Food and Agriculture Organization of the United Nations

FOREST CARBON PARTNERSHIP FACILITY

National Forest Monitoring Team
FAO Forestry Division
March 2021

Introduction to **forest change area estimation**

Information material for forestry generalists on the why and the how of change area estimation in the REDD+ context

Overview

- Why area estimation
- Map-based vs. sample-based area estimation
- How to set up sample-based area estimation
  - Sample design
  - Response design
  - Data collection
  - Data analysis
- Country examples
- References

What is REDD+

Reducing emissions from deforestation and forest degradation (REDD+) is a mechanism developed by Parties to the United Nations Framework Convention on Climate Change (UNFCCC).

What is REDD+

It creates a **financial value for the carbon stored** in forests by offering incentives for **developing countries to reduce emissions** from forested lands and invest in low-carbon paths to sustainable development.

What is REDD+

Developing countries would receive **results-based payments** for results-based actions.

REDD+ goes beyond simply deforestation and forest degradation and includes the role of conservation, sustainable management of forests and enhancement of forest carbon stocks.

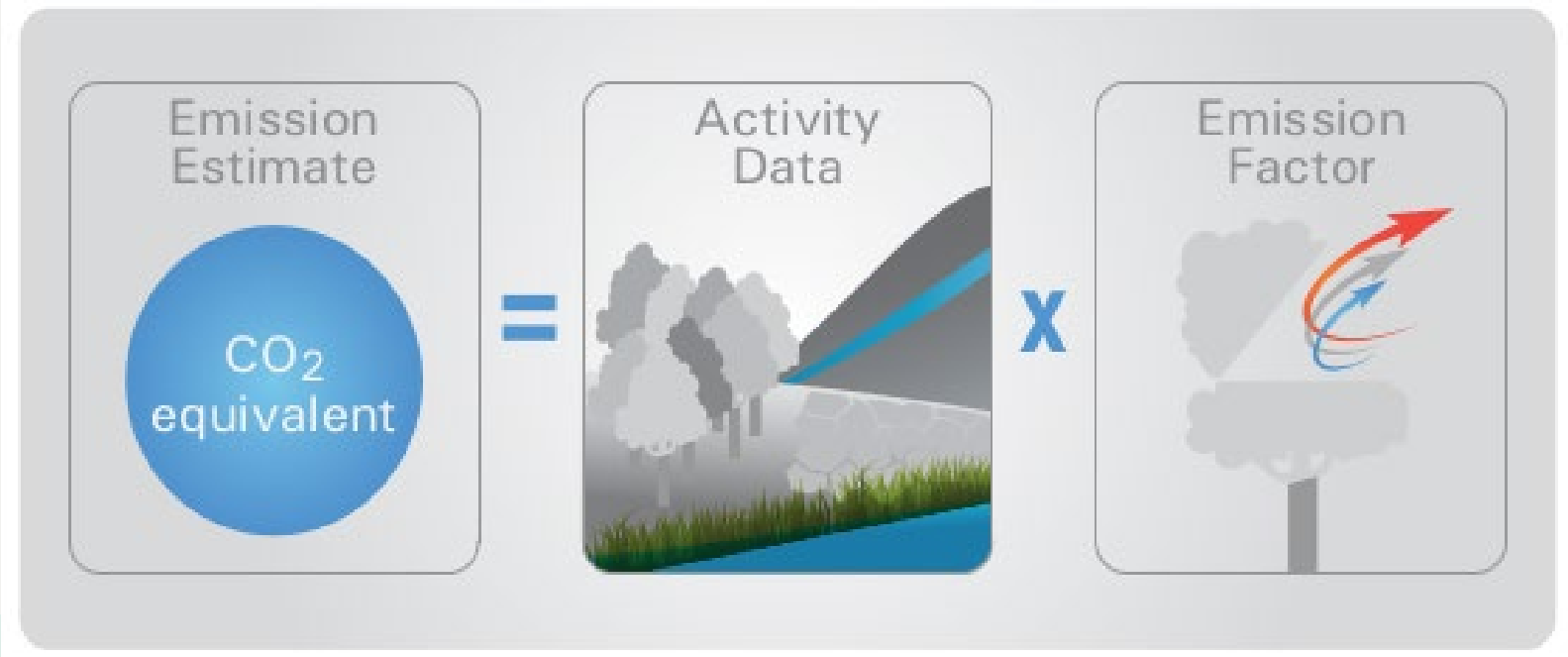
www.unredd.net/about/what-is-redd-plus.html

Estimates of land cover and land use area change are important for determining:

- Rate of deforestation and forest degradation
- Rate of forest re-growth or restoration
- Changes in such rates (as a result of mitigation efforts)
- Amount of associated greenhouse gases emitted or removed by combining with emission factors

These are key components to meet requirements for international reporting in the context of global effort to reduce atmospheric carbon dioxide emissions

IPCC emission estimation



Source and background:

FAO & GFOI 2020, Methods and Guidance

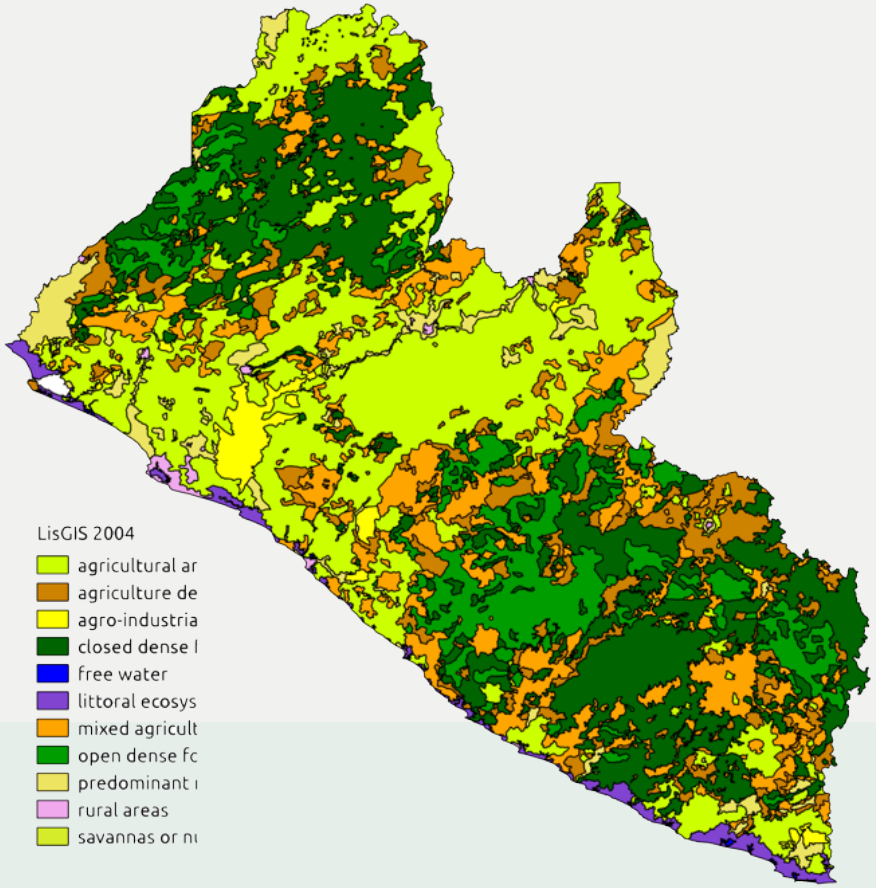
FAO & GFOI, 2021, White Paper: Issues and good practices in sample-based area estimation

Amount of emissions tCO_2 eq / year

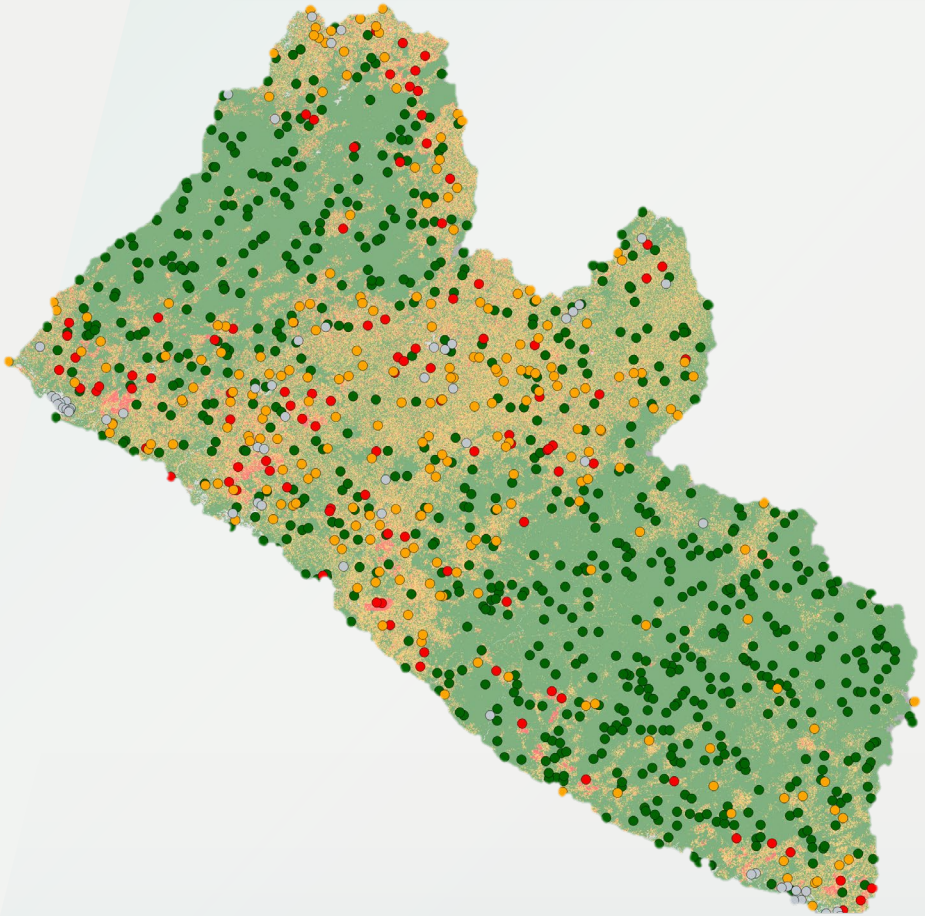
Area of forest change ha /year

Amount of carbon per hectare deforestation tCO_2e /ha

Two basic approaches for estimating areas

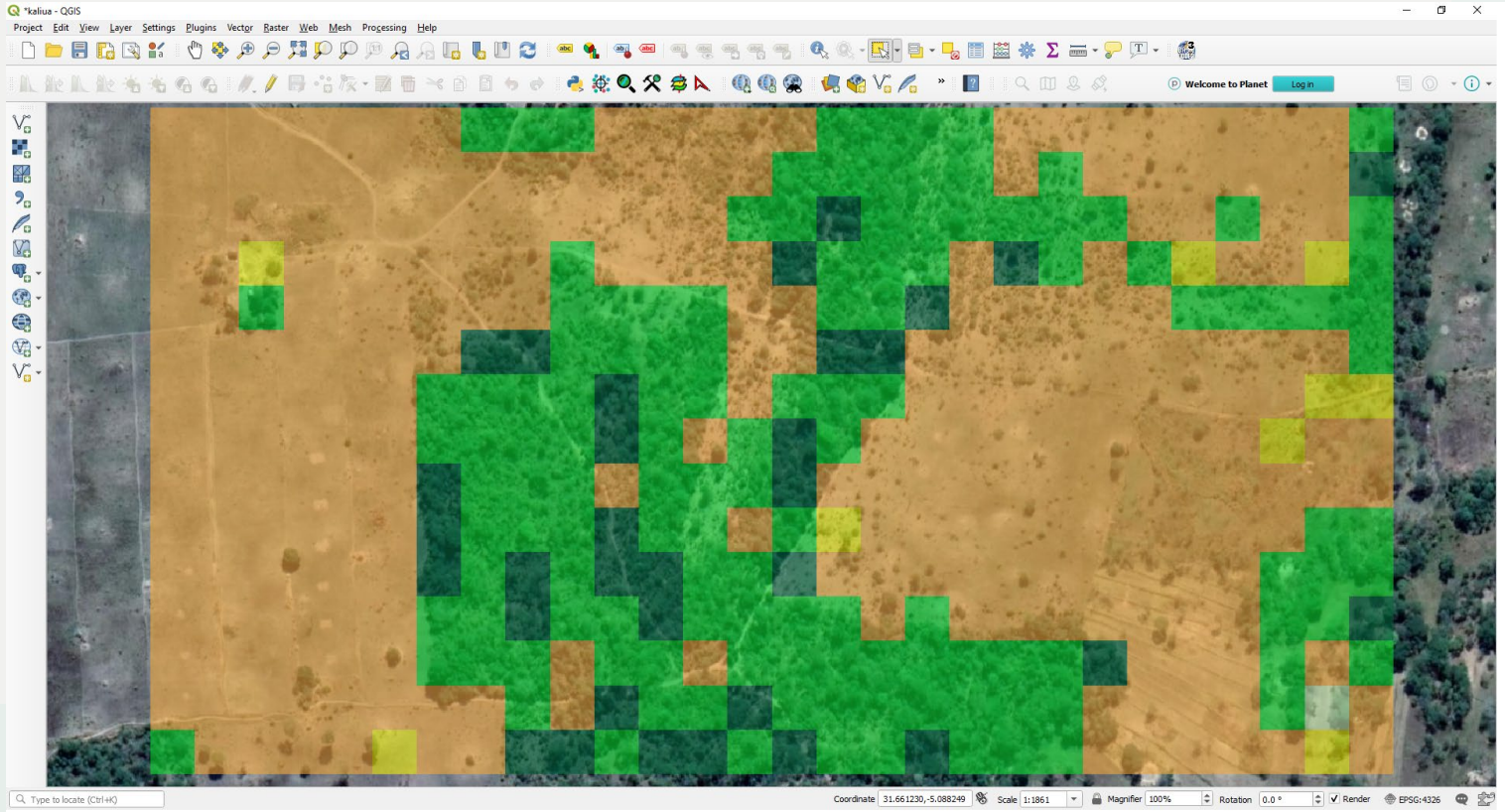


Map-based approach (as in land cover mapping)



Sample-based approach (as in NFI)

Map-based: wall-to-wall measure



Area of the zone:
37.8 ha

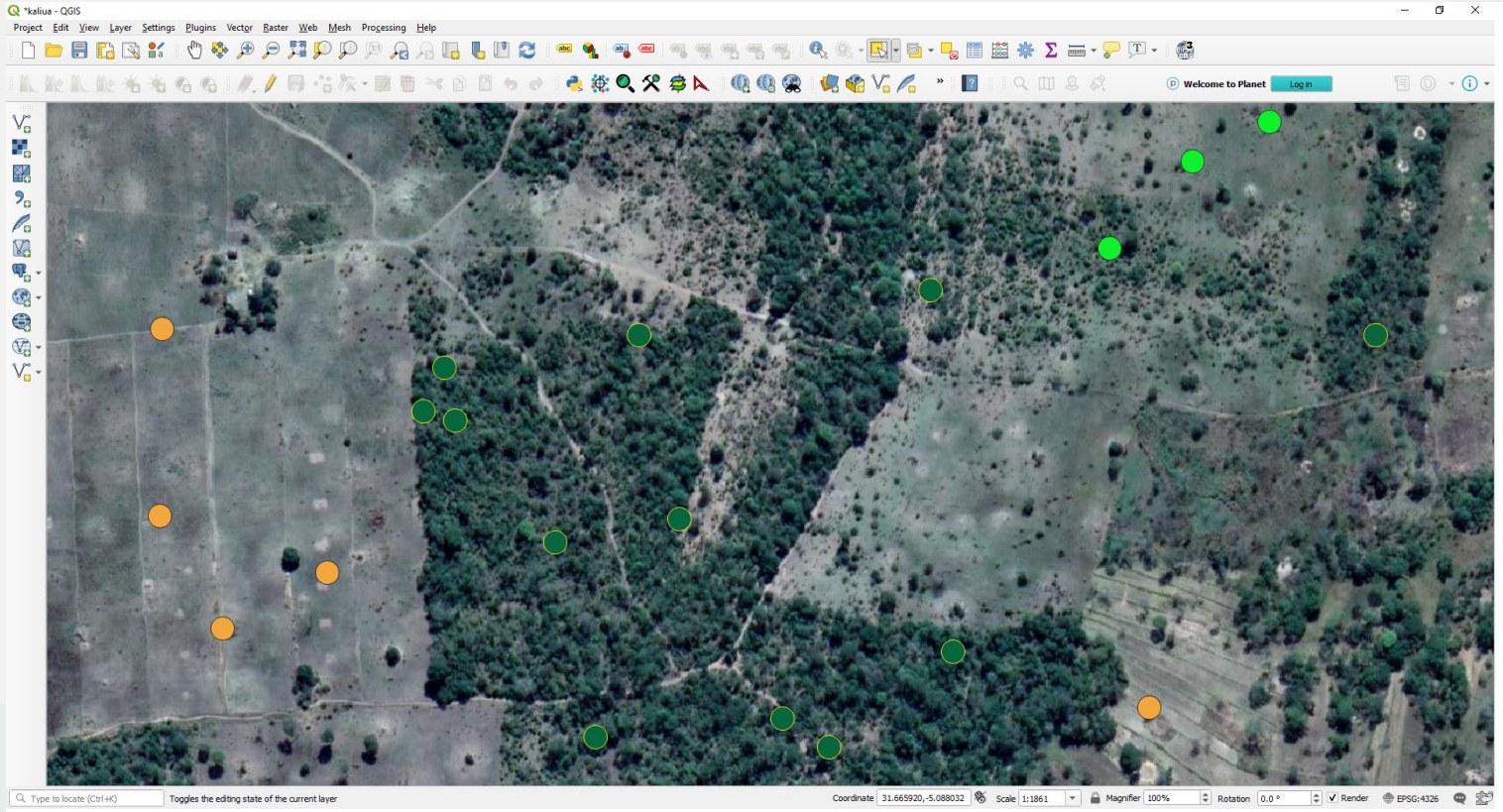
Area of 1 pixel:
30m x 30m = 0.09 ha

Number of pixels:
15*28 = 420 pixels

TC	33 pixels = 2.97 ha
S	1 pixel = 0.09 ha
HCRml	247 pixels = 22.23 ha
TO	130 pixels = 11.70 ha
HCWs	9 pixels = 0.81 ha

Map = combination of automatic procedure (model based) and/or manual interpretation count features (pixels or polygons) and multiply by the area of each feature.

Sample-based: applying proportions



Area of the zone:
37.8 ha

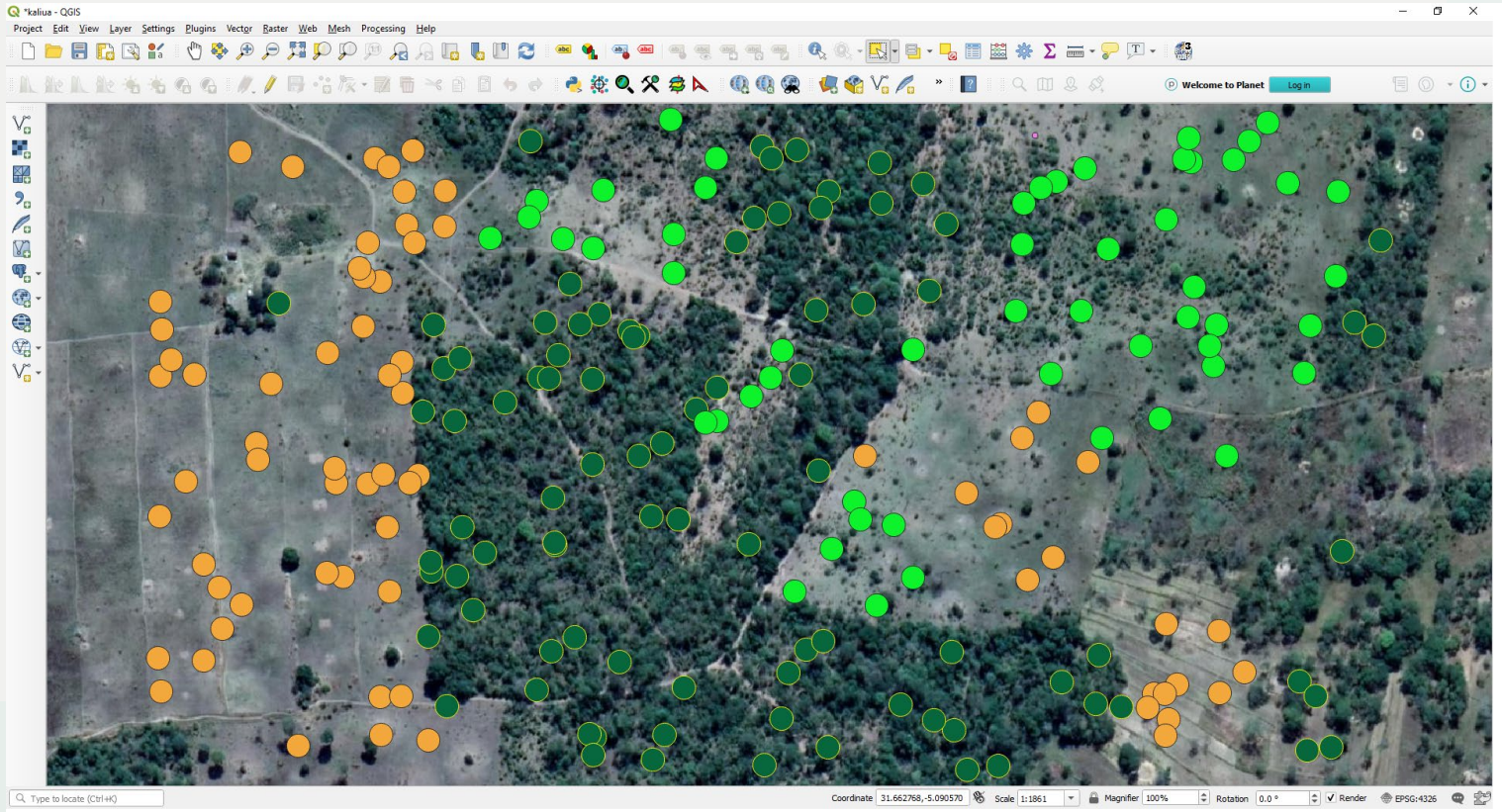
Total sample size:
20 points (random)

Point weight:
37.8/20 = 1.89 ha

Class	Count	Area (ha)	SD (ha)
HCRml	5	9.5	3.7
TC	12	22.7	4.1
TO	3	5.7	3.0
Total	**20**	**37.8**	

Calculate the proportion of points for each class and apply the unitary weight. This is a statistical approach, through visual interpretation.

Sample-based: applying proportions



Area of the zone:
37.8 ha

Total sample size:
20 points (random)

Point weight:
37.8/20 = 1.89 ha

Class	Count	Area (ha)	SD (ha)
HCRml	70	12.3	1.2
TC	89	15.6	1.3
TO	56	9.8	1.1
Total	**215**	**37.8**	

The higher the sampling density, the more accurate the area estimation
Can become very time consuming.

Side by side: Map vs. Sample approach

Map-based area estimation
Map generation relies on application of same classification algorithm and dataset for large areas, potentially introducing error for sub-areas
Consistent data at all spatial scales
The map includes a comprehensive wall-to-wall assessment without sampling uncertainty
Neither takes into account the classification errors nor allows the computation of a confidence interval
Unsuitable for area reporting

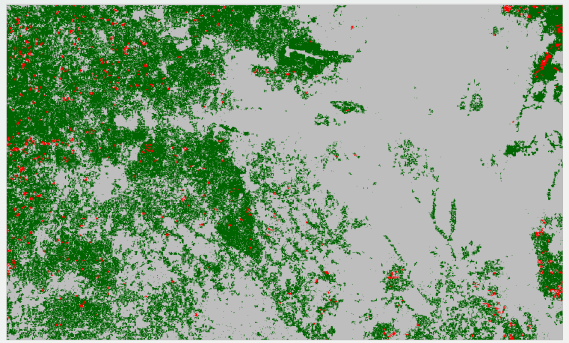
Sample-based area estimation
Sample is carefully interpreted using the best available data for any specific location
Estimates for sub areas require sufficient sampling density
Uncertainty is introduced through the locations of sample units
Allows a confidence interval to be calculated based on sampling error
Suitable for area reporting

Why not pixel counts

Example **accuracy assessment**

		Example accuracy assessment			
		Stable forest	**Stable non-forest**	**Deforestation**	**Total**
Map of forest change 2015-2020	**Stable forest**	900	90	5	**995**
	Stable non-forest	180	1,700	25	**1,905**
	Deforestation	20	20	60	**100**
	Total	**1,100**	**1,810**	**90**	

Map bias



- Map data has classification errors and an accuracy assessment can quantify those errors
- Commission errors are units mapped as one class but observed as another land class
- Omission errors are sample units observed as one land class but mapped as another land class
- The sample data is used to adjust for the bias and account for the classification errors in the map
- Reporting only a pixel count does not account for those errors

Why not pixel counts

Focusing on **deforestation**

		Example accuracy assessment			
		Stable forest	Stable non-forest	Deforestation	Total
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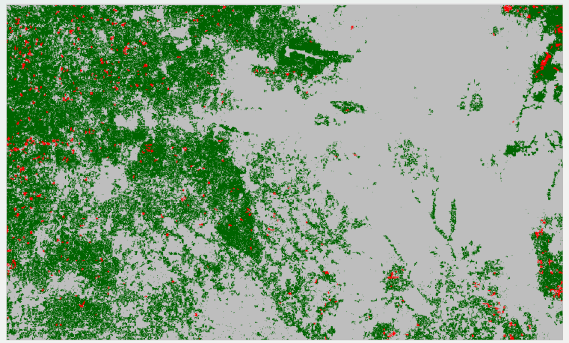

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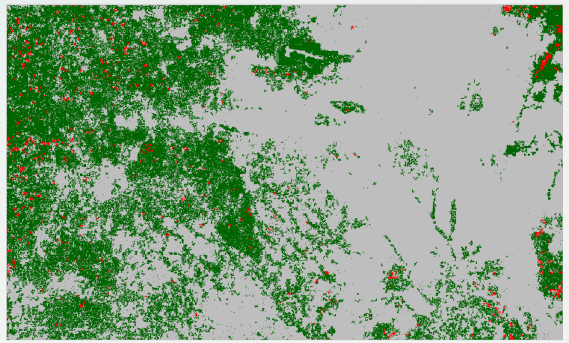

- The **commission error of deforestation is** (20 + 20) (errors highlighted in red)/100 (total number of samples distributed in the deforestation map class highlighted in blue)= **40%**
- The **users accuracy of deforestation** is 60 (highlighted in yellow)/ 100 (total number of samples distributed in the deforestation map class highlighted in blue) = **60%**

Why not pixel counts

Focusing on **deforestation**

		Example accuracy assessment			
		Stable forest	Stable non-forest	Deforestation	Total
Map of forest change 2015-2020	Stable forest	900	90	5	995
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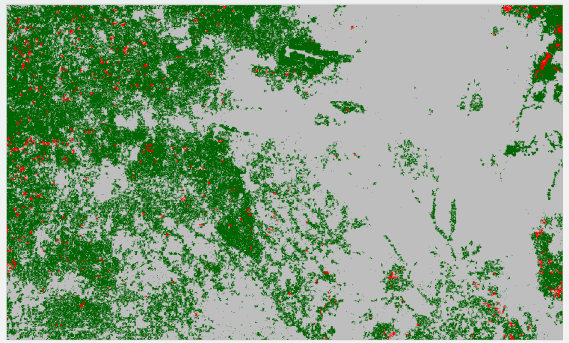
	Deforestation	20	20	60	100
	Total	1,100	1,810	90	

Map bias



- The **omission error of deforestation is** (5 + 25) (errors highlighted in red)/90 (total number of samples identified in the reference data as deforestation highlighted in blue) = **33%**
- The **producer's accuracy of deforestation** is 60 (highlighted in yellow)/ 90 (total number of samples identified in the reference data as deforestation highlighted in blue)= **67%**

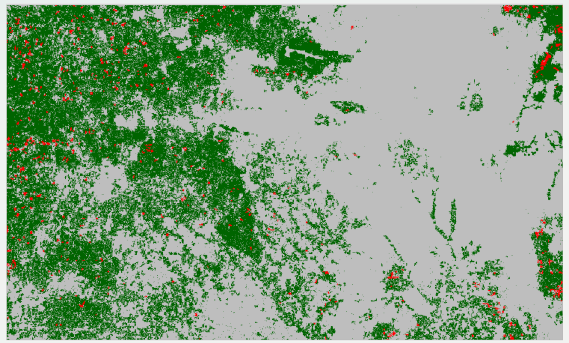
Why not pixel counts

Sample count matrix to a proportional matrix, which accounts for map weights. **The proportional matrix is used for calculating the sample based area estimate and confidence intervals**

Proportional matrix		Sample "reference" data 2015-2020		
		Stable forest	Stable non-forest	Deforestation
Map of forest change 2015-2020	Stable forest	0.179	0.018	0.001
	Stable non-forest	0.075	0.707	0.010
	Deforestation	0.002	0.002	0.006
	Total	**0.256**	**0.727**	**0.017**

Omission errors

Map bias

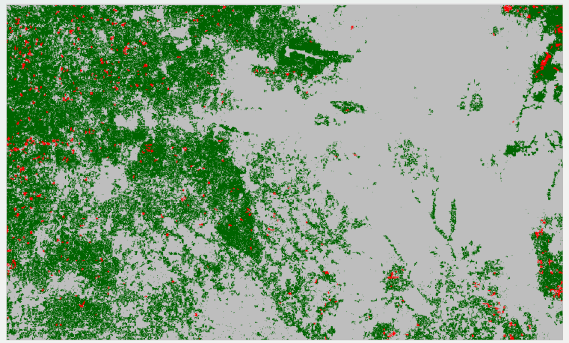


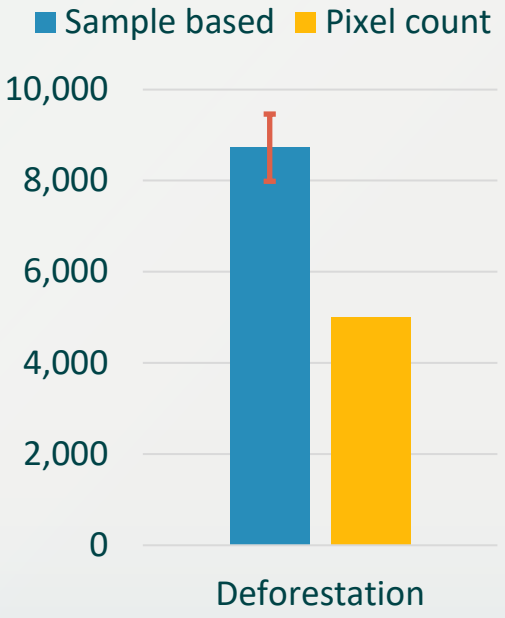
Why not pixel counts

Focusing on **deforestation**

		Example accuracy assessment						
		Stable forest	Stable non-forest	Deforestation	Map pixel count	Sample based area estimate	Standard error	95% Confidence Interval
Map of forest change 2015-2020	Stable forest	0.179	0.018	0.001	100,000	129,050	1,322	2,590
	Stable non-forest	0.075	0.707	0.010	400,000	367,225	4,023	7,886
	Deforestation	0.002	0.002	0.006	5,000	8,724	376	737
	Total	**0.256**	**0.727**	**0.017**	**505,000**			

Map bias

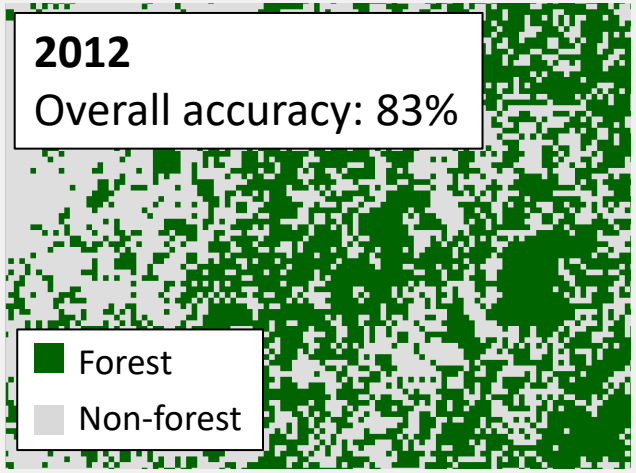


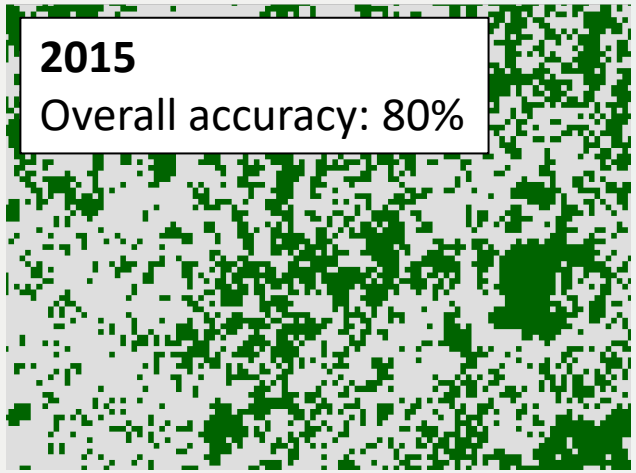


Map **underestimates deforestation** by **74%**

Mapping land cover change - Why not post-classification?

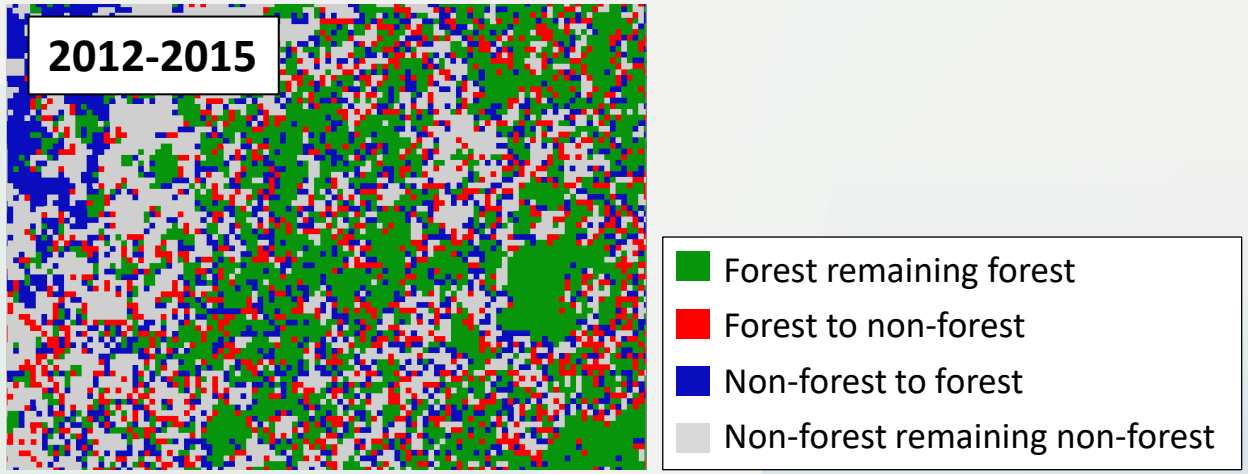
Post-classification is the overlapping and subtraction of independent land cover maps.





A land cover map of a single year may have a high overall accuracy.

When combining the two single year maps to derive changes, the **map errors are compounded** and many of the changes may represent classification errors, pixel misalignment or other errors.



Map vs Sample bias: Example of Ghana

Post-classification is the overlapping and subtraction of independent land cover maps.

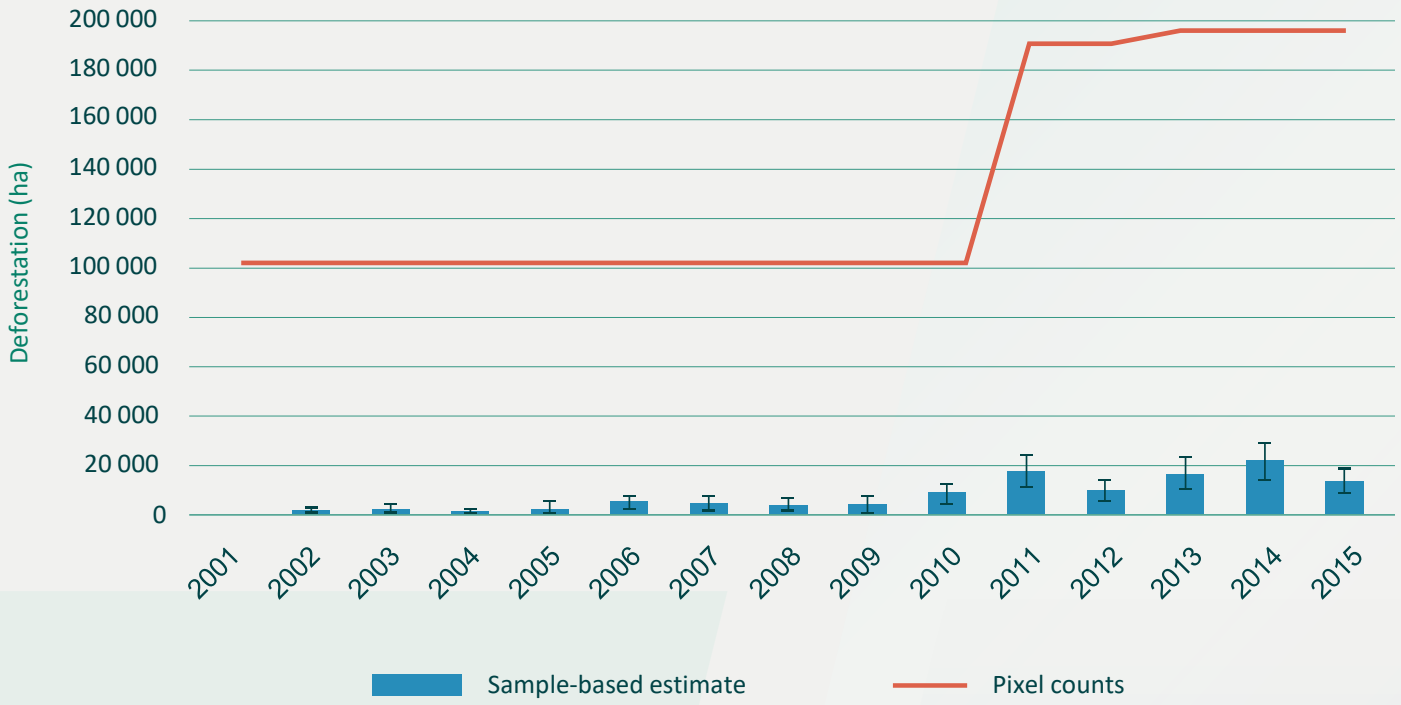


Figure 3. Ghana's deforestation assessment based on pixel counts and sample-based methodology generated from data in Ghana's initial and recalculated reference level for the Carbon Fund (30,49].

Source: Sandker *et al.* 2021. The Importance of High–Quality Data for REDD+ Monitoring and Reporting. *Forests.*

Map vs Sample bias: Example of Mexico

Deforestation estimates in Mexico's two FREL submissions

Sample-based area estimation and common practice in the REDD+ context

Methods for estimating deforestation areas in country submissions to the UNFCCC

For measuring emissions, sample-based area estimation is increasingly common practice

Reasons include:

- Maps often have large biases that are usually unknown
- In sample-based estimation, interpreters can evaluate diverse types of data, including very high-resolution imagery
- Remaining error can be quantified

Guidance on area estimation

- **IPCC 2019 Refinement to the 2006 IPCC Guidelines [here]**
  - Key reference for national greenhouse gas inventories (not specifically for REDD+)
  - Considers both sample-based and map-based approaches: spatially explicit approach 3 to land representation can be achieved with either approach
- **GFOI MGD Version 3.0 [here]**
  - Describes how to apply the IPCC guidance in a REDD+ context
  - Recommends avoiding the use of pixel-counting because it provide no assurance of accuracy and confidence intervals cannot be constructed
- **FCPF methodological framework [here]**
  - Mandatory for ER Programs that report to the Carbon Fund
  - Requires using IPCC approach 3 to land representation

Workflow for sample-based area estimation

1 Sample design

2 Response design

3 Data collection

4 Data analysis

Satellite data analysis for activity data

Terrestrial surveys for emission factors

The workflow for collecting data for activity data and emission factor data is very similar.

Both can rely on sample based methods either via terrestrial surveys or satellite image analysis.

Importance of SOP

SOP

A **standard operating procedure** (SOP) is a set of step-by-step instructions compiled by an organization to help workers carry out routine **operations**.

- **Document** steps and provide reference to relevant background material for generating estimates
- Record parameters for later **replication**
- Ensure **consistency** over time
- Improves **data management**- provides instructions for how to access **archived data**
- Provide **guidelines** for implementation
- **Verification** of methods
  - Referenced by auditors to check methods applied, quality assessment and quality control

Workflow for sample-based area estimation

1 Sample design

- Pilot survey
- Determining the basic sampling design
- Determining the stratification
- Establishing the number of sample units
- Selecting the sample units

2 Response design

- Specifying the classification scheme
- Specifying the data sources Specifying the unit's spatial support
- Specifying the interpretation key
- Specifying the decision tree
- Implementing the response design

3 Data collection

- Planning the data collection
- Preparation of the classification manual
- Training and calibration
- Distribute the sample units among interpreters
- Data collection by interpreters
- Data assembly

4 Data analysis

- Establishing the proportion matrix
- Estimating areas and their uncertainty

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A pilot survey

- Is the first step to a sample-based area estimation, similar to terrestrial surveys.
- Helps us estimate the variance, which is required for the sample size estimation.
- Can give an indication of the occurrence of land use/land use change classes and the number of samples needed to adequately capture those classes.
- Is used as training and testing for different sampling and response designs.
- Is used to identify and adapt to national definitions and ecological conditions.
- Gives a cost estimate of data collection.

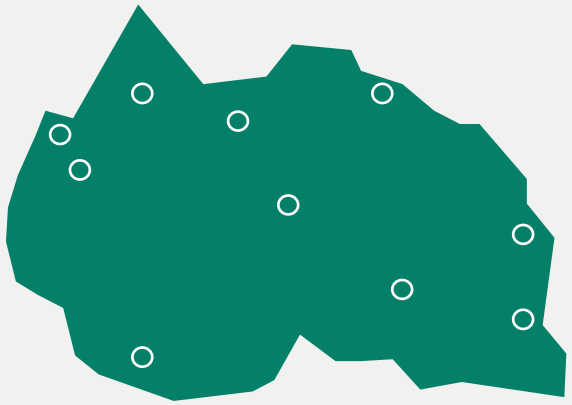
Stratification

Is the process of using auxiliary information about a given AOI to improve estimates derived from sampling

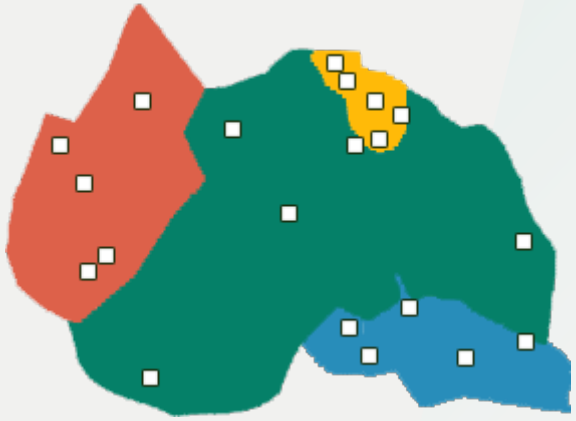
- Increase the efficiency of sampling
  - Lower standard errors with same sampling intensity
  - Reduce sampling intensity with same level of error
- Strata can be informed by the 'pilot study'
- Can come from maps; e.g. administrative boundaries, forest management types, vegetation zones.
- Does not always need to match classes identified in samples (different from map accuracy assessment)
- Can be used for sample intensification
- Can be used after samples are collected as a post-stratifier

The sampling design

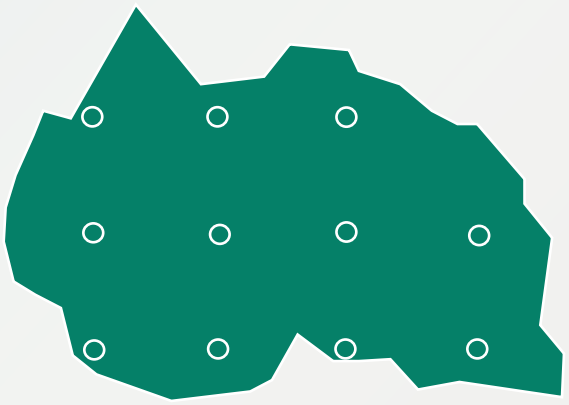
Simple random sample



Stratified random sample



Systematic sample



- Where the sample units are located
- The sample unit selection is always random to avoid bias
- A systematic sample has a random offset
- Samples that are not allocated randomly and based on convenience introduce a bias

- All areas of the region of interest (e.g. country, region) have the same probability to be selected
  - No areas are excluded from having samples
  - All areas have a non-zero inclusion probability

Side by side: most common sampling strategies

STRATIFIED RANDOM SAMPLING

- Need to use new sampling for each update, including updated stratification
- Need a good map for stratification
- Rare events are pre-identified by stratification map
- More precise estimates for the same sample size

SYSTEMATIC SAMPLING

- Easy to update assessment for the same points
- No map required (although post-stratification may be undertaken)
- Difficult to identify rare events
- Higher uncertainties for the same sample size

Workflow for sample-based area estimation

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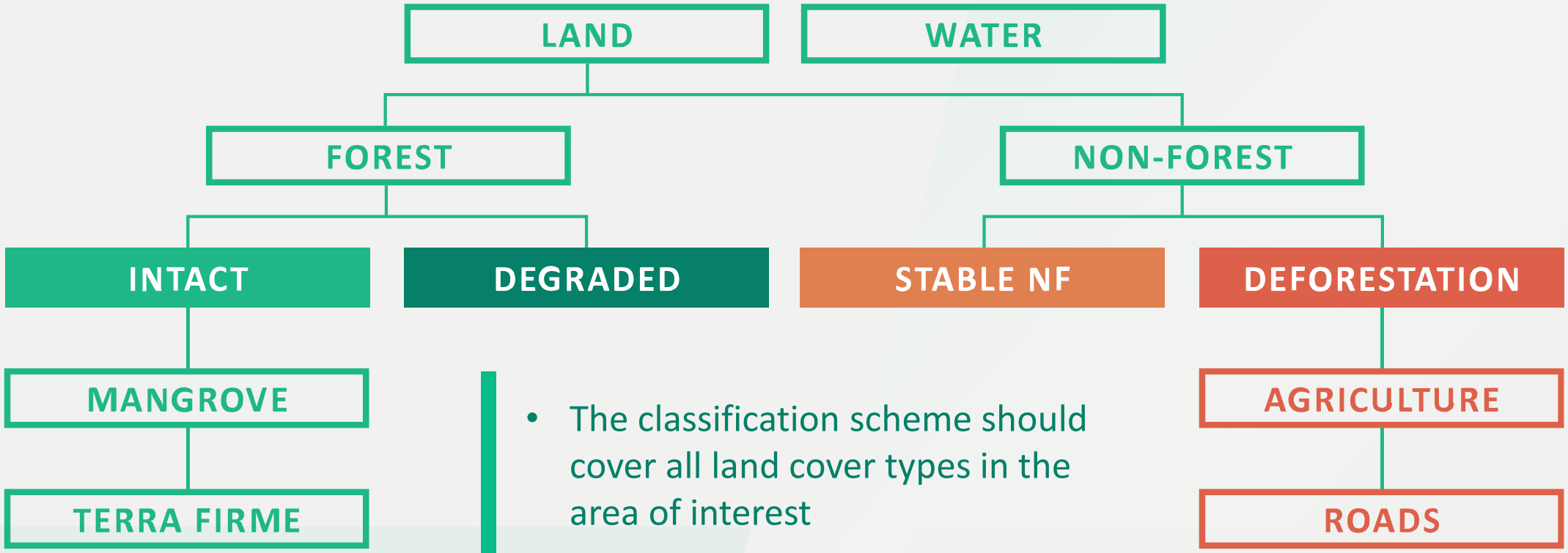
Classification scheme



- The classification scheme should cover all land cover types in the area of interest
- The classes depend on the objective of the assessment
- This an example of classification scheme in the context of REDD+

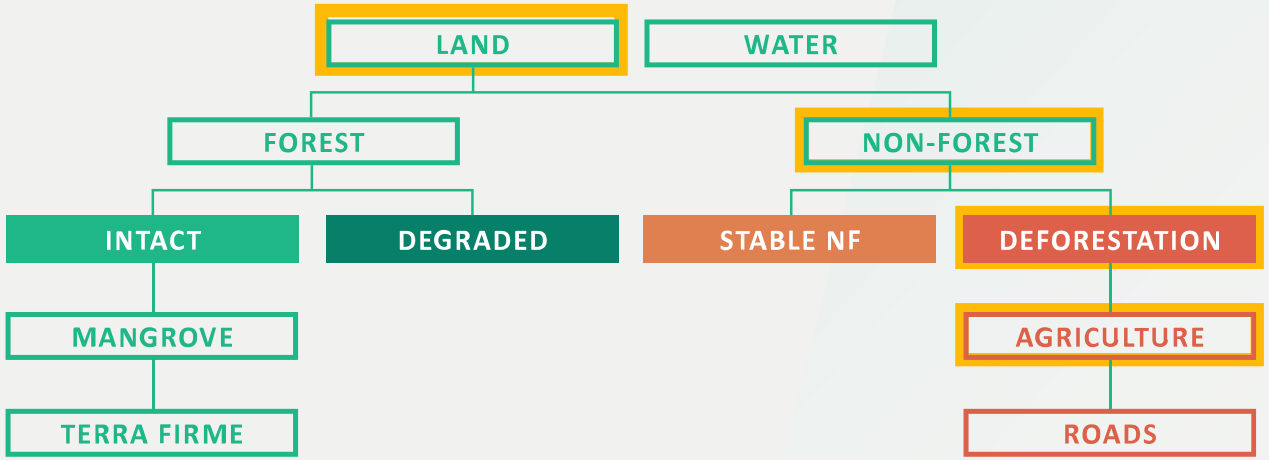
Data sources

Satellite data

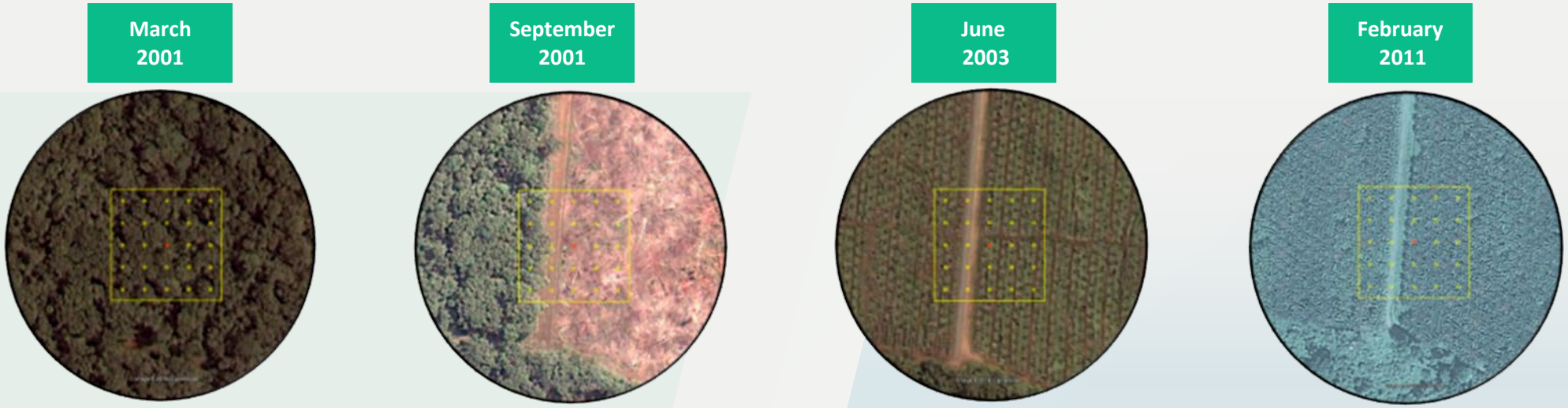
Data name	Data type	Provider	Resolution		Period available
			Spatial	Temporal	
Landsat 8	Optical	NASA	30m	monthly	2013-present
Landsat 7	Optical	NASA	30m	monthly	1999-present
Sentinel 2	Optical	ESA	10m	monthly	2015-present
Sentinel 1	Radar	ESA	25m	time scans	2014-present
ALOS-PALSAR	Radar	JAXA	10m	46 days	2006-2011
Planet Scope	Optical	Planet	3m	daily	2015-present
Digital Globe	Optical	DG	0.5m	as available	2014-present
Worldview	Optical	DG	0.3m	as available	2014-present
Other	Other	Other	Other	Other	Other

Field data NFI plots

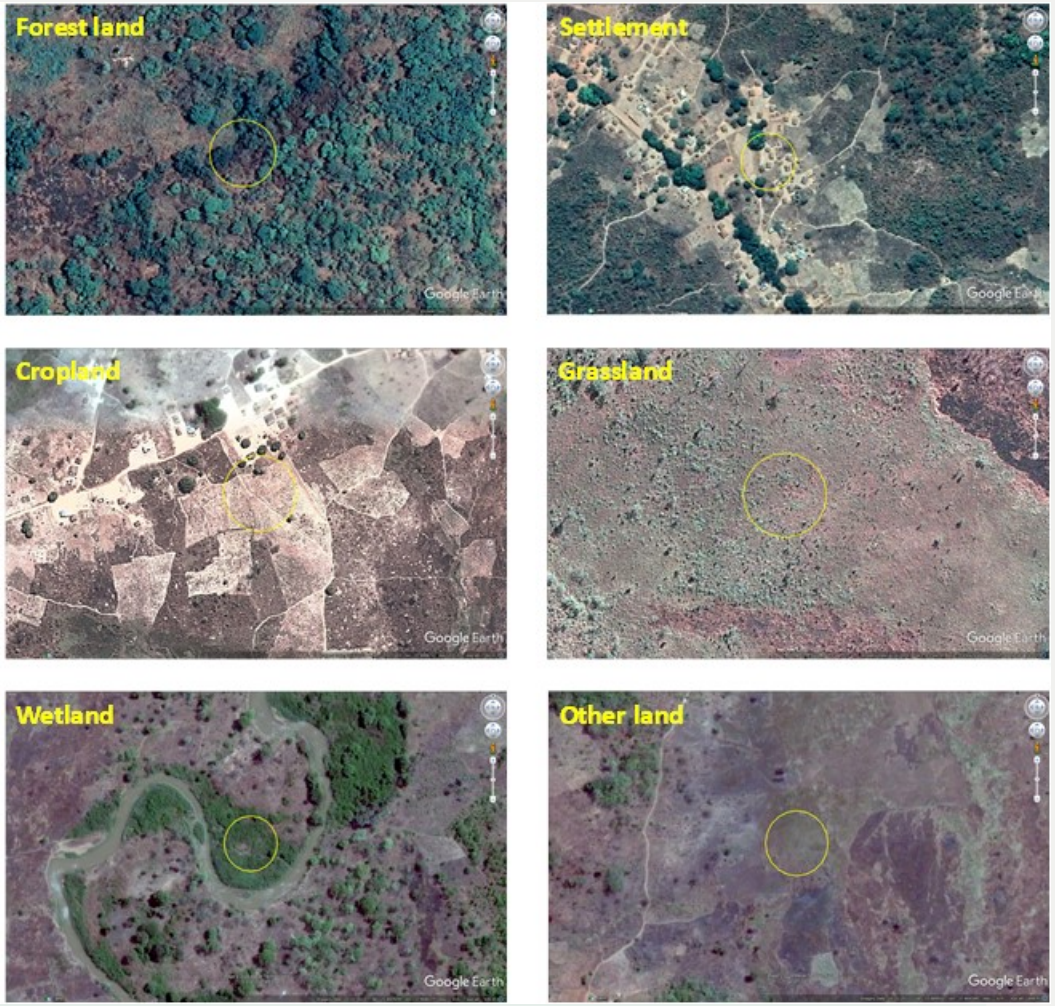
Assessing a RS time series – not time points



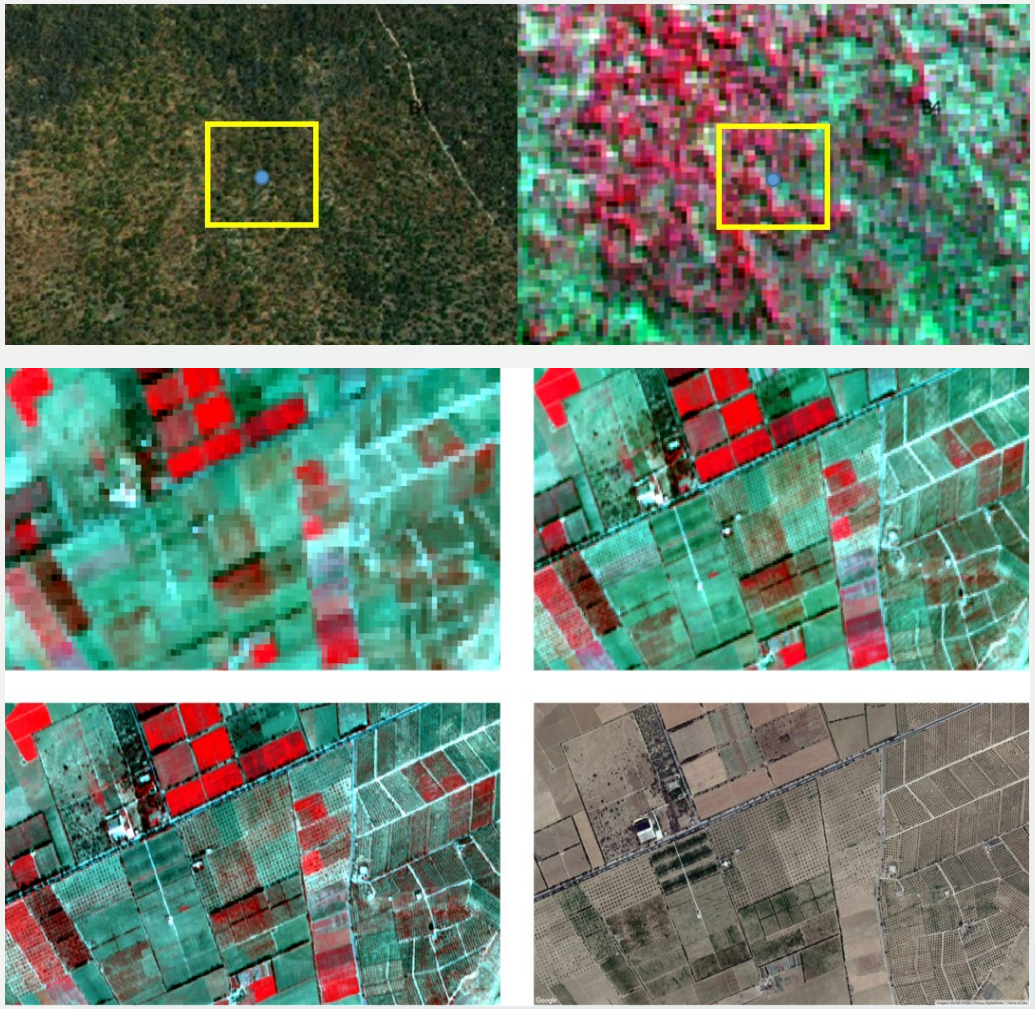
Identifying the land cover change classes from the classification scheme using a time series of data



Preparation of the interpretation key and classification manual



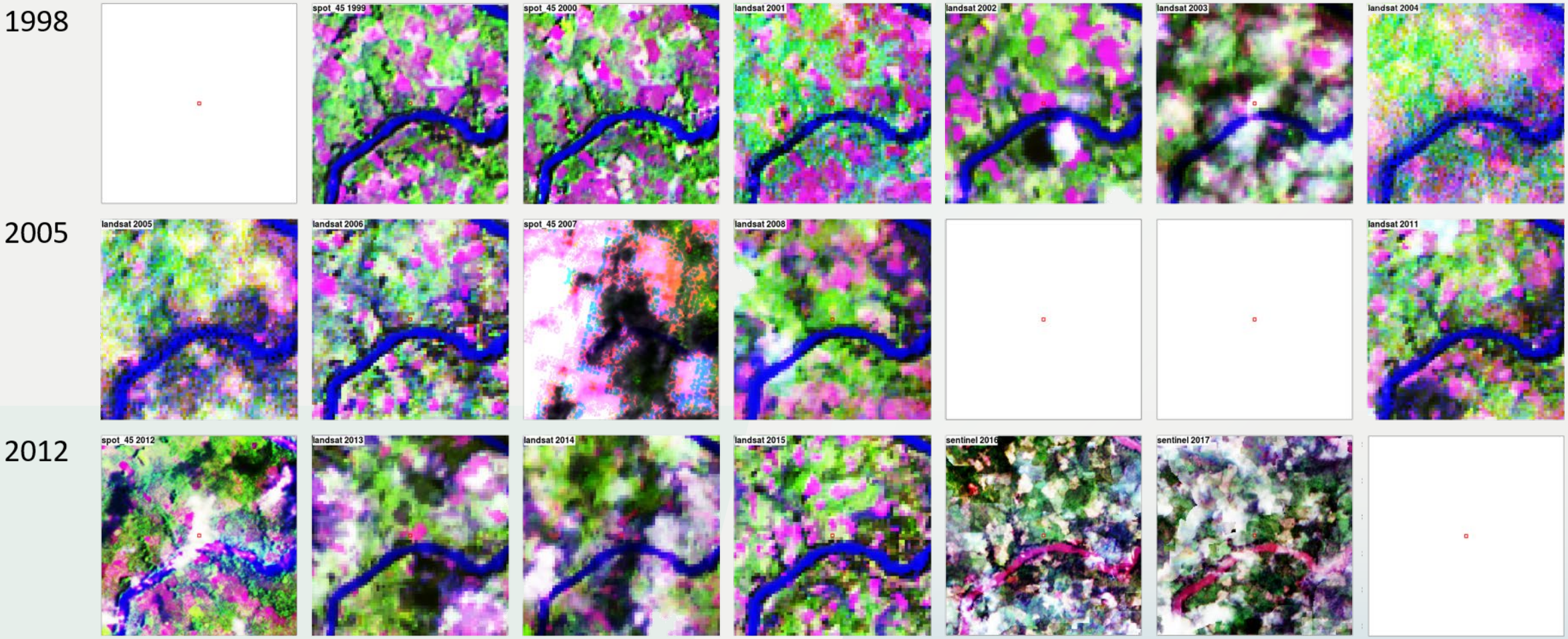
Inclusive of all land use classes



Examples of different sources of imagery and a time series of imagery that show the difference between seasonality and land use change or disturbances

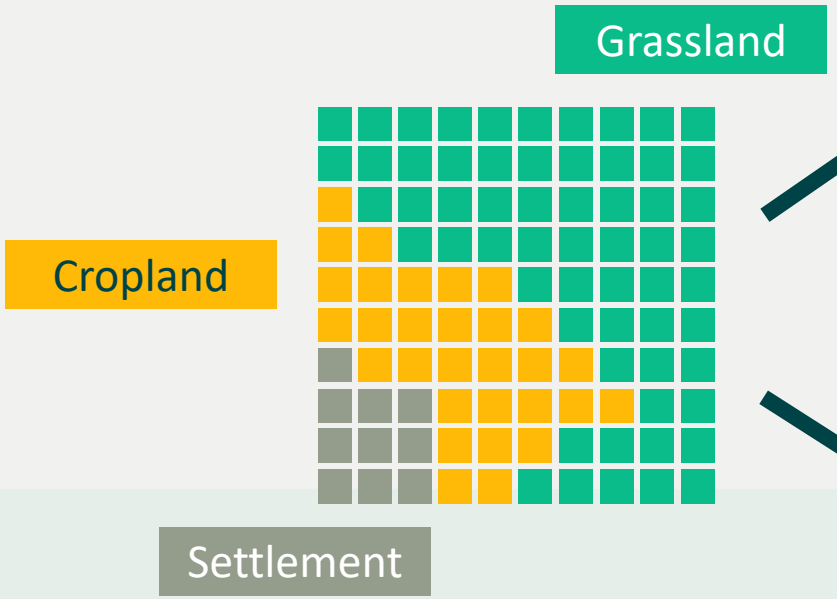
Combine available datasets

Timeseries of Landsat, Sentinel, SPOT 1998 to 2017



Combine available datasets

Countries, following the IPCC, are required to define hierarchical, non-overlapping classes



	Hierarchy	Threshold
1	Settlement	20%
2	Cropland	20%
3	Forest land	20%
4	Grassland	20%
5	Wetland	20%
6	Other land	20%

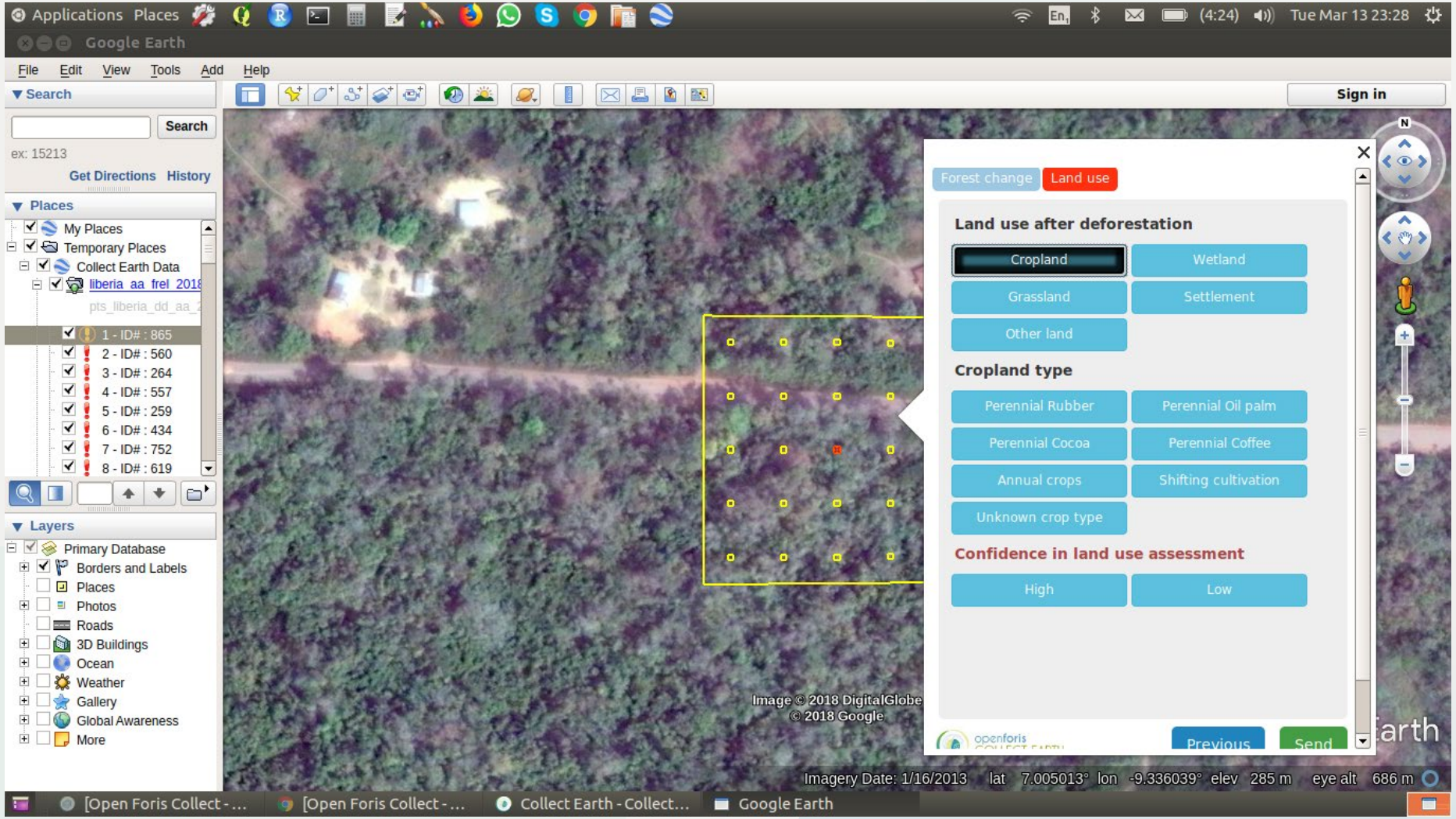
Cropland

	Hierarchy	Threshold
1	Grassland	20%
2	Cropland	20%
3	Settlement	20%
4	Forest land	20%
5	Wetland	20%
6	Other land	20%

Grassland

What class should the interpreter assign to a mixed area unit?

Implementing the response design in Collect Earth



Workflow for sample-based area estimation

1 Sample design

- Pilot survey
- Determining the basic sampling design
- Determining the stratification
- Establishing the number of sample units
- Selecting the sample units

2 Response design

- Specifying the classification scheme
- Specifying the data sources Specifying the unit's spatial support
- Specifying the interpretation key
- Specifying the decision tree
- Implementing the response design

3 Data collection

- Planning the data collection
- Preparation of the classification manual
- Training and calibration
- Distribute the sample units among interpreters
- Data collection by interpreters
- Data assembly

4 Data analysis

- Establishing the proportion matrix
- Estimating areas and their uncertainty

Planning the data collection

- Project management issues:
  - Budget
  - Staff
  - Timetable

- Level of effort
  - Minutes to interpret 1 sample unit * number of sample units = **required level of effort for data collection**

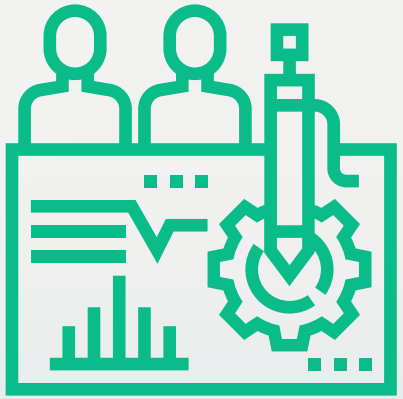
Typical training curriculum for interpreters

All aspects covered in the Standard Operating Procedures (SOP):

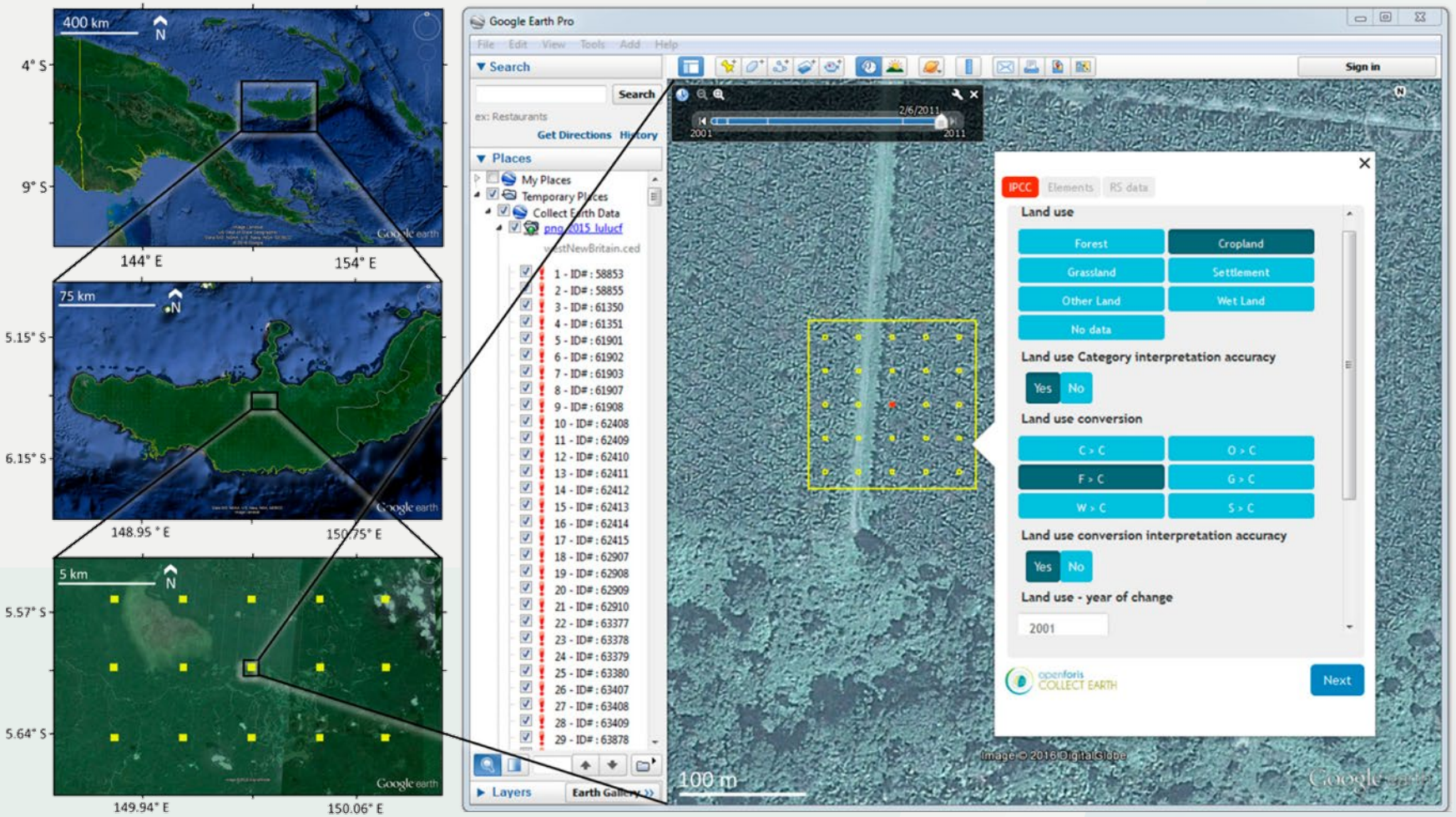
- The sampling and response design
- The software used for the data collection
- Data management and storage
- Understanding of visual interpretation of satellite imagery
- Time series of vegetation indices interpretation
- The data sources available
- Consistency across interpreters and discrepancies in interpretations
- Quality management practices
- The interpretation key

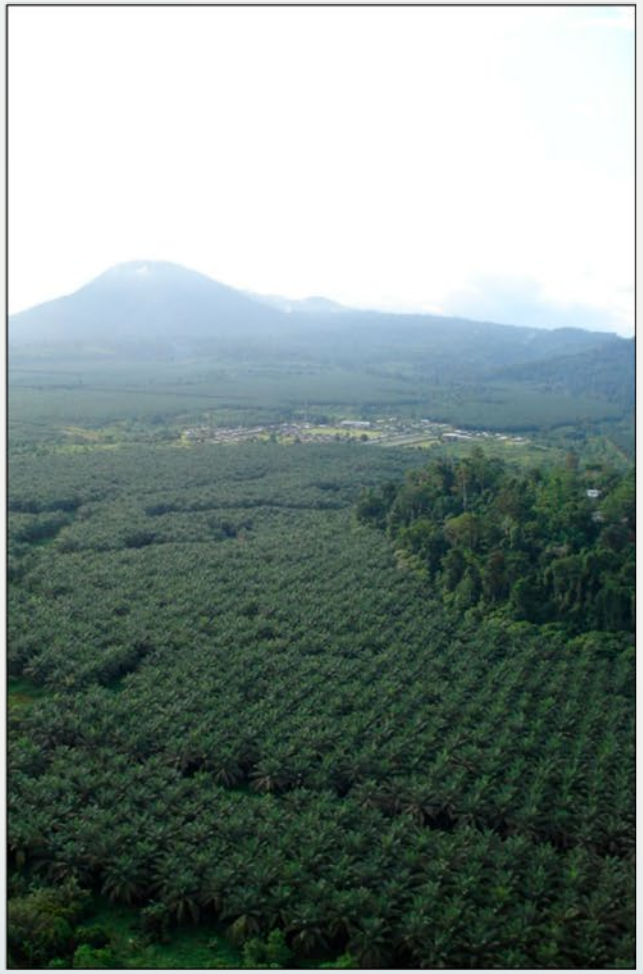
Data collection – often through workshops

Mapathon workshop in Monrovia, Liberia, 2018

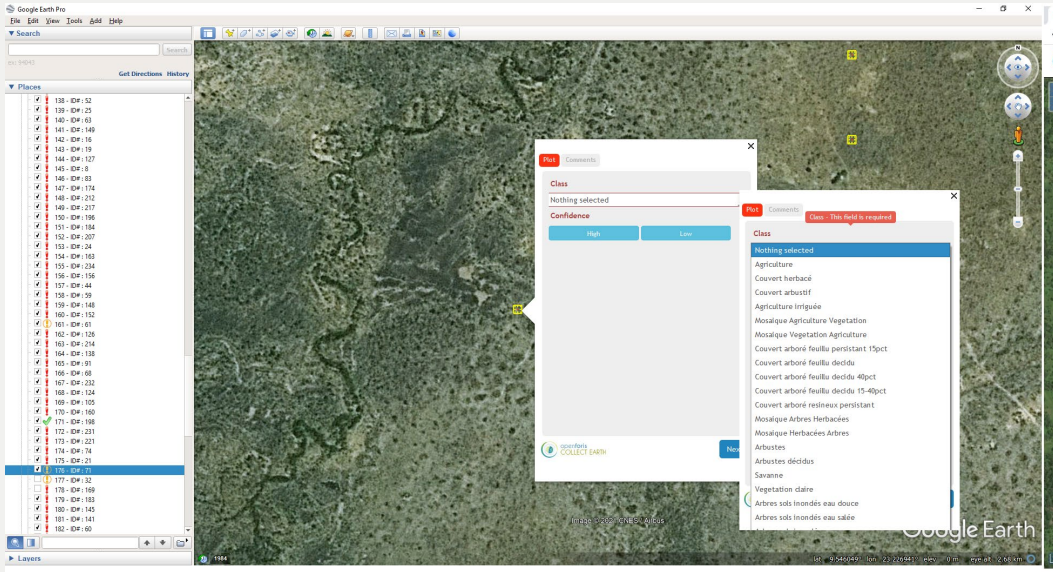


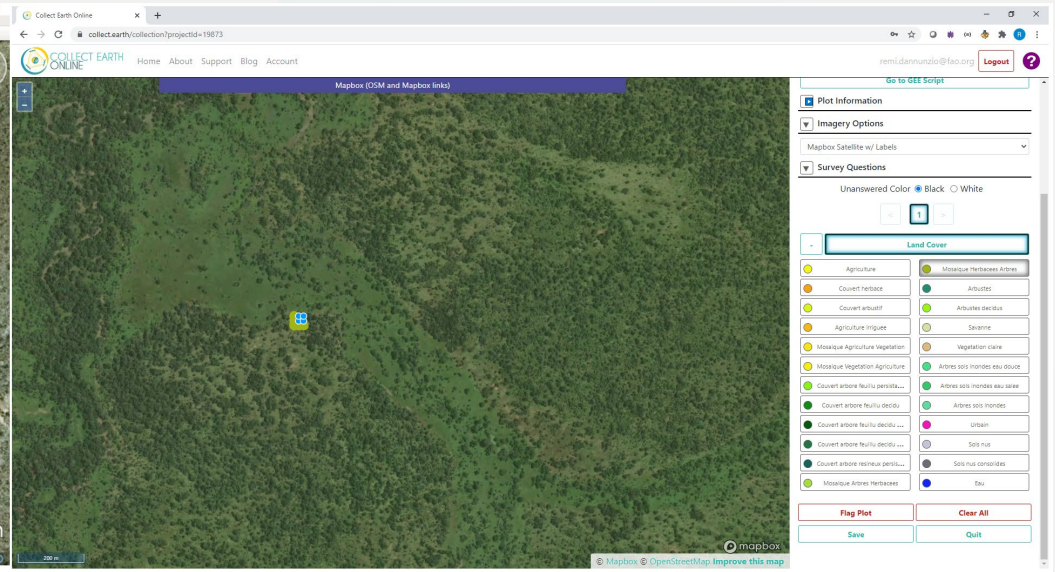
Collect Earth for sample assessment





Collect Earth: Desktop vs Online





Theme	Desktop	Online
Installation	Required + Updates	Online Registration
Project setup	Through Collect (Highly customizable)	Direct in CEO (Limited options)
Interpretation	Sample only	Sample + subplots
Base Data	Google Earth	MapBox
Link to GEE	Direct in GEE (Highly customizable)	Through widgets (Limited options)
Database management	Through XML/CSV files	Centralized (Parallel interpretation)

QA/QC during data collection

One of the most important steps in area estimation. Samples are considered as 'truth'.
If samples are mis-interpreted, the area estimation results will be wrong.

- Split sample randomly between interpreters
- Multiple interpreters per sample – independently
- Random checks (by supervisor) and review errors with the group
- Self-checks - recheck own samples
- Hot and cold checks
- Take into account interpretation fatigue, especially for inexperienced interpreters - schedule breaks in data collection

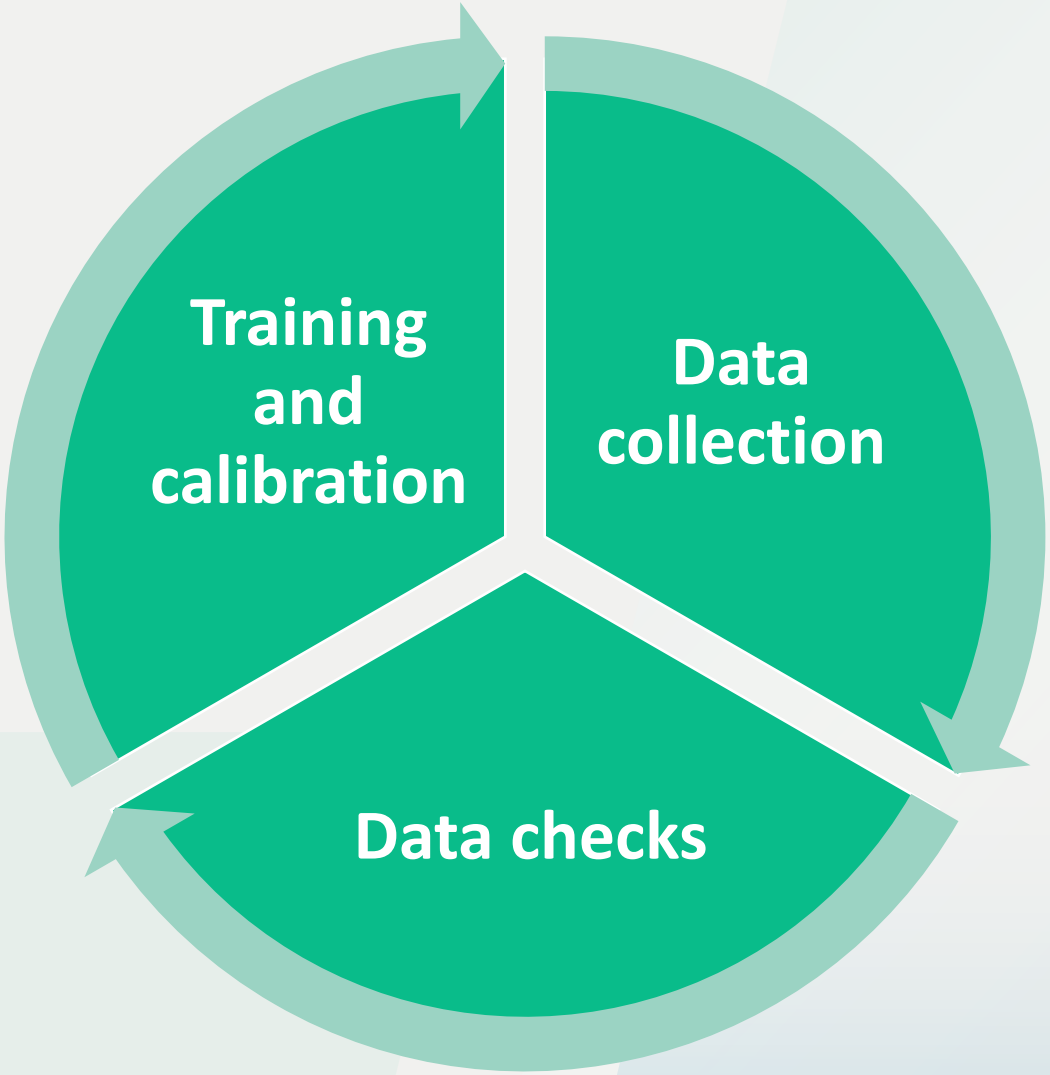
QA/QC after data collection

- Ancillary data check - use other data sources to flag plots for reassessment
- Logical checks - data collected reflects possible conditions
- Recheck plots marked with low confidence

Options for rechecking:

self-check, other interpreter, group, supervisor, field data, external.

QA/QC – an iterative process



QA/QC – identifying impossible transitions

Example from Panama Forest Reference Level

Sub-category	Mature forest	Disturbed mature forest	Secondary forest	Plantation	Mangrove swamp	Cropland	Pasture	Shrubland
Mature forest	Yes	Yes	No	No	No	Yes	Yes	Yes
Disturbed mature forest	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Secondary forest	Yes	No	Yes	Yes	No	Yes	Yes	Yes
Plantation	No	No	No	Yes	No	Yes	Yes	No
Mangrove swamp	No	No	No	Yes	Yes	Yes	Yes	Yes
Cropland	No	No	No	Yes	Yes	Yes	Yes	Yes
Pasture	No	No	No	No	Yes	Yes	Yes	Yes
Shrubland	No	No	Yes	No	Yes	Yes	Yes	Yes

QA/QC – comparing multiple interpretations and interpreters' error

Expert Interpretations (Consistency Assessment)

Original Interpretation	Cropland	Forest	Grassland	Otherland	Settlement	Wetland	Row total	Consistency
Cropland	438	4	0	1	1	1	445	98.43%
Forest	2	821	0	1	0	0	824	99.64%
Grassland	0	0	6	1	0	0	7	85.71%
Otherland	2	1	5	540	0	1	549	98.83%
Settlement	0	0	0	1	23	0	24	95.83%
Wetland	0	1	0	1	0	20	22	90.91%
Total	442	827	11	545	24	22	1871	

Data assembly

- Collect data from all interpreters and compile.
- Database management is essential.
- The use of Collect Earth Online facilitates those aspects.

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Data analysis

- Sample data is used to estimate the area for each class and the confidence intervals for the estimate
- If the sample has no stratification, the areas are calculated using proportions
- If the sample were stratified, the stratum weights are applied to each class to generate a proportional matrix
- The proportional matrix is used for area estimation and calculation of confidence intervals.

Data analysis

		Sample "reference" data 2015-2020					
		Stable forest	Stable non-forest	Deforestation	Total	Map Area	Map Weight
Map of forest change 2015-2020	Stable forest	900	90	5	995	100 000	0.2
	Stable non-forest	180	1 700	25	1 905	400 000	0.79
	Deforestation	20	20	60	100	5 000	0.01
	Total	1 100	1 810	90		505 000	

SAMPLE COUNT MATRIX

Data analysis

		Sample "reference" data 2015-2020		
		Stable forest	Stable non-forest	Deforestation
Map of forest change 2015-2020	Stable forest	0.179	0.018	0.001
	Stable non-forest	0.075	0.707	0.010
	Deforestation	0.002	0.002	0.006
	Total	**0.256**	**0.727**	**0.017**

PROPORTIONAL MATRIX

Data analysis

		Sample "reference" data 2015-2020		
		Stable forest	Stable non-forest	Deforestation
Map of forest change 2015-2020	Stable forest	90452.261	9045.226	502.513
	Stable non-forest	37795.276	356955.381	5249.344
	Deforestation	1000.000	1000.000	3000.000
	Total	129247.537	367000.607	8751.856

AREA MATRIX

Tools for analysis - area and uncertainty estimation

Data collection

OpenForis – Collect Earth

Collect Earth - Online

User Interfaces for analysis

SEPAL - Stratified area estimator analysis

Area^2 – Area estimation & Accuracy Assessment

QGIS ACATAMA

Build custom analysis

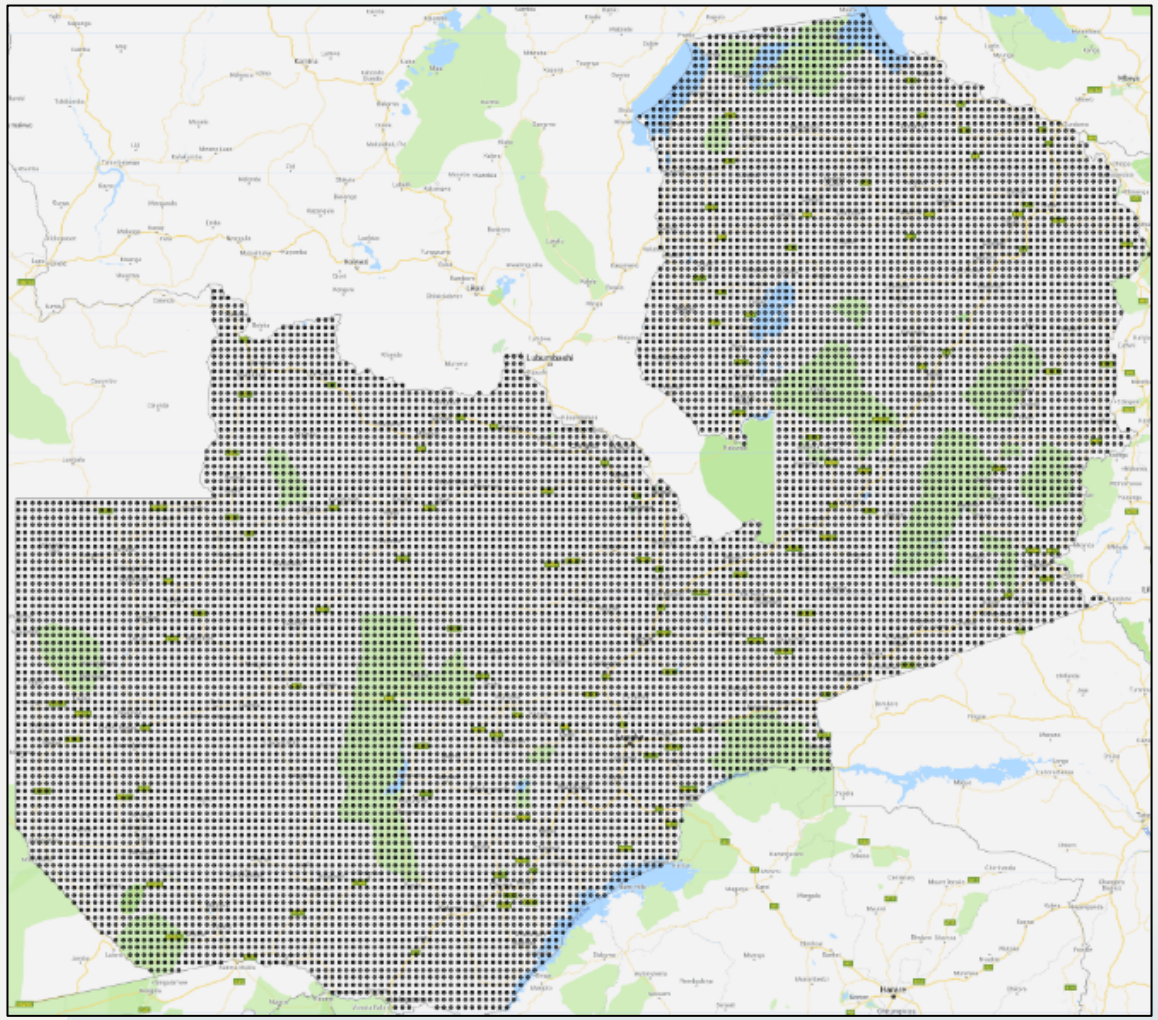
Microsoft Excel

Python Software Foundation

RStudio

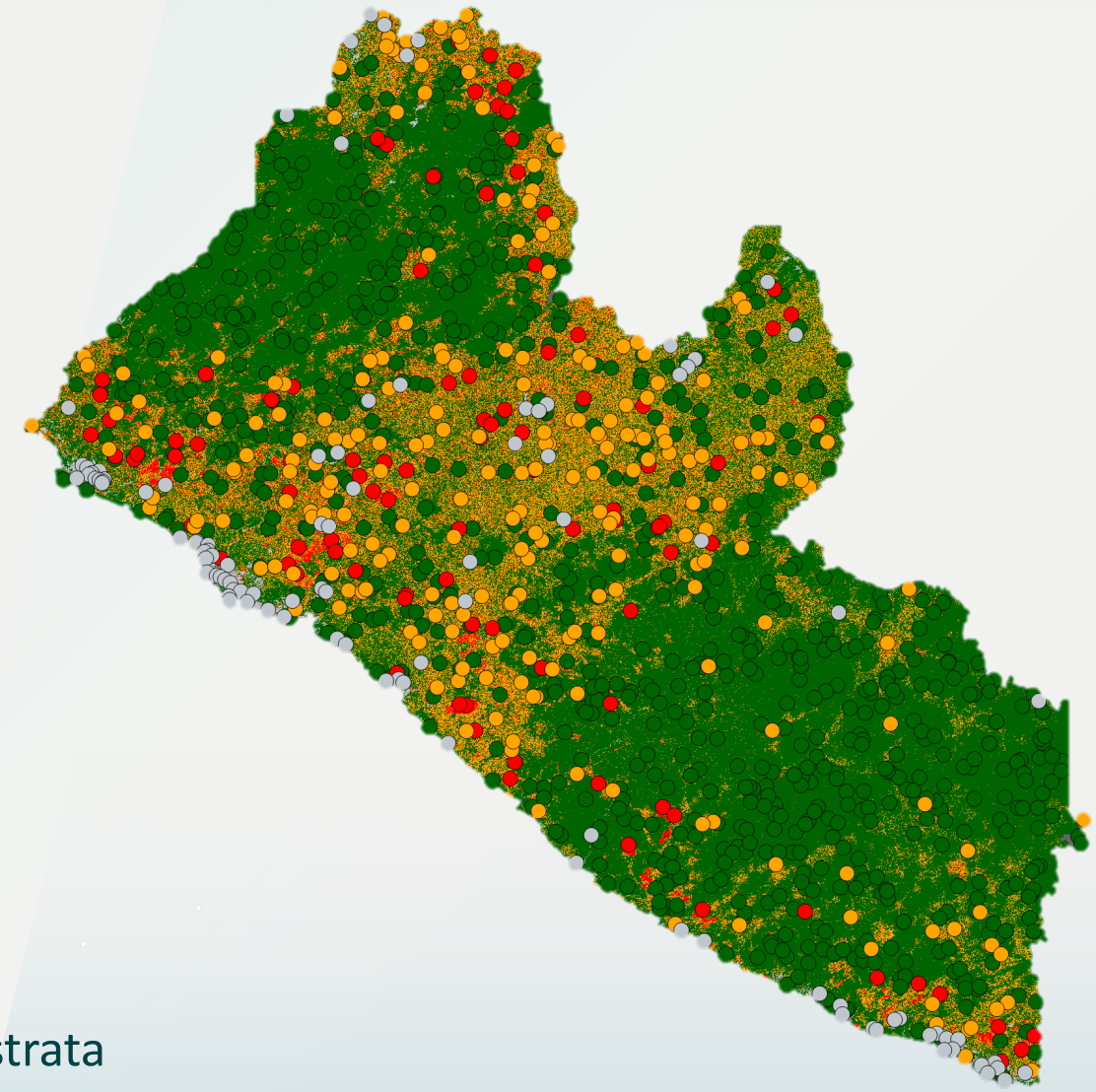
Example Zambia: Systematic sample

- Assessment done in 2019 for updating the reference level
- 8x8 km grid with approximately 12,000 sample units
- Assessment for 2000-2018
- Deforestation and forest degradation
- Collect Earth was used
- 10 days data collection workshop with 20 interpreters
- Total cost approximately USD 30 000
- Basis for annual emission estimates and emission estimates by province



Example Liberia: Stratified sample

- Assessment done in 2019 for updating the reference level
- Global forest change product to stratify stable forest, stable non-forest, deforestation and forest degradation
- Random sample
- Assessment for 2007-2016
- Deforestation and forest degradation, Integrate commodity agriculture into stable non-forest
- Collect Earth was used
- 27 days 5 data collection workshops with 6 interpreters
- Total cost approximately USD 15,000
- Basis for annual emission estimates for three principal strata



Tool and resources

Open Foris	http://openforis.org/
SEPAL	https://sepal.io/
Collect Earth	http://www.openforis.org/tools/collect-earth.html
Collect Earth Online	https://collect.earth/
AcATaMa (QGIS)	https://plugins.qgis.org/plugins/AcATaMa/
Area2	https://area2.readthedocs.io/en/latest/

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FAO & GFOI, *In press, White Paper: Issues and good practices in sample-based area estimation*

FAO. 2020. *From reference levels to results reporting: REDD+ under the United Nations Framework Convention on Climate Change – 2020 update*. Rome, FAO.

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Further reading

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P. Olofsson, P. Arévalo, A.B. Espejo, C. Green, E. Lindquist, R.E. McRoberts, M.J. Sanz. *Mitigating the effects of omission errors on area and area change estimates Remote Sens*. Environ., 236 (2020), Article 111492

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