

*Regional Workshop: “Capacity Development for
Sustainable National Greenhouse Gas Inventories – AFOLU sector
(CD-REDD II) Programme*

Lesson 8 - *Good Practice in Designing a Forest Inventory*

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Outline



I. Phase: Sampling design

- (1) *Stratification of the area*
- (2) *Plot shape*
- (3) *Plot size*
- (4) *Sample size*
- (5) *Plot allocation*

II. Phase: Ground data collection

- (1) *Implementation steps*
- (2) *Carbon pools to be measured*
- (3) *Required equipment*

III. Phase: Inferences from collected data

1.Phase: Sampling Design



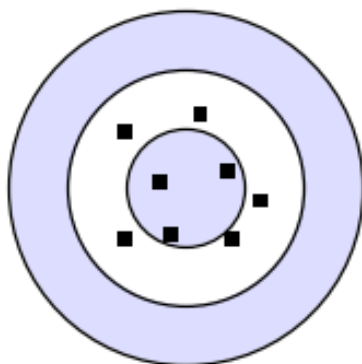
- “...determines how the sampling units are selected from the population and thus what statistical estimation procedure should be applied to make inferences from the sample.”
(2006 IPCC Guidelines for National GHG Inventories)
- The sampling design should aim for a good compromise between accuracy and costs of the estimates.

Accuracy and Precision

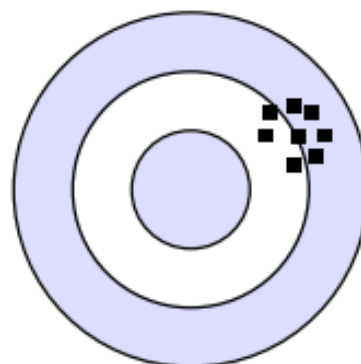
Accuracy is a relative measure of the exactness of the value of an inferred variable for a population. It means how close the estimates are to the actual true value.

Precision is the closeness of agreement between independent results of measurements obtained under stipulated conditions. It is the inverse of uncertainty in the sense that the more precise something is, the less uncertain it is.

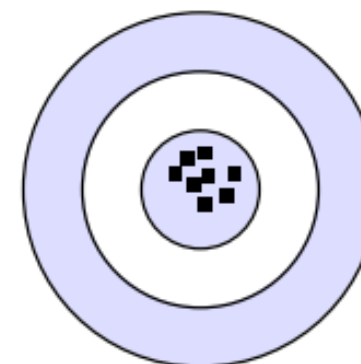
Accurate, but not precise



Precise, but not accurate



Accurate and precise



Uncertainty

Uncertainty is the lack of knowledge of the true value of a variable that can be described as a **probability density function (PDF)** characterizing the range and likelihood of possible values.

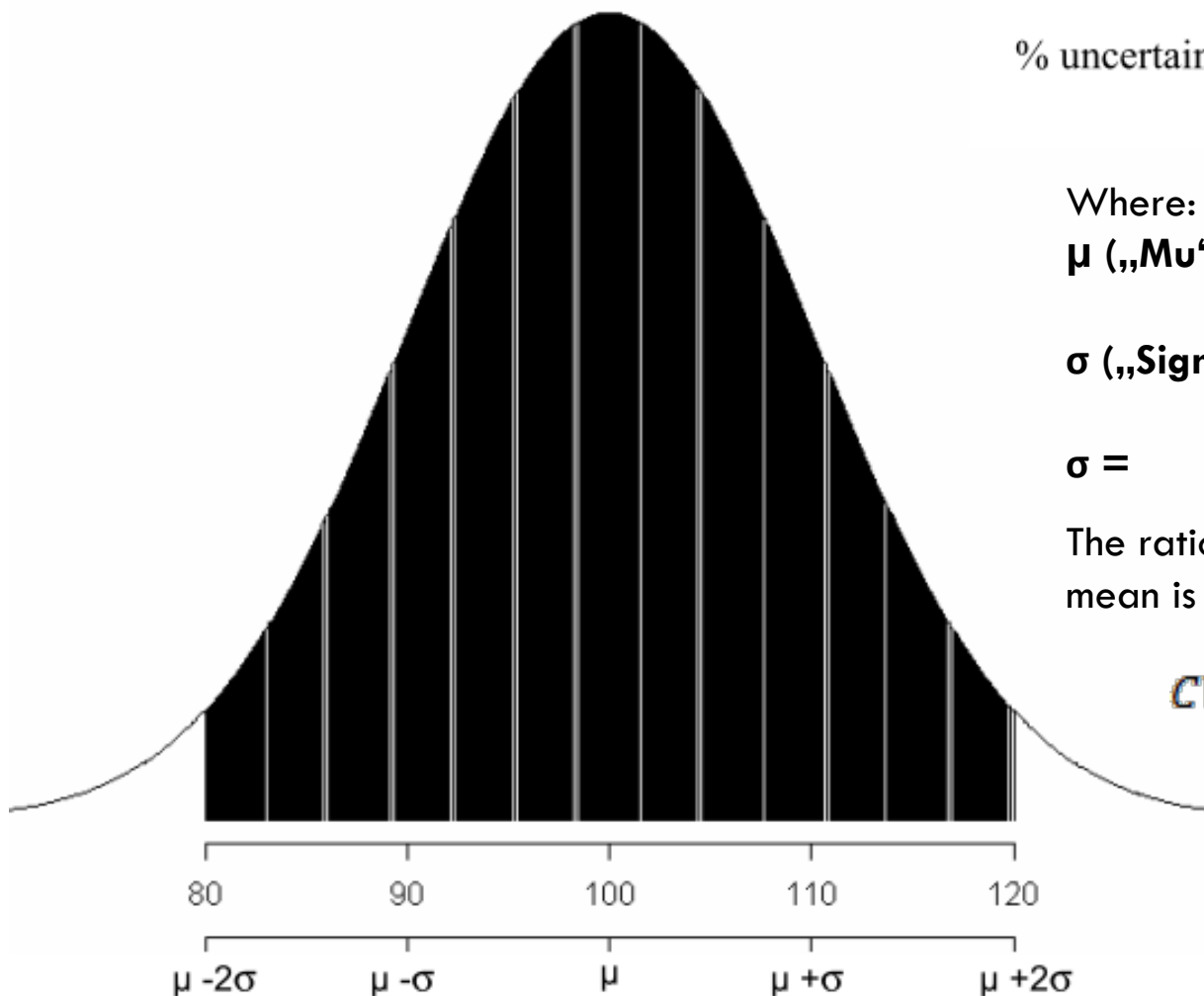
$$\% \text{ uncertainty} = \frac{\frac{1}{2} (95\% \text{ Confidence Interval width})}{\mu} \times 100$$

Where:

μ („**Mu**“) is the mean of the distribution

The **confidence interval** is a range that encloses the true value of an unknown fixed quantity with a specified confidence (probability). Typically, a 95 percent confidence interval is used in greenhouse gas inventories. From a statistical perspective, a 95 percent confidence interval has a 95 percent probability of enclosing the true but unknown value of the quantity. The 95% confidence interval is enclosed by the 2.5th and 97.5th percentiles of the PDF.

Example of uncertainty expression (95% confidence interval)



$$\% \text{ uncertainty} = \frac{\frac{1}{2}(4\sigma)}{\mu} \times 100 = \frac{2\sigma}{\mu} \times 100 = \frac{20}{100} \times 100 = 20\%$$

Where:

μ („Mu“) is the mean of the distribution

σ („Sigma“) is the standard deviation

$$\sigma = \sqrt{\text{variance}} = 10$$

The ratio of the standard deviation and the mean is called the **Coefficient of variation (CV)**

$$CV = \frac{\sigma}{|\mu|}$$

If the CV is expressed in percent, it is multiplied by 100

Uncertainty analysis

An uncertainty analysis aims to provide quantitative measures of the uncertainty and includes random errors and bias. **Bias (systematic error)** is the lack of accuracy and can be reduced by identifying the causes of this systematic error.

Random error is inversely proportional to precision and describes a random variation below or above a mean value.

The PDF can be used to describe either uncertainty in the estimate or inherent variability of the variables. In uncertainty analysis of inventories, one is typically interested in the uncertainty of the average rather than the entire range of variability. Variability is an inherent property of the system of nature, and not of the analyst. Thus, variability can only be reduced by sampling entire populations or stratification of the area.

Continuous sampling design

- The scope of greenhouse gas inventories is to assess changes in carbon stocks over time, however for estimating those it is equally important to assess carbon densities per unit of land
- This requires sampling repeated over time, whose frequency could be determined by the frequency of the events that cause the changes
- For reporting GHG inventories, estimates are required annually and therefore a continuous sampling design is recommended
- In a continuous sampling design, a subset of the total amount of samples is measured each year within a cycle period (e.g. for a cycle period of 5 years each plot is re-measured every 5 years)

--> This sampling design is implemented in several steps...

(1) Stratification of the area

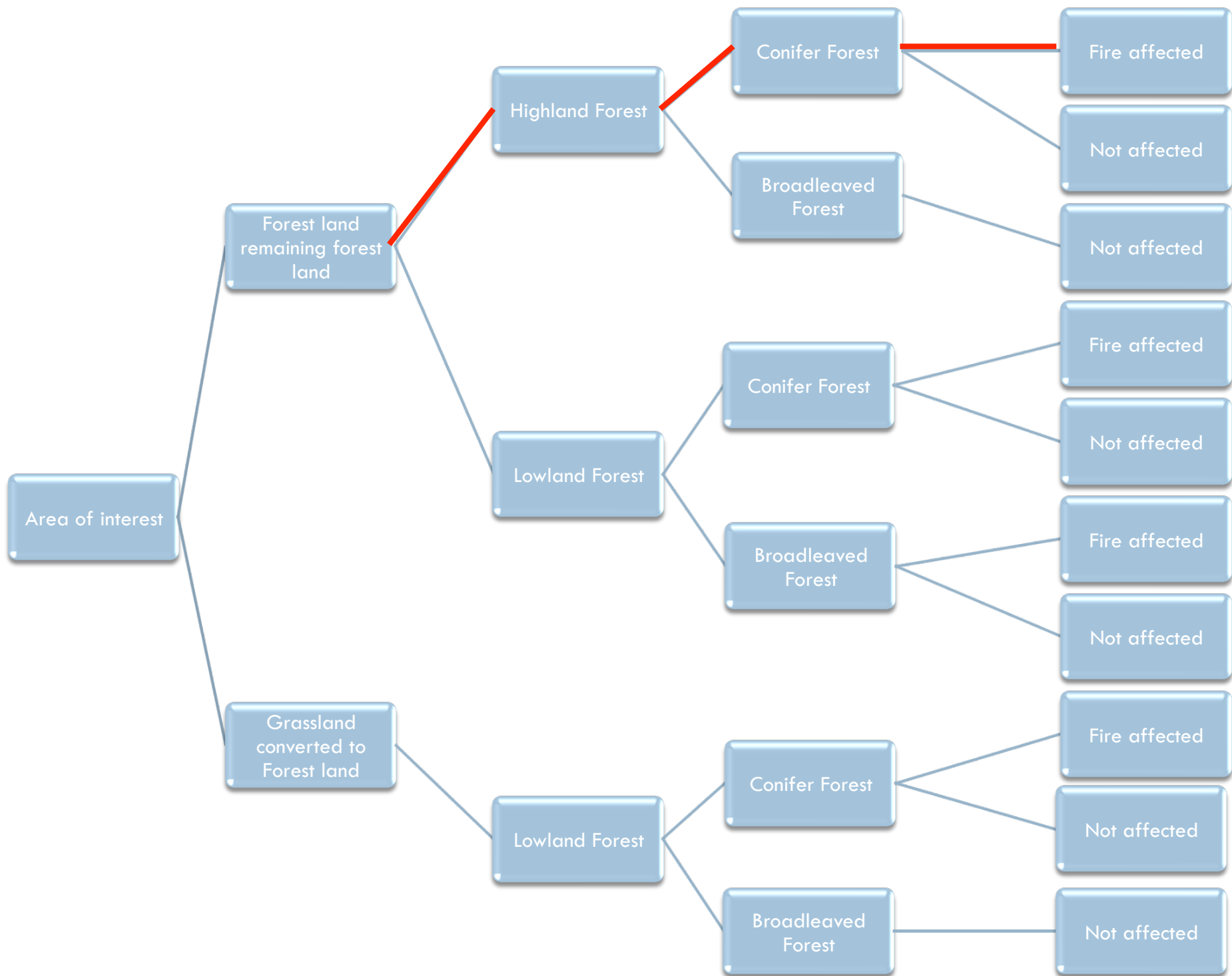
- Stratification means to divide a heterogeneous population into subpopulations (strata) based on common grouping criteria
- Criteria should be used that are directly related to the variables to be measured; in this case carbon stocks and carbon stock change
- Carbon stocks and carbon stock changes are depending on several factors which can be divided into:
 - I. **physical factors** (climate and soil)
 - II. **biological factors** (tree composition as species and ages, stand density)
 - III. **anthropogenic factors** (management practices, disturbances history)

Why stratification?

- Different forest areas differ in carbon stocks and carbon stock dynamics
- For instance; an intensely logged forest contains lower carbon stocks than a primary forest, or an area converted to forest shows different carbon stock dynamics over time than a forest area converted to other land use
- Stratification allows to associate a less uncertain value of carbon density and/or dynamic to a given area so allowing to prepare more accurate estimates of net emissions due to deforestation and degradation
- The variability between sample plots within a stratum is reduced compared to the variability within the entire forest area, consequently
 - > a smaller amount of samples (unevenly distributed among strata) is needed to achieve the same level of precision
 - > the sampling efficiency is increased by reducing time and costs

Steps for stratifying the area

1. **Define Land-Use Categories;** the broad land-use which forms the basis of estimating and reporting GHG emissions and removals, (e.g. Forest Land, Cropland, Grassland...)
2. Land-Use Categories are reported as either **land remaining in the category or land converted to a new category;** e.g. “Forest Land remaining Forest Land”, “Land converted to Forest Land”
3. **Further stratification of each land-use category** into more homogenous (in carbon density and dynamic) spatial units considering biological, physical and anthropogenic factors




Use of remotely sensed (RS) data for stratification

- RS data is obtained by sensors (optical, radar, lidar) on satellites or by cameras equipped with optical or infrared films, installed in aircrafts
- RS data covers large and/or remote areas which are otherwise difficult to access
- RS data identifies boundaries between different land-use categories and may provide information on the variability of carbon stocks depending on the resolution of the data
- Archives of past RS data can span several decades and can be used to establish time-series in land uses and land-use changes

Most common RS types

- 1) **Aerial photographs**; can identify forest tree species, forest structure and age distribution, smallest spatial unit 1 square meter
- 2) **Satellite imagery**; medium resolution (10-60 m), complete land-use/land cover of large areas, long time-series data can be obtained
- 3) **Radar imagery (Synthetic Aperture Radar)**; fine resolution (< 5 m), operates at microwave frequencies, can penetrate clouds and haze, identifies land cover categories and
- 4) **Lidar (Light detection and ranging)**; fine resolution (< 5 m), uses same principles as radar and may be combined with ground data to assess the biomass contents of vegetation

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- While Radar imagery and Lidar (fine resolution, $< 5\text{m}$) are very costly, satellite imagery is available for free or at low costs
 - For example “Landsat” (medium resolution 10-60m) provides complete global coverage for early 1990s, early 2000s and 2005
--> Primary tool to identify land-use categories and monitoring area change (e.g. deforestation)
 - Coarse resolution data (250m – 1 km, e.g. Modis, SPOT-VGT) can not be used to estimate area changes but provides daily data and can be used to control cover changes possibly in combination with medium resolution data or ground reference data

Evaluation of map accuracy (Ground reference data)

- It is good practice to complement RS data with ground reference data (“ground truth data”)
- Ground reference data can be obtained from existing forest inventories or can be collected independently
- Reliability of RS data differs depending on resolution and varies between land categories, e.g. deciduous forest are easily confounded with Grassland
- Land categories which are easily misclassified need special consideration

Integration of remote sensing and GIS



- It is good practice to represent RS data with a Geographical Information System (GIS; e.g. Arc View)
- GIS is a (cost-) efficient way for interpretation of RS data and representation of strata, e.g. by merging of different spectral data
- Ground based measurements or map data can be combined with RS data in order to create a “stratification map”

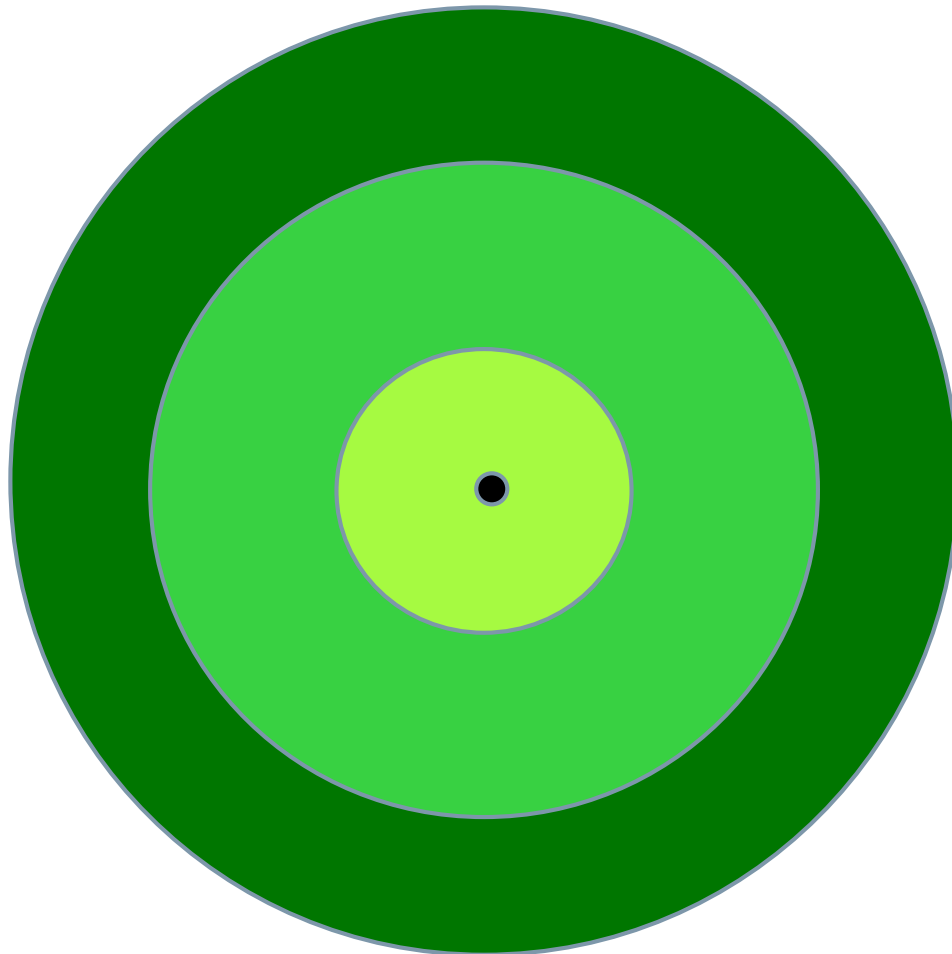
(2) Plot shape

- Types of plots used in forest inventories: **fixed area plots** that can be nested, **variable radius or point sampling plots** (e.g. prism or relascope plots) **or transects**
- The most common shape for fixed area plots are **circular** and **square**
- Nested plots contain smaller subunits of various shapes and sizes depending on the variables to be measured
- For example, saplings could be measured on a small subunit, trees between 5-50 cm on a medium subunit and trees above 50 cm could be measured on the entire plot
- Nested plots can be cost-efficient for forests with a wide range of tree diameters or stands with changing diameters and stem densities

Circular plots

- It is good practice to design fixed size circular plots since they are easy to establish, preferably with distance measuring equipment (DME) because then the boundary of the plot does not need to be marked
- Circular plots are less vulnerable to errors in the plot area than square plots since the perimeter (boundary of the plot) is smaller in relation to the area and thus the number of trees on the edge is less
- Nested circular plots consists of several concentric circles, the smaller circles for smaller trees and the larger circles for larger trees
- Depending on local circumstances and skills of the inventory team it might be easier to establish square plots

Example of a nested circular plot

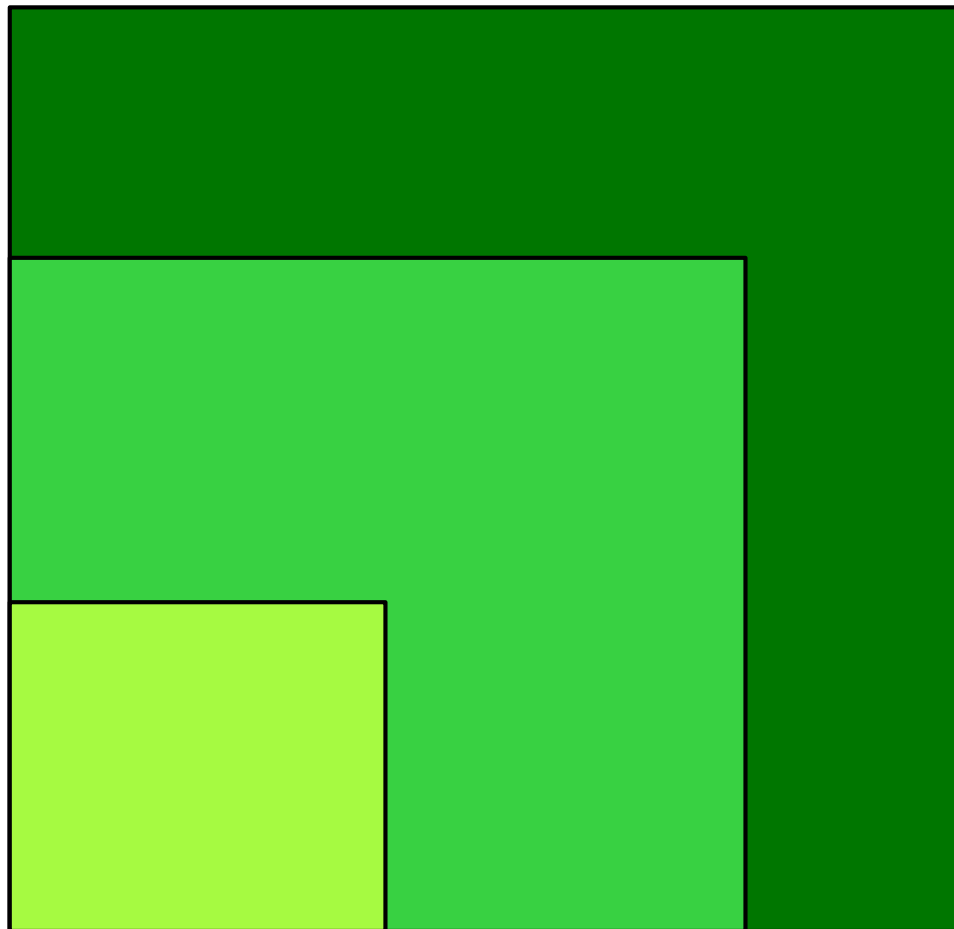





- Plot center
- Subunit 1 (e.g. saplings)
- Subunit 2 (e.g. small trees, 5-50 cm dbh)
- Subunit 3 (e.g. large trees, > 50 cm dbh)

Square plots

- Square plots are established by first defining one side and two corners
- Afterwards, right angles are traced at these corners and the other two corners are located
- The distance between the last two corners (and possibly the two diagonals) should be measured in order to ensure the measurements
- Square plots are very vulnerable to errors in the plot area due to the large perimeter and a difficult establishment
 - > a wrong angle of the plot corners would significantly change the area of the plot and thus bias the estimates

Example of a nested square plot



-  Subunit 1 (e.g. saplings)
-  Subunit 2 (e.g. small trees, 5-50 cm dbh)
-  Subunit 3 (e.g. large trees, > 50 cm dbh)

Transects

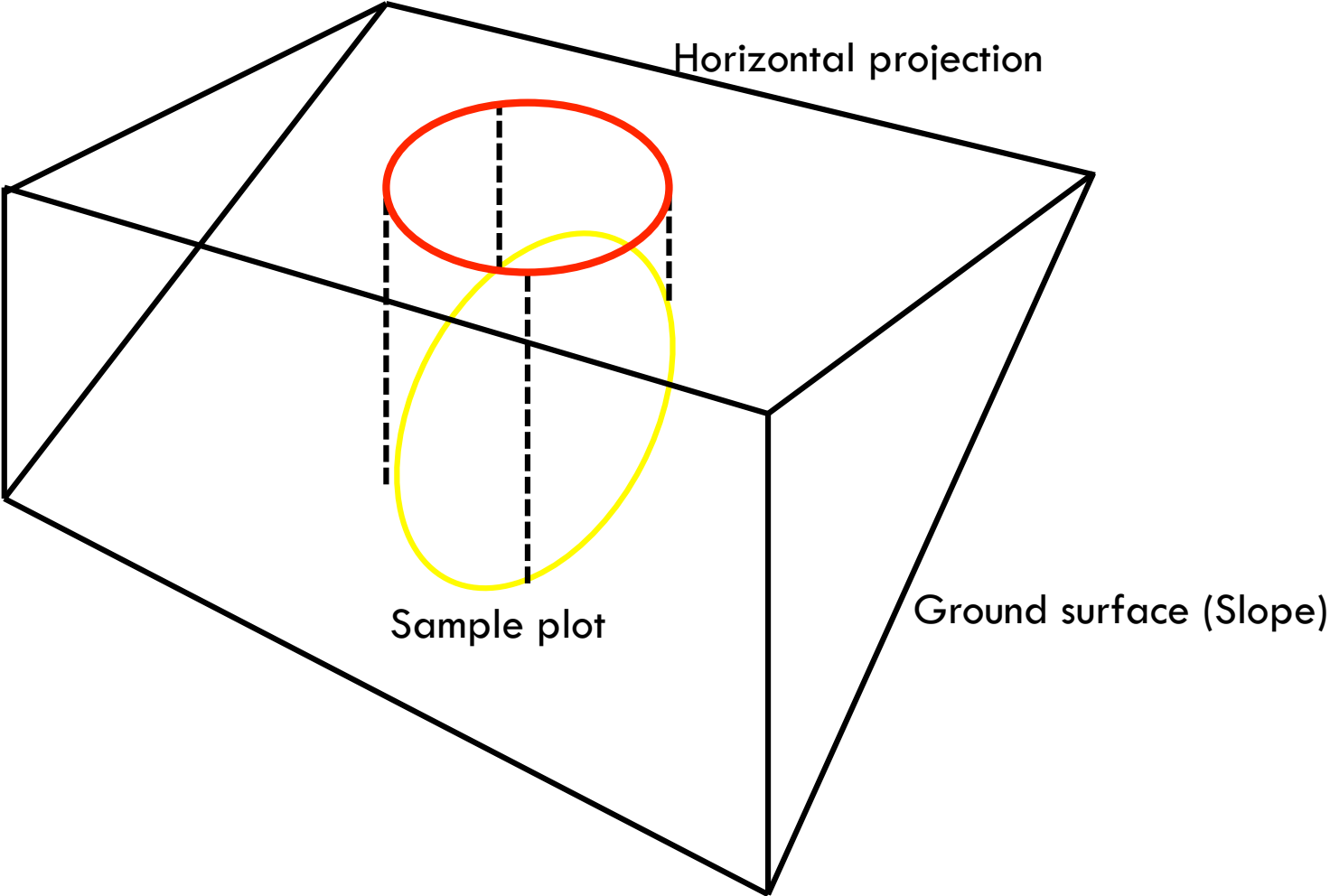


- A transect is a path along the inventory person records and counts the occurrence of certain variables
- It is not used for entire inventories but it is good practice using transects to sample dead wood

Slope corrections

- Generally it is assumed that: 1) the area on which the sample plot (of all shapes and sizes) is plain and 2) the entire area to be sampled is plain
- Therefore, if a plot is located on a slope, a slope correction will be needed
- This correction accounts for the fact that distances measured along a slope are smaller when they are projected to the horizontal
- This will cause bias in the estimates because sample plots would differ in their sizes (and thus measurements) and would correlate wrongly with the size of the total area

Illustration of slope correction



Slope corrections

- With circular plots the slope can be corrected by measuring the distance to each tree exactly horizontally from the plot center
- Difficult if there are many plots on slope and the slope is steep
- Alternatively the radius of the circular plot can be enlarged by multiplying it with $\sqrt{1/\cos\beta}$, where β is the maximum slope angle
- With a rectangular plot, the side perpendicular to slope will remain unaffected but the sides parallel to the slope need to be extended by $1/\cos\beta$

Edge corrections

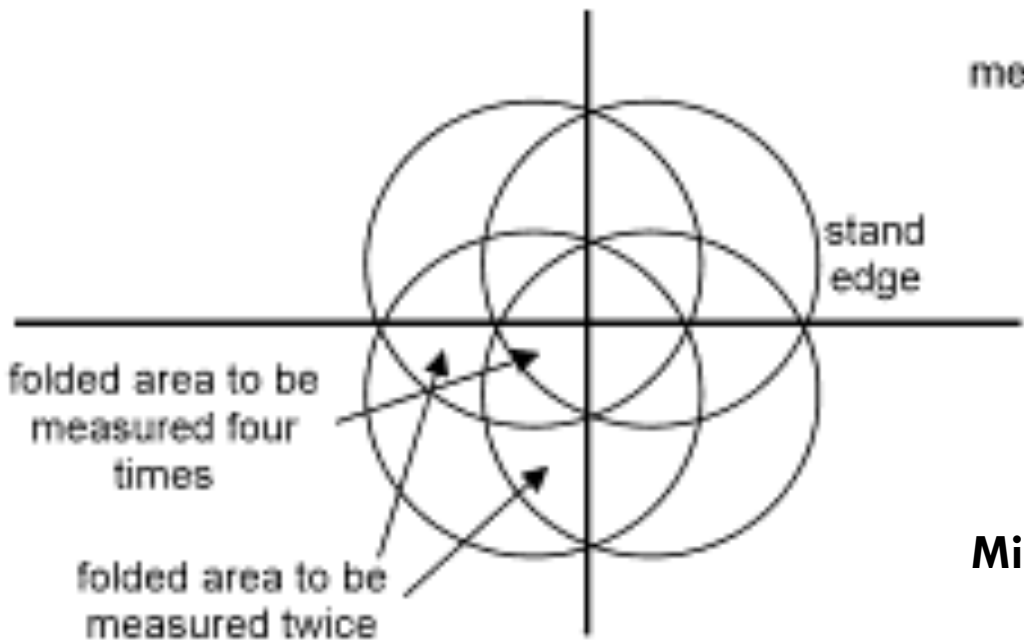
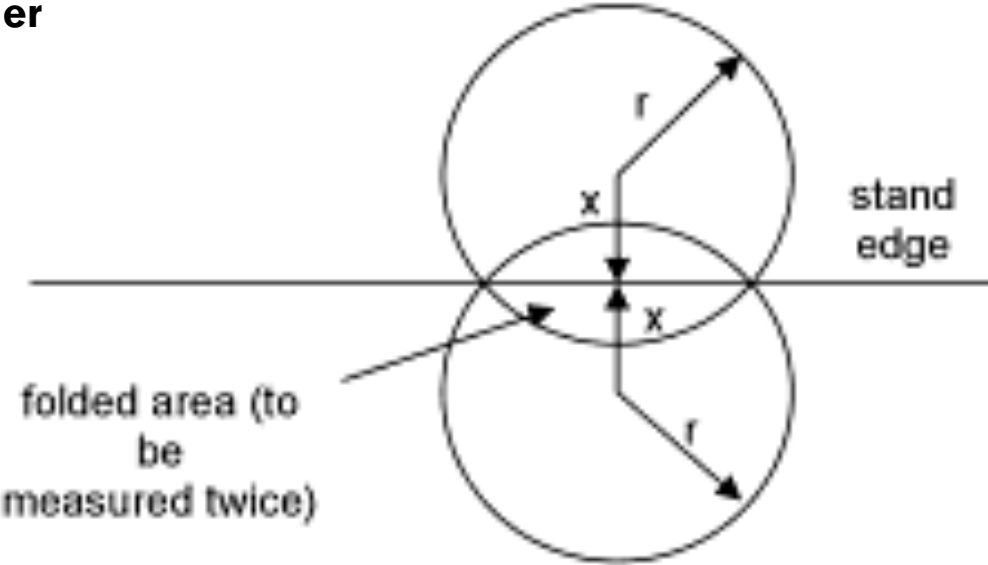
- Forest stands often include voids, such as roads, lakes or power lines and the surveyor may be tempted to move the plot to a wooden spot
- Sample plots on voids are needed to estimate the mean volume accurately (except certain types of voids are excluded from the forest stands from the beginning)
- An edge correction is required if the plot is located close to a stand (forest-) edge, i.e. if the distance to the edge is less than the radius r
- In that case, the area of the plot inside the stand would be smaller than the nominal area and thus, less trees would be measured which would lead to an underestimate and biased results

Edge correction by “mirage method”

- The most common and accurate method is the “mirage method” which is easy to apply especially for circular and variable radius plots
- If the radius r is larger than the distance x to the edge, a mirroring sample plot is located at the same distance x from the edge on the other side
- On this mirroring plot, only the trees inside the original stand are measured, i.e. those trees are measured twice where the mirroring- and the original sample plot overlap
- This method can be problematic in case there are crossing borders and some trees need to be measured once, some twice and others three or four times
- Mirroring non-circular plots might be difficult if the edge is not linear as the mirage plot may contain trees which are not in the original plot area

Example of edge correction

Mirroring at linear border



Mirroring at crossing borders

(3) Plot size

- The plot size needs to be decided before calculating the required number of plots
 - The larger the plots are, the more time-consuming and expensive it is to measure them while the variation among plots diminishes with an increasing plot size
 - Plot size is related to the number of trees (stand density), tree diameter, and variance of carbon stocks among plots
 - The relation between the coefficient of variation and the plot area can be described as:
$$CV_2^2 = CV_1^2 \sqrt{a_1/a_2}$$
where a_1 and a_2 represent different sample plot areas and their corresponding coefficient of variation (CV)
- > By increasing the sample plot area, variation among plots can be reduced permitting the use of small sample size at the same precision level


- Usually, the plot size varies between 100 m² for dense stands (1000 trees/ha) and 1000 m² for sparse stands
- General recommendations for plot sizes in table below:

Stem diameter	Circular plot	Square plot
< 5 cm dbh	1 m	2 m x 2 m
5 – 20 cm dbh	4 m	7 m x 7 m
20 – 50 cm dbh	14 m	25 m x 25 m
> 50 cm dbh	20 m	35 m x 35 m


(4) Sampling size (number of sample plots)

- The sample size is crucial for a forest inventory since it determines the uncertainty and costs of the estimate of the population
- The number of sample plots depends on the desired level of precision in the results
- The more variance* in the carbon stocks, the more sample plots are needed for a low uncertainty
- Stratification reduces the variability* between plots and thus the required sampling size

* **Variability** refers to the observed true heterogeneity or diversity in a population and is an inherent property of the system of nature. **Variance** is a statistical term and one of several descriptors of probability distribution, describing how far the number lie from the mean (expected value).

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- In order to calculate the sampling size following information is required:
 - ✓ Total area (ha)
 - ✓ Plot size (ha)
 - ✓ Mean carbon density (t C/ha) in each stratum
 - ✓ Variance of the carbon stock in each stratum
 - ✓ Desired level of precision (%)

 - Experience in the LULUCF sector has shown that carbon stocks and carbon stock changes in complex forests can be estimated to precision levels of within $\pm 10\%$ of the mean at 95 % confidence at a modest cost

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- Usually the variance of carbon stocks is not known at this point of time and it is necessary to obtain an estimate of it
 - This can be accomplished either from existing data which are representative for the proposed project, or a pilot inventory has to be done
 - Here, it is sufficient to obtain the variance in the main carbon pool (e.g. trees) as this captures most of the total variance
 - The sampling size can initially be estimated using the desired level of precision and by allocating the estimated sample size proportionally to the area of each stratum using Equations 1 and 2

Initial sampling size

$$(1) \quad n = \frac{t_{st}^2 \times (CV\%)^2}{(E\%)^2 + \frac{t_{st}^2 \times (CV\%)^2}{N}}$$

$$(2) \quad n_i = n \times \frac{N_i}{N}$$

Where:

$i = 1, 2, 3, \dots, L$ strata

L = total number of strata

t_{st} = t -student value for a 95% confidence level (initial value $t=2$)

n = total number of sample units to be measured (in all strata)

$E\%$ = allowable sample error in percentage ($\pm 10\%$)


$CV\%$ = the highest coefficient of variation (%) reported in the literature from different volume or biomass forest inventories in forest plantations, natural forest, agro-forestry and/or silvo-pastoral systems

n_i = number of sample units to be measured in stratum i that is allocated proportional to the size of the stratum. If $n_i < 3$ set $n_i = 3$

N_i = maximum number of possible sampling units for stratum i , calculated by dividing the area of stratum i by the measurement plot area

N = population size or maximum number of possible sample units (all strata),

$$N = \sum_{i=1}^{m_p} N_i$$

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- The t-student for a 95% confidence interval is approximately 2 when the number of sample plots is over 30
 - Initially 2 can be used as the t-student value, and if the resulting n is less than 30, the new n can be used to obtain a new t-value
 - Once data on the variability of carbon stocks within each stratum was collected, the sample size and allocation are recalculated using equations 3 and 4, which also account for costs of the measurement. Where costs are not a significant consideration, C_i can be set equal to 1
 - Note that the allowable error in equation 3 is an absolute value and can be estimated as $\pm 10\%$ of the overall average carbon stock per hectare

Recalculation and reallocation of sampling size

$$(3) \quad n = \left(\frac{t_{st}}{E}\right)^2 \left[\sum_{i=1}^{m_p} W_i \times S_i \times \sqrt{C_i} \right] \times \left[\sum_{i=1}^{m_p} W_i \times S_i / \sqrt{C_i} \right]$$

$$(4) \quad n_i = n \times \frac{W_i \times S_i / \sqrt{C_i}}{\sum_{i=1}^{m_p} W_i \times S_i / \sqrt{C_i}}$$

Where:

$i = 1, 2, 3, \dots, L$ strata

$L =$ total number of strata

$t_{st} =$ t -student for a 95% confidence interval, with $n-2$ degrees of freedom

$E =$ allowable error ($\pm 10\%$ of the mean)

$S_i =$ Standard deviation of stratum i

$n_i =$ number of sample units to be measured in stratum i that is allocated proportional to $W_i \times S_i / \sqrt{C_i}$ If $n_i < 3$ set $n_i = 3$

$W_i = N_i / N$

$n =$ total number of sample units to be measured (in all strata)

$N_i =$ maximum number of possible sampling units for stratum i , calculated by dividing the area of stratum i by the measurement plot area

$N =$ population size or maximum number of possible sample units (all strata),

$C_i =$ cost to select and measure a plot of stratum i

$$N = \sum_{i=1}^{m_p} N_i$$

Calculation example (with stratification)

	Stratum 1	Stratum 2	Stratum 3	Total
Area (ha)	3,400	900	700	5,000
Plot size (ha)	0.08	0.08	0.08	0.08
Mean carbon density (t C/ha)	126.6	76.0	102.2	101.6
Standard deviation	26.2	14.0	8.2	27.1
N	$3,400/0.08$ = 42,500	$900/0.08$ = 11,250	$700/0.08$ = 8,750	$5,000/0.08$ = 62,500
Desired precision				10
E				101.6×0.1 = 10.16
Cost				100 \$

(3)

$$n = \left(\frac{2}{10.16}\right)^2 \left[\frac{42,500}{62,500} \times 26.2 \times \sqrt{100} + \frac{11,250}{62,500} \times 14 \times \sqrt{100} + \frac{8,750}{62,500} \times 8.2 \right] \\ \times \left[\frac{42,500}{62,500} \times 26.2/\sqrt{100} + \frac{11,250}{62,500} \times 14/\sqrt{100} + \frac{8,750}{62,500} / \sqrt{100} \right] = 18$$

(4)

$$n_1 = 18 \times \frac{\frac{42,500}{62,500} \times 26.2/\sqrt{100}}{\frac{42,500}{62,500} \times 26.2/\sqrt{100} + \frac{11,250}{62,500} \times 14/\sqrt{100} + \frac{8,750}{62,500} \times 8.2/\sqrt{100}} = 15$$

$$n_2 = 2$$


$$n_3 = 1$$

Note: If $n_i < 3$ set $n_i = 3$!

Calculation example without stratification

$$n = \left(\frac{2}{10.16} \right)^2 \left[\frac{62,500}{62,500} \times 27.1 \times \sqrt{100} \right] \times \left[\frac{62,500}{62,500} \times 27.1 / \sqrt{100} \right] = 29$$

--> With stratification, 11 sample plots less are required to achieve the same level of precision!!

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- With the required information available, the calculation of the sample size can be simplified using an online tool (Winrock Sampling Calculator):

<http://www.winrock.org/Ecosystems/tools.asp>

- It is good practice to install an additional of 10% of the calculated plots to account for unexpected events that may make it impossible to re-locate all plots in future
- It is appropriate to modify the boundaries of strata after each sampling based on the actual carbon stock density and carbon stock dynamics

(5) Plot allocation

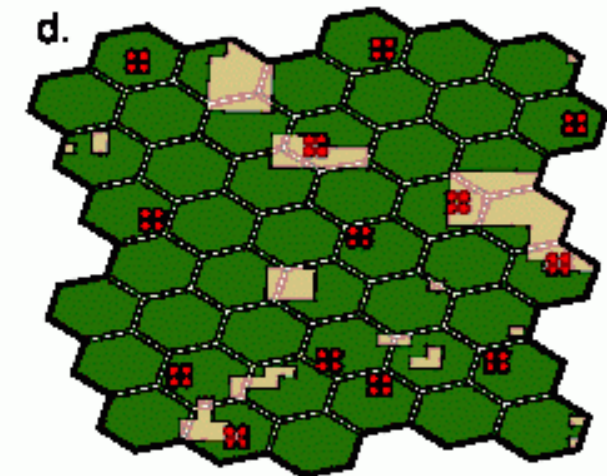
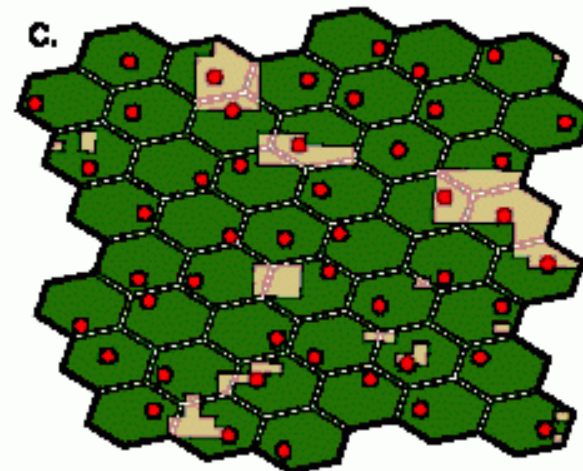
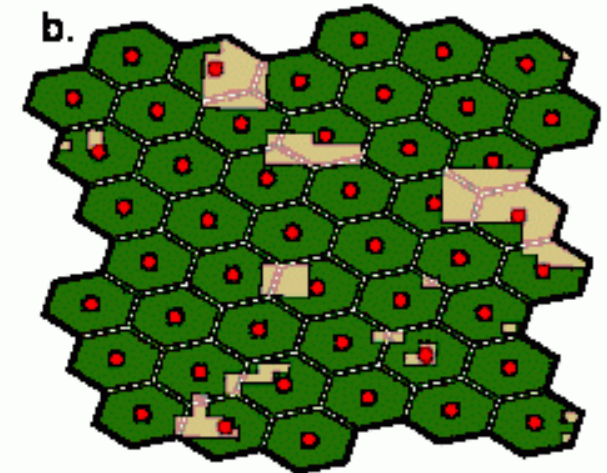
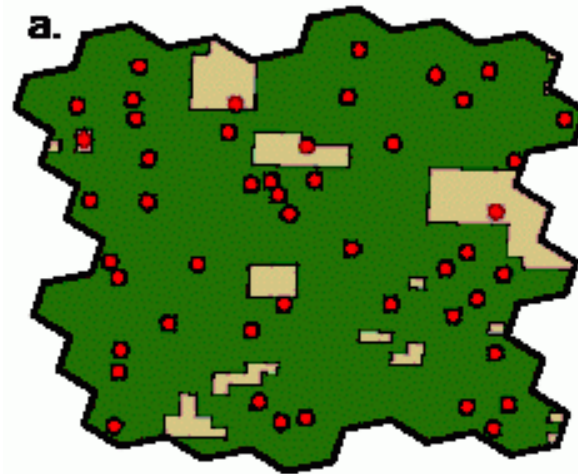
- To avoid subjective choice of plot locations, sample plots (or clusters of plots) should be located randomly on a map of the area, which shows clearly the boundaries of different strata
- This can be accomplished with a random function in GIS programs or random number tables
- It is good practice to locate the plots systematically, using a regular grid which is then located randomly over the project area, as it ensures that plots are evenly distributed over the area
- In order to locate the grid randomly, a random number is used to select the starting point and the direction of the grid
- On the grid, sample plots are either located on the intersection of the gridlines, the middle of each square (**aligned**) or randomly within each square of the grid (**unaligned**)

Clusters



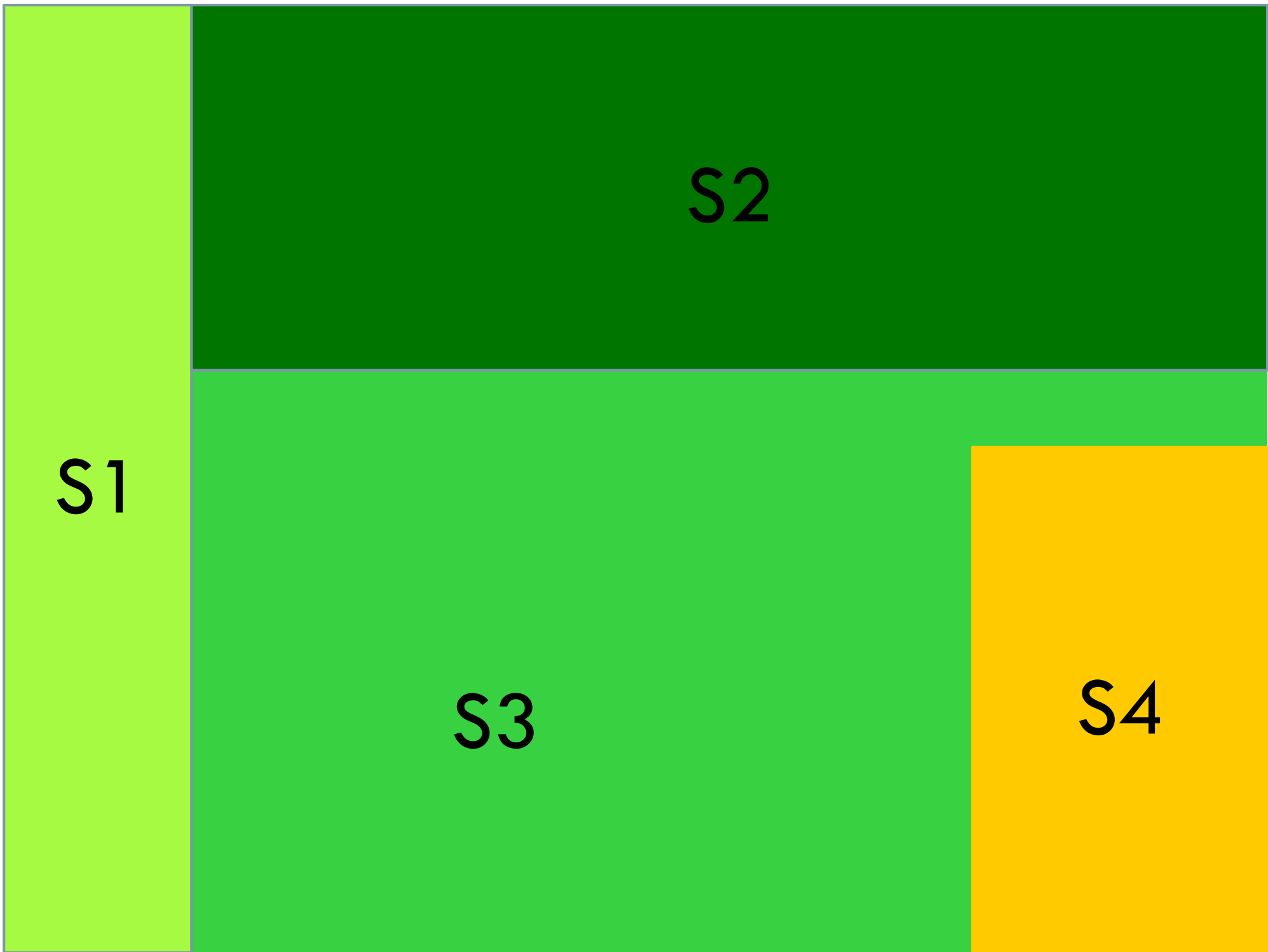
- Within a systematic sampling approach, sample plots may be organized into clusters, i.e. groups of sample plots located near each other
- Clusters are very cost efficient: a cluster design reduces travel distances between sample plots and thus, more units can be measured with the same budget (which also increases accuracy of the estimates)
- It is usually not as efficient because the sampling units in one cluster might be correlated, i.e. the information gained from measuring a new unit is less than it would be with independent units
- Therefore, distances between the units in one cluster should be large enough to avoid major between-plot correlations (at least 250-300m, depending on the size of stratum)

- a. Simple random sampling
- b. Systematic sampling (aligned)
- c. Systematic sampling (unaligned)
- d. Cluster sampling



Permanent – temporary plots?

- Plots can be designed differently to assess changes; 1) permanent sampling units 2) temporary sampling units 3) sampling with partial replacement
- It is good practice to use permanent plots since these are more efficient in assessing changes in carbon stocks/ -dynamics than temporary plots where changes over time might be due to changed plot location
- A great risk with permanent sample plots is that if the location gets known to land managers (e.g. by visible marking), the management might differ from other areas
- In that case, the permanent plots are not longer representative and lead to biased results
- Therefore it is recommended to mark plot centers or boundaries inconspicuous

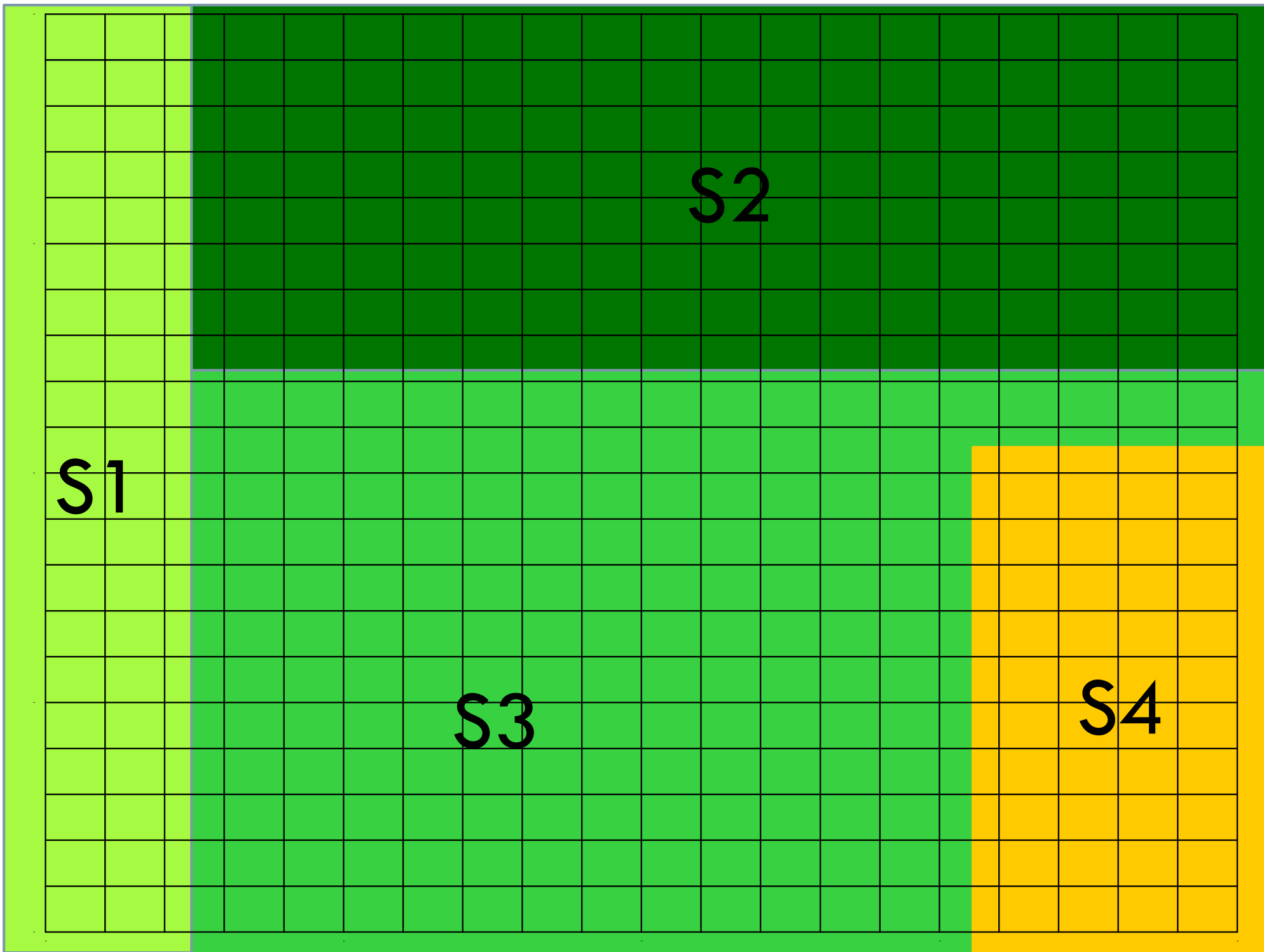


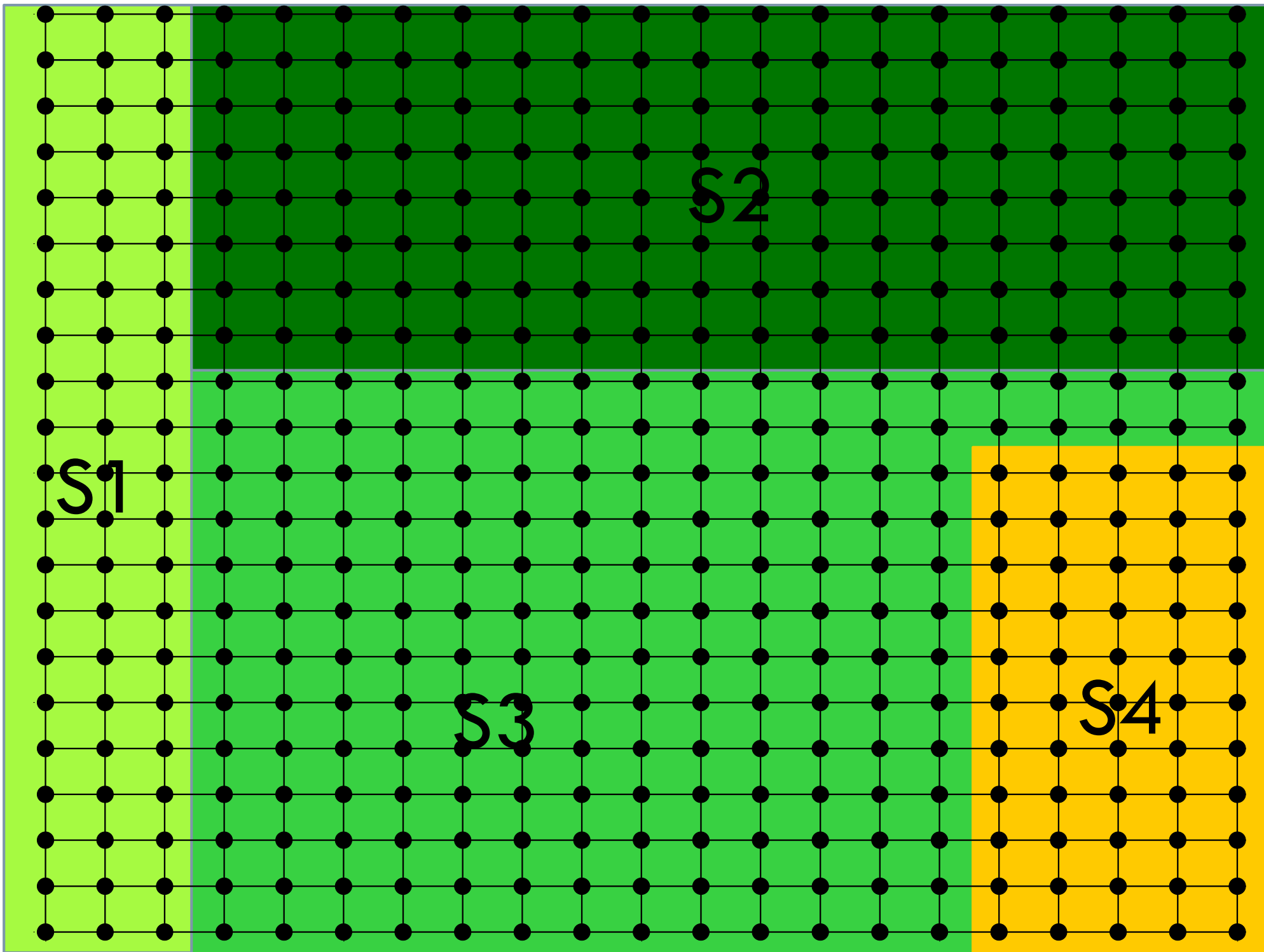
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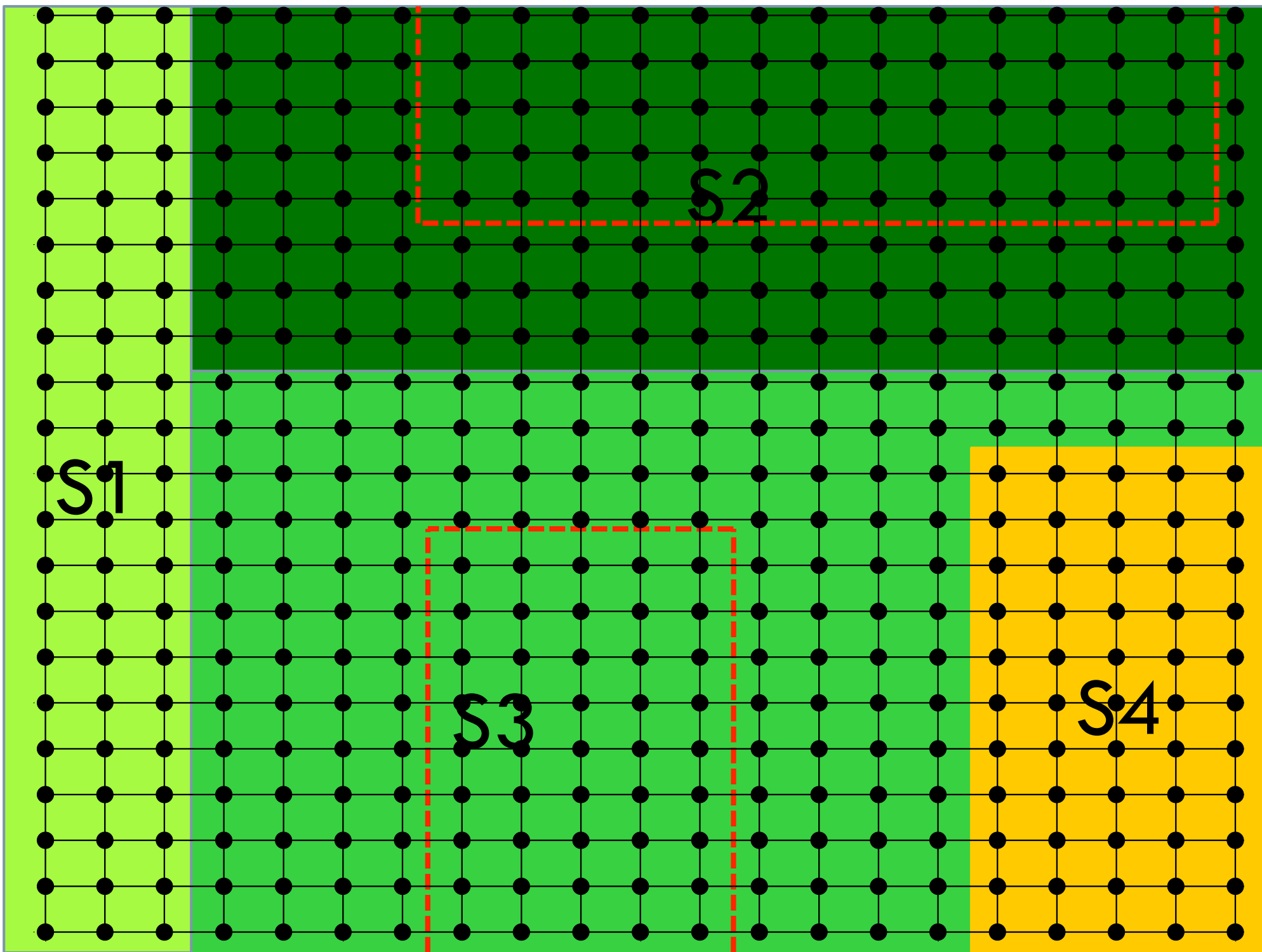
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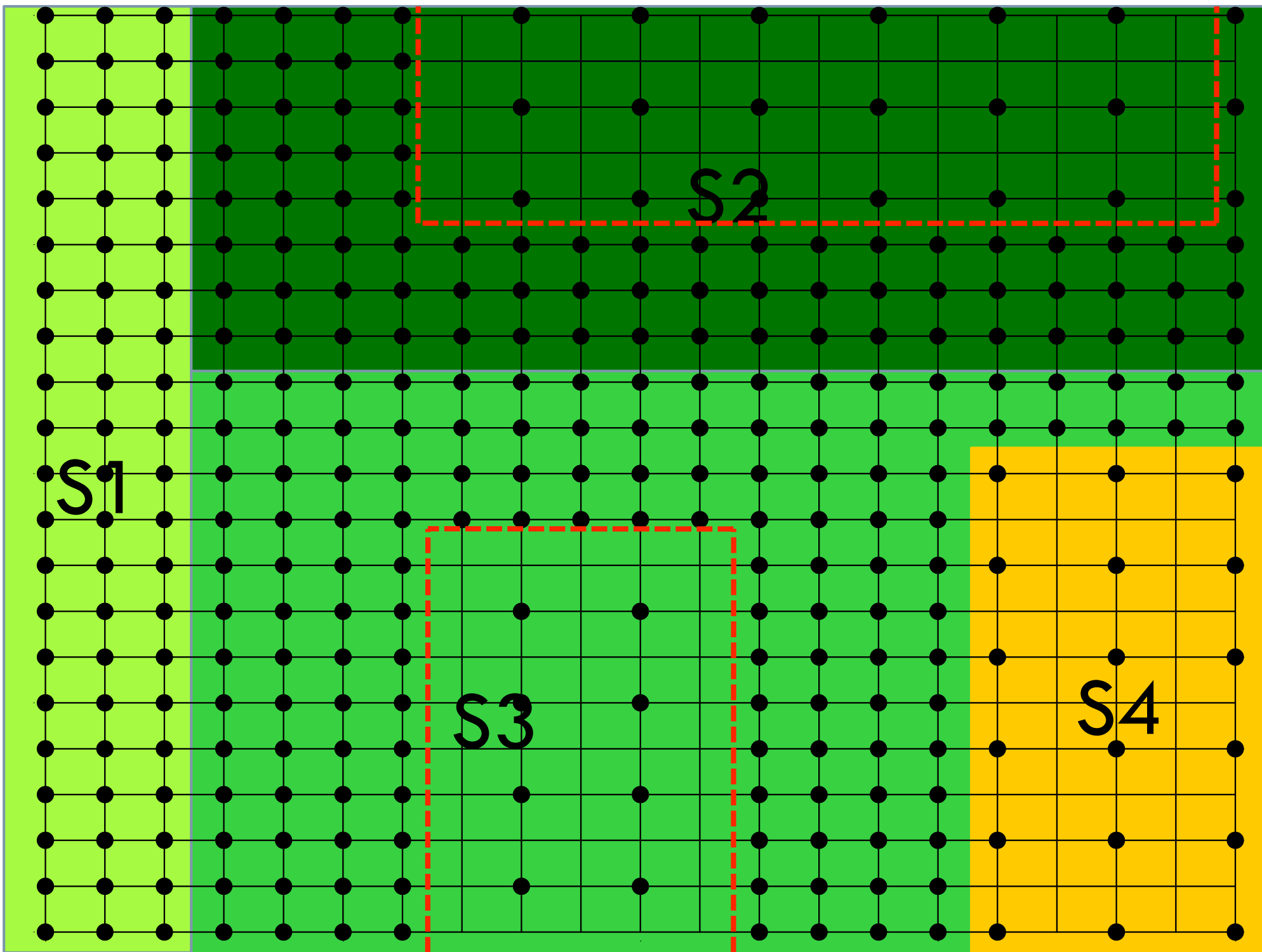
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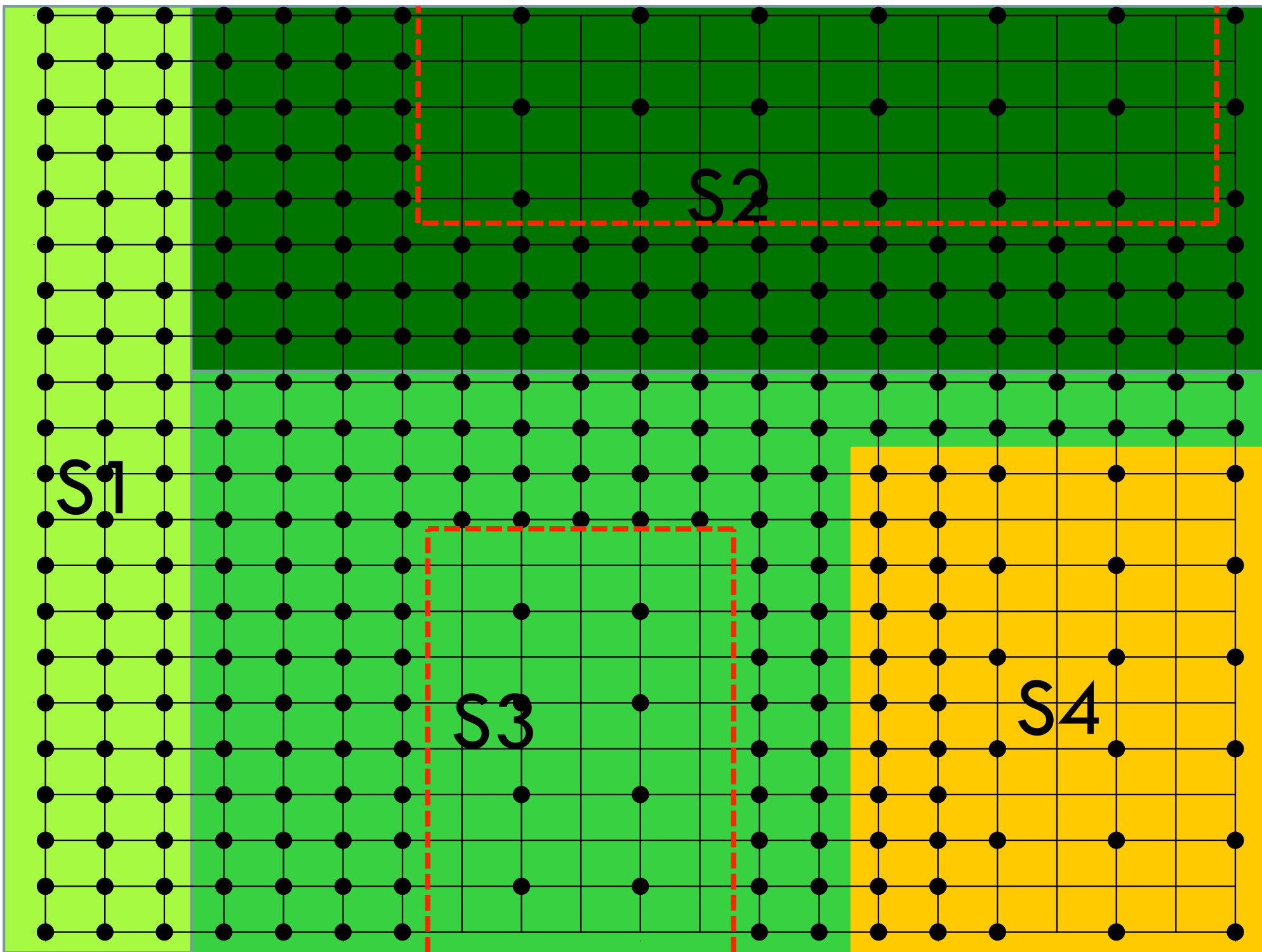
S4











2. Phase: Ground data collection



- During the 1. Phase of designing the sampling, it was recommended to create a stratification map with help of a GIS program
- In this stratification map the sample plots are located and connected with a GPS-coordinate and can be used to find the sample plots in the field with help of a GPS instrument
- Efficient planning for field works is essential to reduce unnecessary labor costs, avoid safety risks and ensure accurate carbon estimates

(1) Implementation steps



1) **Personnel and training**

- Selection
- Plan “chain of command”
- Training (Initial, Monitoring, Encouragement)

2) **Planning of logistics**

- Office equipment
- Field equipment
- Transport
- Accommodation
- Safety
- Communication



3) **Field measurements**

- Design field forms (recording data in the field)
- Supply detailed instructions
- Select equipment carefully
- Check equipment periodically
- Proportionally to the size of the stratum, distribute the amount of sample plots to be sampled each year over the cycle period (5 years)
- Field sampling should be conducted during season of the year with the most suitable and stable weather conditions in order to ensure an efficient field work, safety issues and good working conditions

(2) Carbon pools to be measured

- There are five main carbon pools which need to be considered during the project activity, although not all of them will be significantly affected:

- 1) Aboveground biomass
 - Trees
 - Non-tree vegetation
- 2) Belowground biomass (roots)
 - Trees
 - Non-tree vegetation
- 4) Litter (or forest floor)
- 6) Dead wood
- 8) Soil organic matter

Trees



- Parameters to be recorded are the diameter at breast height (DBH), the height and the tree species of all trees above a minimum diameter (usually 5 cm DBH)
- Diameter at breast height is measured at 1,3 meters above ground
- Measurement instrument: caliper or DBH-tape, clinometer
- With nested sampling plots, trees can be divided in different dbh-classes to be measured in different sub-units of the entire plot

Non-tree vegetation

- For example; herbaceous plants, grasses, shrubs and small trees < 5 cm dbh
- Good practice to measure non-tree vegetation by simple harvesting techniques on up to 4 small sub-plots ($\sim 1 \text{ m}^2$)
- The vegetation on the subplot is cut to ground and weighted
- Well-mixed subsamples of each plot are then collected and oven-dried in order to determine dry-to-wet matter ratios
- If shrubs are too large, local shrub allometric equations can be developed alternatively

Belowground biomass (roots)

- Belowground biomass is an important carbon pool, accounting for around 26 percent of the total biomass
- Belowground biomass is difficult and time-consuming to measure and methods are generally not standardized
- Live and dead roots are generally not distinguished and therefore root biomass is reported as total live and dead roots
- Main methods to estimate belowground biomass include:
 - 1) **Excavation of roots**
 - 2) **Soil core or pit for non-tree vegetation**
 - 3) **Root-to-shoot ratios**
 - 4) **Allometric equations**
- Since measurements in the field are very costly and require huge human effort, it is good practice to apply root-to-shoot ratios or allometric equations

Excavation of roots

- If no root-to-shoot ratios or allometric equations suitable for the tree species or region are available, it might be necessary to measure the biomass:
- Plots are selected and located in each stratum
- All trees in the plots are recorded regarding species, DBH and height
- Trees are harvested and roots are excavated separately for each species
- Fresh and dry weight of the roots needs to be measured in order to obtain a dry-to-wet ratio
- Dry weights can be extrapolated to plot-, stratum- and total area
- Finally, information can be used to develop regression equations on the relations between above- and belowground biomass

Soil core or pit for non-tree vegetation

- For non-tree vegetation a metallic soil core (5-10 cm in diameter and 30 cm deep) can be used to estimate root biomass
- The core is driven into the soil and soil along with roots are removed
- Soil and roots are separated and roots should be washed and weighted
- Roots are oven-dried and the dry matter values can be extrapolated to plot-, stratum- and total area

Belowground biomass (roots)

- IPCC-GPG refers to a comprehensive literature review (Cairns *et. al* 2007) which includes 160 studies estimating above- and belowground biomass (native tropical, temperate and boreal forests)
--> Average belowground to aboveground dry matter ratio was 0.26 (range of 0.18-0.30)
- It is good practice to estimate belowground biomass using the “root-to-shoot ratios” given in table 4.A.4, Annex 4A 2 IPCC Good Practice Guidance

Litter

- Litter includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2mm) and less than the minimum diameter chosen for lying dead wood (10 cm), in various states of decomposition above- or within the soil
- Litter biomass might be an important carbon pool especially in older forests
- The method to sample litter is similar to non-tree vegetation
- Litter is collected and weighted on up to 4 small subplots and a well-mixed sub-sample of taken in order to determine the dry-to-wet matter ratio
- Litter should be sampled always during the same time of the year to avoid seasonal effects

Dead wood

- Dead wood can be divided into standing and lying dead wood
- **Standing dead wood** is measured as part of the tree inventory but is recorded as dead wood since its carbon contents differs from live trees
- **Lying dead wood** is measured with the line-intersect method; it is good practice to use at least 100m length of line (or 2 x 50m), on which the diameter of each piece of dead wood is measured and classified into one of several density classes
- If the amount of dead wood is expected to be high (>15% of total aboveground biomass), it is good practice to do a complete inventory on the sample plot

Soil organic carbon

- It is good practice to estimate soil organic carbon from 2-4 soil samples taken in each sample plot
- Soil samples are usually taken with a metallic cylinder or by the excavation method depending on the soil type
- In coarse textured, stony soils it is inadequate to take soil samples since it would overestimate the bulk density of the fine soil
- Instead, the excavation method is recommended, supplemented with an estimate of the percent volume occupied by stones
- It is good practice to take soil samples at a depth of 30 cm as this is the depth at which changes in the soil carbon pool are fast enough to be monitored during the project period
- If soils are shallower than 30 cm it is important to measure and record the depth of each sample taken

(3) Required equipment

- Compass (orientation and directions)
- Fiberglass meter tapes (100m + 30m)
- Global Positioning System (GPS)
- Plot center marker (rebar/PVC tubing)
- Metal detector (to find belowground marked plot center)
- Tree diameter at breast height (DBH) tape
- Clinometers (percent scale) for measuring tree height
- Colored ropes and pegs or a digital measuring device if circular plots (DME)
- 100m line or two 50 m lines (for dead wood intersect measures)
- Calipers (for DBH)
- Hand saw
- Spring scales (1kg and 300 g)
- Large plastic sheets
- Cloth (e.g. Tyrek) or paper bags
- Metallic cylinder (for soil sample)
- Rubber mallet (to insert cylinder in soil)
- Frame (for sampling non-tree veg. and litter, 1x1 m)

3. Phase: Inferences from collected data

- It is good practice to resample 10% of the total plots by an independent 3rd party in order to identify errors in the sampling and to obtain the accuracy of the estimates
- From the data collected, conclusions can be drawn, including standard errors of mean and total values per hectare and the confidence interval of the population mean

	A (area of the stratum)	n (number of sample plots)
Stratum 1	3400	12
Stratum 2	900	3
Stratum 3	700	3

Mean carbon stocks for each carbon pool (tonnes of carbon/hectare)

$$\bar{y}_1 = \frac{1}{n_1} \sum_{i=1}^{n_1} y_i = \frac{1}{12} \sum_{i=1}^{18} y_1 = 126.6 \text{ tC/ha}$$

$$\bar{y}_2 = 76 \text{ tC/ha}$$

$$\bar{y}_3 = 102.2 \text{ tC/ha}$$

Where:

n (1,2,3...) = the number of sample plots taken in each stratum

y_i = the mean carbon stock in the plot i

Variance of the carbon stock for stratum i

$$s_{y_1}^2 = \sum_{i=1}^{n_1} \frac{(y_i - \bar{y}_1)^2}{n_1 - 1} = 688.44 \text{ (tCha)}$$

$$s_{y_2}^2 = 196.44 \text{ tCha}$$

$$s_{y_3}^2 = 67.24 \text{ tCha}$$

Standard error of the mean carbon stocks

$$s_{\bar{y}_1} = \sqrt{\left(1 - \frac{n_1}{N_1}\right) \frac{s_{y_1}^2}{n_1}} = \sqrt{(1 - 0.00028) \frac{688.44}{12}} = \sqrt{57.35} = 7.6 \text{ tCha}$$

$$s_{\bar{y}_2} = 8.08 \text{ tCha}$$

$$s_{\bar{y}_3} = 4.7 \text{ tCha}$$

Where:

n_1 = number of sample plots in stratum i

N_1 = the maximum possible amount of sample plots in stratum i (total area / sample plot area)

Total carbon stock in each stratum

Total carbon stocks in each stratum:

$$\hat{T}_1 = A_1 \bar{y}_1 = 3400 \times 126.6 = 430,440 \text{ tC}$$

$$\hat{T}_2 = 68,400 \text{ tC}$$

$$\hat{T}_3 = 71,540 \text{ tC}$$

Where:

$A_{1,2,3,\dots}$ = the area of stratum i

$y_{1,2,3,\dots}$ = mean carbon stock per hectare in stratum i

Standard error of total carbon stocks

$$s_{\hat{T}_1} = \sqrt{\text{var}(T_1)} = \sqrt{A_1^2 \text{var}(\bar{y}_1)} = \sqrt{3,400^2 \times 686.44} = 89,080 \text{ tC}$$

$$s_{\hat{T}_2} = 12,600 \text{ tC}$$

$$s_{\hat{T}_B} = 5,740 \text{ tC}$$

Mean carbon stock per hectare for whole area

$$\bar{y}_{\text{tarea}} = \sum_{h=1}^3 W_h \bar{y}_h = 0.68 \times 126.6 + 0.18 \times 76.0 + 0.14 \times 102.2 = 114.076 \text{ tCha}$$

and it's standard error:

$$s_{\bar{y}_{\text{tarea}}} = \sqrt{\sum_{h=1}^3 W_h^2 \text{var}(\bar{y}_h)} = \sqrt{0.68^2 \times 686.44 + 0.18^2 \times 196 + 0.14^2 \times 67.24} = \sqrt{325,07} \\ = 18.03 \text{ tCha}$$

Where:

W_h = ratio of the stratum to the total area

y_h = mean carbon stock in stratum i

Total carbon stock for whole area

$$T_{\text{tarea}} = \sum_{h=1}^3 \bar{T}_h = 430,440 + 68,400 + 71,540 = 570,380 \text{ tC}$$

and it's standard error:

$$S_{\widehat{y}_{\text{tarea}}} = \sqrt{\sum_{h=1}^3 W_h^2 \text{var}(\widehat{y}_i)} = \sqrt{7,935,246,400 + 158,760,000 + 32,947,600} = 90,149 \text{ tC}$$

Confidence interval for the true population mean

$$\left(\hat{y} - z_{\left(\frac{\alpha}{2}\right)} s_e; \hat{y} + z_{\left(\frac{\alpha}{2}\right)} s_e\right)$$

where $z_{(\alpha/2)}$ is a value from the normal distribution with a confidence level α . Thus the 95% confidence interval for the true mean carbon stock per hectare (for the whole area) would be:

$$(114.076 - 1.96 \times 18.03; 114.076 + 1.96 \times 18.03) =$$

78 tC/ha – 114.076 – 149.4 tC/ha

where 1.96 is the approximate value of the 97.5th percentile of the PDF, i.e. 95% of the area under the PDF lies roughly within 1.96 standard deviations of the mean.

Regional workshop for the “Capacity Development for sustainable national Greenhouse Gas Inventories – AFOLU sector” (CD-REDD II) Programme

**Thank you very much
for your attention!**