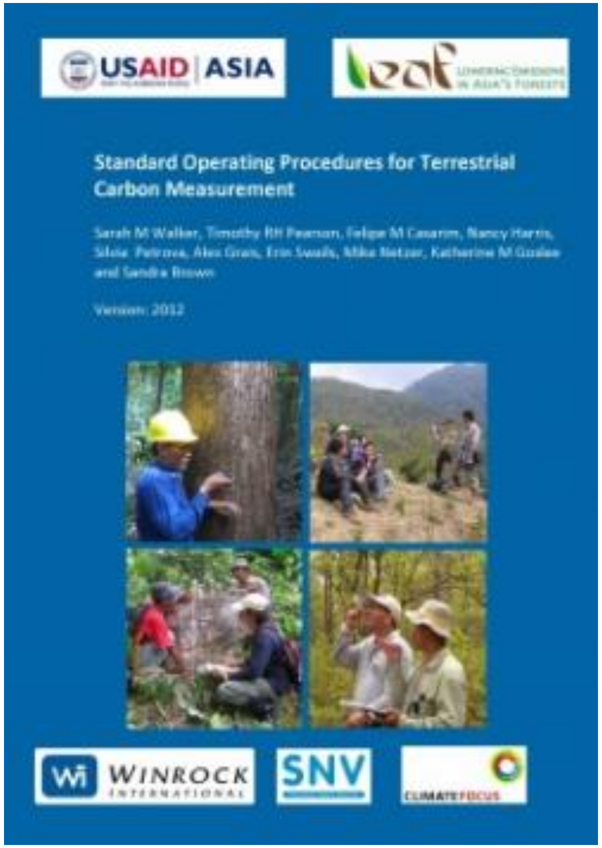
- Measure different carbon pools within strata.
- Repeat measurements in many sample plots across landscape, using to a stratification strategy.





Methods for field measurements

- Methods for field measurements must be developed and documented prior to sampling.
- Methods must be standardized to ensure measurements are implemented consistently between field crews and inventories.
- For example, Winrock Standard Operating Procedures (SOPs) for Terrestrial Carbon Measurements can be used to measure carbon stocks of forests and other land cover types.
- More info on importance of SOPs, see Module 3.1.



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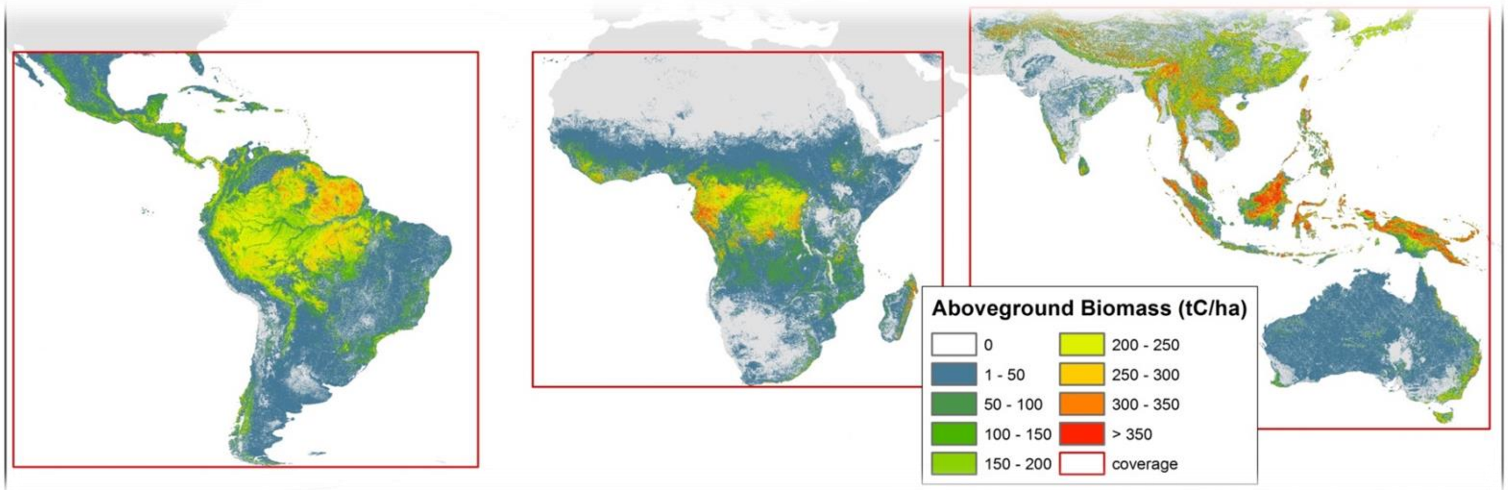
Developing EFs at Tier 1

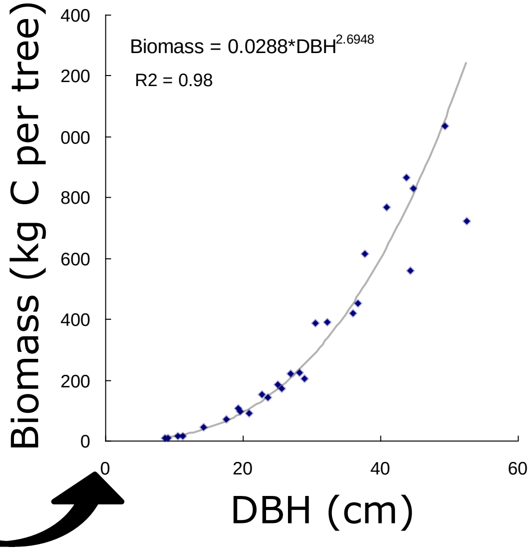
- Biomass C stock maps can be useful for an IPCC Tier 1–type emission factor for deforestation, although Biomass C stock maps are constantly improving. (The map shown here is an improvement over the IPCC Tier 1 values.)
- EFs can be developed using biomass C stock maps, which provide estimates of carbon stocks by each strata (described in this module's section 4.ii) and used with the stock-difference method.



Developed by S. Saatchi 2013, in collaboration with Winrock and Applied GeoSolutions; map at 250 m resolution.

Procedure for calculating average forest carbon stocks

- Measurements of carbon pools are recorded in the field.
- Models and conversion factors are used to estimate carbon stocks in each major pool based on field measurements.
- Statistical analysis is used to calculate average forest carbon stocks based on plot data.



Data analysis

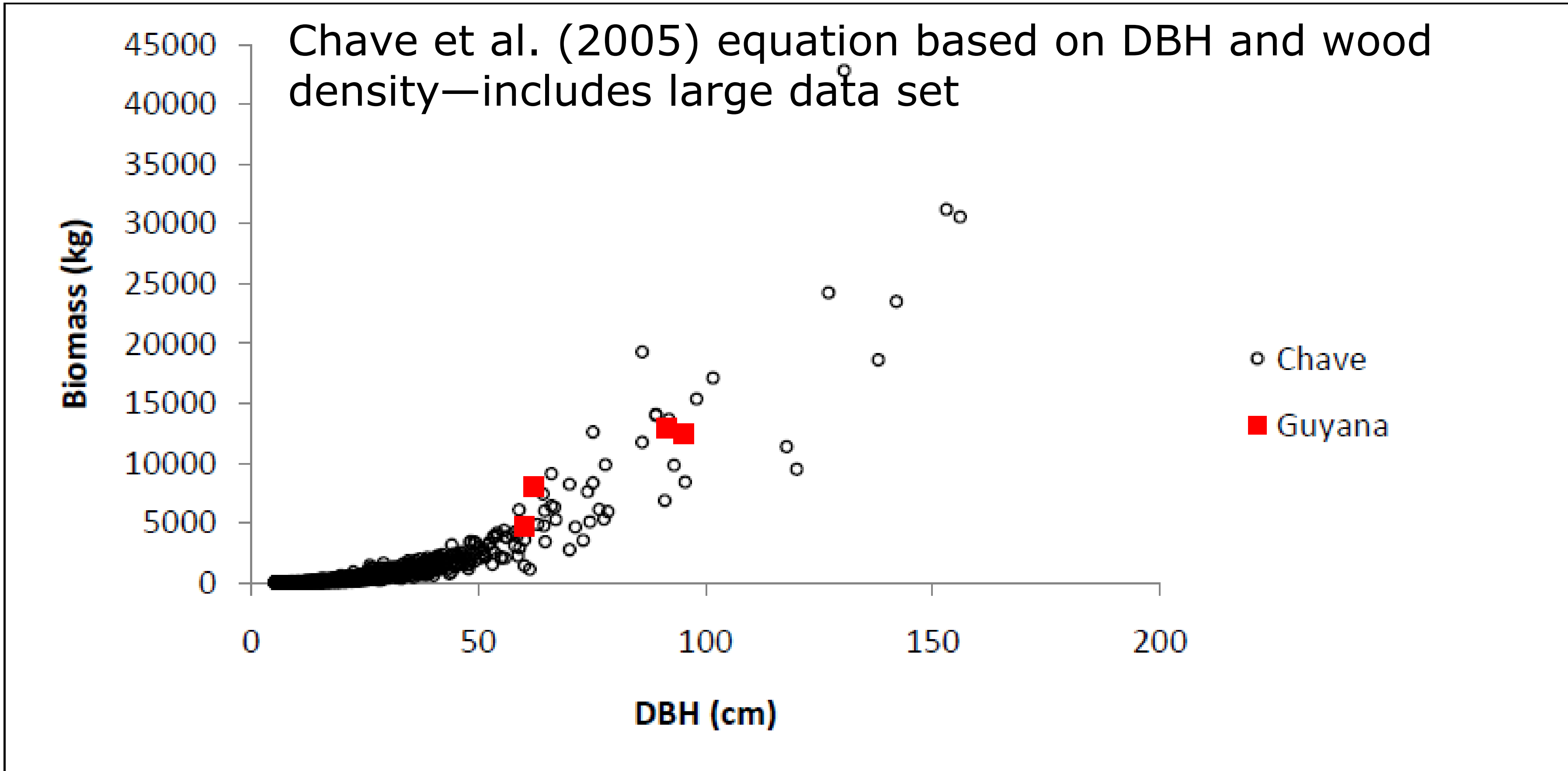
- Trees often have predictable relationships among their height, diameter, and roots.
- Mathematical formulas are available or can be developed to express these relationships.
- Forest field data can be applied to these mathematical formulas to indirectly estimate biomass.
- Biomass estimates can be converted to carbon using the conversion factor of 1 unit biomass = 0.5 unit of C.
- 44/12 = Conversion factor for C to CO_2.

Estimate aboveground biomass carbon using allometric equations

- An allometric equation describes the relationship between a readily measureable variable and mass (biomass) of tree.
- There are many equations published for forests worldwide based on DBH or a combination of DBH, species wood density, and height.
- Local regression equations may exist in literature but would need to be verified with local data or through destructive sampling.

Validating existing allometric equations

An example of validating existing equations with destructive sampling of local trees



Estimating belowground biomass carbon

- Belowground tree biomass (roots) is rarely measured. A root-to-shoot ratio can be applied instead, such as those from IPCC.

Table 2.3.3. Root to shoot ratios modified* from Table 4.4. in IPCC GL AFOLU.

Domain	Ecological Zone	Above-ground biomass	Root-to-shoot ratio	Range
Tropical	Tropical rainforest or humid forest	<125 t.ha-1	0.20	0.09-0.25
		>125 t.ha-1	0.24	0.22-0.33
	Tropical dry forest	<20 t.ha-1	0.56	0.28-0.68
		>20 t.ha-1	0.28	0.27-0.28
Subtropical	Subtropical humid forest	<125 t.ha-1	0.20	0.09-0.25
		>125 t.ha-1	0.24	0.22-0.33
	Subtropical dry forest	<20 t.ha-1	0.56	0.28-0.68
		>20 t.ha-1	0.28	0.27-0.28

*the modification corrects an error in the table based on communications with Karel Mokany, the lead author of the peer reviewed paper from which the data were extracted.

Estimating soil carbon

What about soil C? IPCC guidelines for the different Tiers for estimating soil carbon changes in deforested areas are:

Soil carbon pool	Tier 1	Tier 2	Tier 3
Organic carbon in mineral soil	Default reference C stocks and stock change factors from IPCC	Country-specific data on reference C stocks & stock change factors	Validated model complemented by measures, or direct measures of stock change through monitoring networks
Organic carbon in organic soil	Default emission factor from IPCC	Country-specific data on emission factors	Validated model complemented by measures, or direct measures of stock change

Tier 2 approach for soil carbon

- Tier 2 approach for soil carbon stocks and change:
  - Reference or initial soil carbon stock to 30 cm obtained from field soil sampling—need samples for estimating both bulk density (in g/cm^3) and carbon content (in %)
  - Change in soil carbon stock = $[CS_0 - CS_D]/D$, where:
    - CS_O = Initial or reference soil organic carbon, t C ha-1
    - CS_D = Soil organic carbon at default time D, t C ha-1
    - D = Default time period to transition to a new equilibrium value (20 year)
  - $CS_D = CS_O * F_{LU} * F_{MG} * F_I$, where the F parameters are stock change factors related to land use system, soil management regime, and organic matter inputs (from IPCC, 2006, AFOLU GL)

F stock change factors (future land use)

- Example values of F stock change factors (all are dimensionless):
  - F_{LU}= factor for land use; F_{MG}= factor for management regime; and F_I= factor for input of organic matter

Converted to:	F_{LU}	F_{MG},	F_I
i. Conversion to permanent agriculture	0.48	1.0	1.0
(assumes continuous cultivation for 20 yr, full annual tillage, and <30% of ground covered with residues, and medium inputs typical of annual crops).			
ii. Conversion to unpaved roads:	0.82	1.0	0.92
(assumes idle land that is set aside with no further tillage, substantial initial soil disturbance and < 30% of surface covered by residues and low inputs).			
iii. Shifting cultivation	0.65/0.80	1.0	1.0
(short and long fallow)			

From sample plots to estimating total biomass C

- Biomass estimates from sample plots are scaled up to calculate carbon in each biomass pool:
  1. Estimate biomass stocks for each pool
  2. Scale each sample to per hectare level
  3. Convert biomass values to carbon values
  4. Calculate average and 95% confidence interval of carbon stock in each pool within each stratum
  5. Sum mean stock per pool

Example of EF development for deforestation

- Example of EF for conversion of forest to annual cropland where no wood was extracted for products

Carbon Pool	Carbon Stock (t C ha^{-1})
Aboveground tree biomass	190.6 ± 15.5
Belowground tree biomass	44.8± 3.7
Saplings	5.2 ± 0.6
Dead wood (standing)	3.3 ± 1.7
Dead wood (lying)	19.3 ± 3.7
Total carbon stock	263.2
Soil to 30 cm	102 ± 23.7
Annual crops	3.0

→ **Assume all emissions occur at time of event**

EF for biomass components:

$=(Cpre-Cpost-Cwp) \times 44/12$
$=(263.2-3.0-0) \times 44/12$
$= 954$ t CO_2/ha

EF for soil (slides 44 & 45):

$= (CS_o - CS_O * F_{LU} * F_{MG} * F_I)$
$=(102 - 102 \times 0.48 \times 1 \times 1) \times 44/12$
$= 194$ t CO_2/ha

Total EF = 1,148 t CO_2/ha

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4. **Estimating emission factors for deforestation**
   i. Strategies
   ii. Stratification of lands
   iii. Carbon pools
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   v. Estimating C stocks and developing EFs
   vi. **Sources of error and Quality assurance/Quality control**
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Sources of error

- There are three main sources of error:
    - Sampling error
    - Measurement error
    - Model or Regression error
- Total error is the sum of these sources.
- See Module 2.7 for details on how to estimate total error.

Sampling error

- Sampling error reflects the variability in the estimate due to measuring only a subset of the population of interest.
- A large sampling error can result from incorrect distribution or number of plots used for sampling C stocks.
- Plot size and distribution must adequately and efficiently capture spatial variability.

Measurement error

There are many opportunities to make measurement and recording mistakes during field inventory!



Model or regression error

- Regression equations are developed specifically for a specific set of tree species within a specific DBH range.
- A regression line generally does not go through all the data: approximating the data using the regression line entails some error.
- Large regression errors can occur if field inventory DBH values are applied to an inappropriate regression formula for the DBH and species range.

Quality assurance / Quality control (1/2)

To minimize error, data collection and analysis should include quality assurance/quality control (QA/QC) measures for:

- Collecting reliable field measurements
- Verifying methods used to collect field data
- Verifying data entry and analysis techniques
- Maintaining and archiving data

See Module 3.1 on national data organization and management for implementing QA/QC and the importance of sound data management.

Quality assurance / Quality control (2/2)

- Data collection should follow a set of standard operating procedures (SOPs) (See Module 3.1).
- Field measurements should be complemented by regular checks by supervisors to verify measurement.
- Entered data should be reviewed and examined for outliers and mistakes.
- All data should be stored in a secure location and backed up routinely.
- Copies of data should be stored separately in fire-proof facilities.

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Strategies for estimating EFs

- Forest lands undergoing selective logging activities must be identified.
- Sampling must take place very soon after felling timber trees—if possible while timber tree is still in the forest
  - Hard to assess damage if not sampled quickly
  - Avoids miscounting from regrowth
  - Reduces uncertainty from key parameters (DBH, L_{log})
- Sampling plans should be designed to meet a targeted or required level of certainty and to *meet international standard of representative, unbiased*, *consistent*, *transparent*, and *verifiable*.

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Estimating EF for selective logging (1/2)

- Carbon losses—or EF—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: dead biomass carbon left behind in gap from felled tree and incidental damage (t C/m^3 extracted)
  - LIF = logging infrastructure factor: dead biomass carbon caused by construction of infrastructure (t C/m^3)

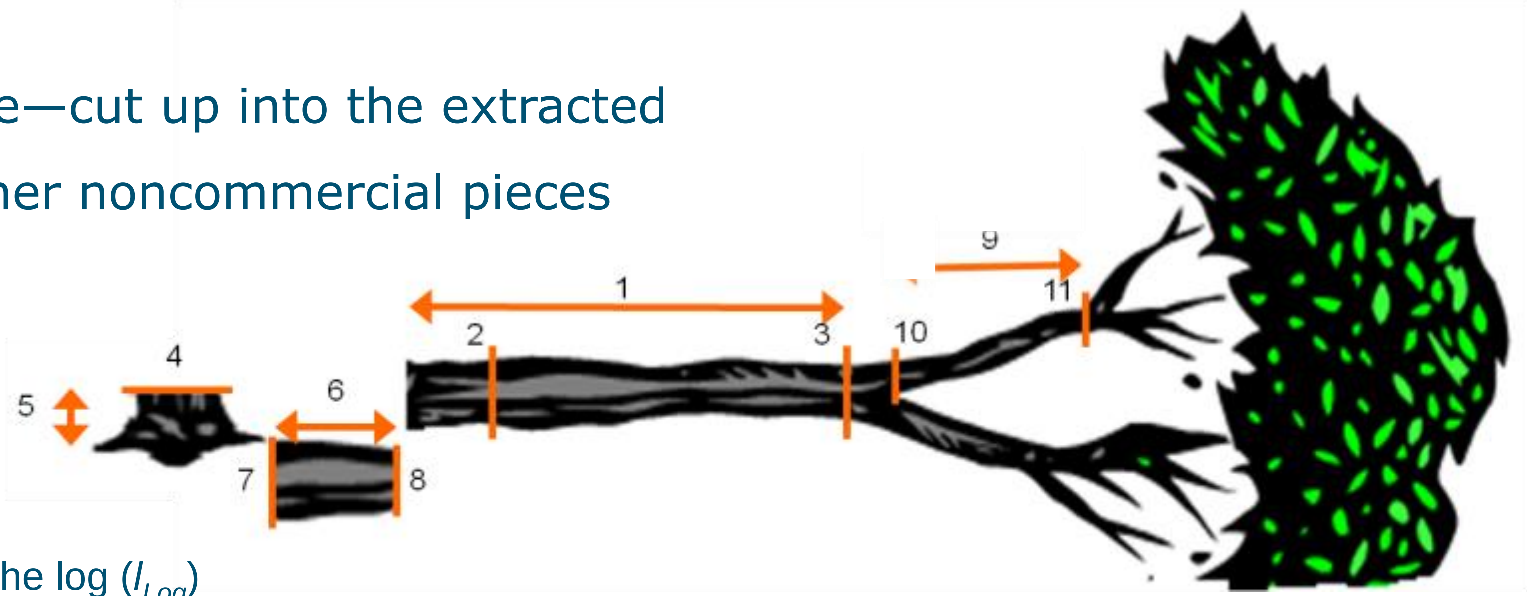
- Field data are collected from multiple logging gaps (>100 plots) to quantify each of these factors—the steps to collect data are given next. (See Pearson, Brown, and Casarim 2014)

Estimating EF for selective logging (2/2)

- Relate total selective logging carbon emissions to easily measurable parameters:
  - Area of canopy gaps (m^2)
  - Volume of timber extracted (m^3) –> easier to track
- Logging components that impact C emissions:
  - Extracted volume
  - Amount of timber going into long-lived (>100 year) wood products
  - Portions of timber tree left in forest (crown, stump)
  - Incidental damage to surrounding trees (the increase in dead wood resulting from felling and extraction)
  - Logging infrastructure (skids, log landings, and roads)

Field measurements for selective logging EF development (1/2)

Timber tree—cut up into the extracted log and other noncommercial pieces



1. Length of the log (l_{Log})
2. DBH (and diameter of top of the piece – $d_{Piece-T}$)
3. Diameter at the top cut of the log (d_{Top})
4. Diameter of the stump (D_{Stump})
5. Height of the stump (H_{Stump})
6. Length of the noncommercial piece or pieces (l_{Piece})
7. Diameter of the bottom of the noncommercial piece ($d_{Piece-B}$)
8. Diameter of the top of the noncommercial piece ($d_{Piece-T}$)

Field measurements for selective logging EF development (2/2)

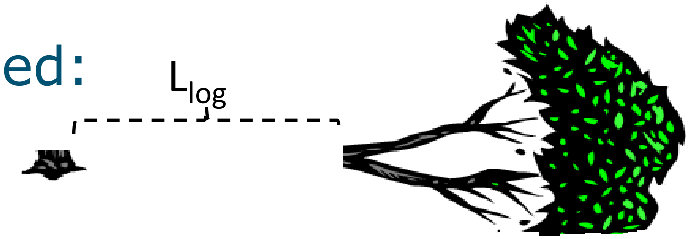
Timber tree: It is very important to know the DBH of the felled tree and its species because these two pieces of data are used to estimate the biomass of the felled tree.

If felled tree still present:

- Measure DBH and L_{log} directly

If felled tree has already been extracted:

- Measure L_{log}
- Estimate DBH through taper factor

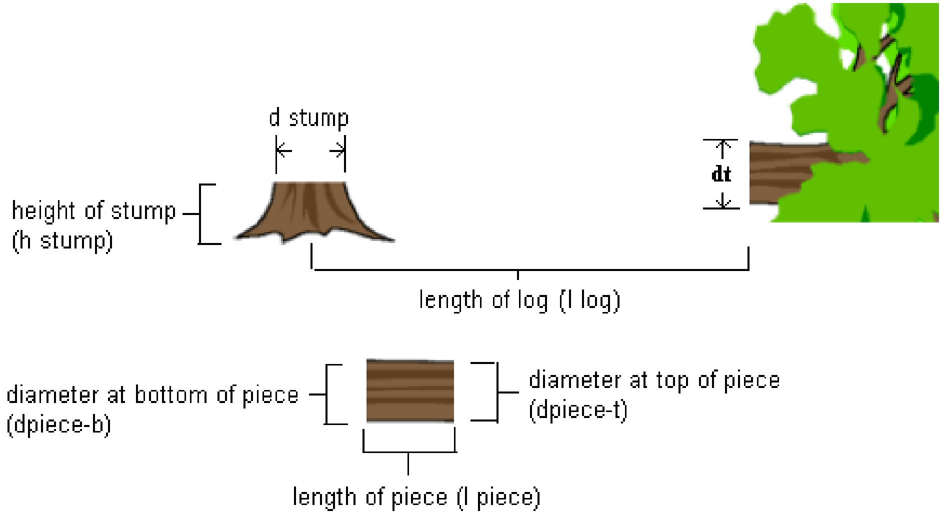


$$DBH = D_{stump} - \left[\frac{D_{stump} - D_{top}}{L_{\log} \times 100} \times \left(130 - H_{stump}\right) \right]$$

Estimating DBH using taper factor

Applying the taper factor equation to estimate DBH

Field Measurements:
Dstump = 70.8 cm
Dtop = 49.7 cm
Length = 19.9 m
Hstump = 80 cm



Tree taper = $\frac{70.8 - 49.7}{19.9}$ = 1.06 cm/m

Change in length = 130 – 80 = 50 cm

$$DBH = 70.8 - \left[\frac{70.8 - 49.7}{19.9 \times 100} \times (130 - 80) \right] = 70.27$$

Extracted log emissions (ELE)

- Apply the appropriate allometric equation to the felled tree parameters to estimate aboveground biomass.
- Biomass left in forest = biomass of felled tree – biomass of volume extracted [=volume X species-specific wood density].

Logging damage factor (LDF)

Incidental damage:

- Measure DBH of all surrounding trees fatally damaged due to timber tree falling:
  - Classify damaged trees into:
    - Snapped
    - Uprooted
- Measure broken branches from surrounding trees.
- Estimate damaged biomass using appropriate allometric equations for damaged trees.

Logging infrastructure factor (LIF)

Infrastructure

Roads, skid trails, and decks:
✓ Length
✓ Width

Infrastructure emission factor
(Skid trails+decks+roads)

Estimate C impact for constructing each

Skids likely have lower impact than larger roads or tracks as they deviate around larger trees

Total logging infrastructure impact is estimated as tons of C per m^3 extracted

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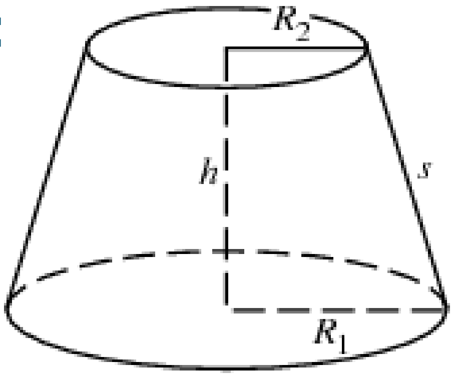
Estimating ELE (t C/m³)

- Estimate log volume:
  - What shape best approximates a tree log?



Conical Frustum (cone with top sliced off)

- **Biomass = Density x Log Volume**

  Density = *species-specific* wood density (t/m³)

- Repeat for all logging gaps to estimate mean ELE

Estimating LDF

Sum biomass:

- Top + stump + pieces left in forest
(biomass of timber tree – biomass of log)

- Incidentally damaged trees
(snapped + uprooted + broken branches)
- Repeat for all plots and estimate mean
LDF

Estimating LIF

- Sum C impact of:
  skids + roads + decks
- The C impact is estimated as the product of C stock estimates of unlogged forest and area of infrastructure.
- Divide by total harvested volume in m^3.

Estimating total emissions

C emissions, t C/yr =

[vol x ELE x (1-LTP)]+[vol x LDF]+[vol x LIF]

Where:
Vol = volume timber extracted over bark per logging block (m3)
ELE = extracted log emissions (t C/m^3)
LTP = proportion of extracted wood in long term products still in use after 100 yr (dimensionless)
LDF = logging damage factor (t C/m3)—dead wood left behind in gap
LIF = logging infrastructure factor (t C/m3)—dead wood produced by construction

Example of estimating total emissions

Concession TBD Inc. constructs 15 km of skid trails and roads to harvest 10 m^3/ha on 500 ha in 2013. No decks are built as logs are piled alongside wide roads. Five percent of the harvested wood went into long-term wood product storage.

Assumed factors:
ELE= 0.36 t C/m^3
LTP= 0.05
LDF= 1.05 t C/m^3
LIF= 1.49 t C/m^3

C emissions, t C/yr = [vol x ELE x (1-LTP)]+[vol x LDF]+[vol x LIF]

C = [(500*10) x 0.36 x (1-0.05)] + [(500*10) x 1.05] + [(500*10) x 1.49]

C = 1,710 + 5,250 + 7,450

C = 14,410 t C ~ 52,837 tCO_2

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How to estimate gains through regrowth

- Gains by growth—need improved guidance:
  - Need regrowth rate of stand after logging per unit area per year for multiple years
  - Regrowth occurs only in and around the gaps and may not enhance carbon accumulation (smaller trees and gap closure)
  - Occurs over limited time frame
- How to estimate—need time course of carbon accumulation by ingrowth of new trees, growth of surviving trees, and delayed mortality of previously damaged trees:
  - Long-term plots established around logging gaps and measured over time
  - Establish and measure a chronosequence of logging gaps with a standard design

In summary

- The IPCC recommends that it is good practice to use higher Tiers for the measurement of significant sources/sinks.
- The stock-difference method is most commonly applied for estimating emissions from deforestation.
- The gain-loss method is the most suitable method to estimate emissions form forest degradation.
- Allometric equations that link tree variables (DBH, height, wood density) to tree biomass are used to estimate C emissions from deforestation.
- Emissions from forest degradation can be estimated by summing emissions from extracted logs, logging damage, and infrastructure damage.
- The use of SOPs and quality assessment/quality control are important to ensure the quality of estimates and to minimize errors.

Country examples and exercises

Country example

- Estimating emission factors (biomass and soil) for forest cover change in Guyana

Exercises

- Tutorial on how to estimate EFs:
    - Estimating Emissions from Deforestation
    - Estimating Emissions from Degradation by Logging

Recommended modules as follow-up

- Module 2.4 to learn about involving communities / local experts in monitoring changes in forest area and carbon stocks.
- Module 2.5 to estimate carbon emissions from deforestation and forest degradation
- Modules 3.1 to 3.3 to proceed REDD+ assessment and reporting.

References

- Brown, S., F. M. Casarim, S. K. Grimland, and T. Pearson. 2011. *Carbon Impacts from Selective Logging of Forests in Berau District, East Kalimantan, Indonesia*: *Final Report to the Nature Conservancy*. Arlington, VA: Nature Conservancy. http://www.winrock.org/resources/carbon-impacts-selective-logging-forests-berau-district-east-kalimantan-indonesia.
- Chave, J., et al. 2005. "Tree Allometry and Improved Estimation of Carbon Stocks and Balance in Tropical Forests." *Oecologia* 145: 87–99. http://www.winrock.org/resources/tree-allometry-and-improved-estimation-carbon-stocks-and-balance-tropical-forests.
- GFOI (Global Forest Observations Initiative). 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 Observations Initiative*. (Often GFOI MGD.) Geneva, Switzerland: Group on Earth Observations, version 1.0. http://www.gfoi.org/methods-guidance/.
- GOFC-GOLD (Global Observation of Forest Cover and Land Dynamics). 2014. *A Sourcebook of Methods and Procedures for Monitoring and Reporting Anthropogenic Greenhouse Gas Emissions and Removals Associated with Deforestation, Gains and Losses of Carbon Stocks in Forests Remaining Forests, and Forestation*. (Often GOFC-GOLD Sourcebook.) Netherland: GOFC-GOLD Land Cover Project Office, Wageningen University. http://www.gofcgold.wur.nl/redd/index.php.

- IPCC 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Volume 4: Agriculture, Forestry and Other Land Use. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html (Often referred to as IPCC AFOLU GL)

- Pearson, T. R. H., S. Brown, and F. M. Casarim. 2014. "Carbon Emissions from Tropical Forest Degradation Caused by Logging." *Environmental Research Letters* 9: 034017. doi:10.1088/1748-9326/9/3/034017.

- UNFCCC COP (United Nations Framework Convention on Climate Change Conference of the Parties) Decisions. This module refers to and draws from various UNFCCC COP decisions. Specific decisions for this module are listed in the "Background Material" slides. All COP decisions can be found from the UNFCCC webpage "Search Decisions of the COP and CMP." http://unfccc.int/documentation/decisions/items/3597.php#beg.