Recent experiences with advanced technologies for forest monitoring in a developing country: Tanzania

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Background

- Requirements for forest monitoring in a developing country.
  - COP decisions and UNFCCC reporting

About estimation (COP15; Copenhagen):
"Developing country Parties are requested ….. to use the most recent IPCC guidance and guidelines, as adopted or encouraged by the COP, as appropriate as a basis for estimating anthropogenic forest-related GHG emissions and removals…"

IPCC Good Practice Guidance

"Defines inventories consistent with good practice as those which contain **neither over- nor underestimates so far as can be judged, and in which <u>uncertainties are reduced as far as is practicable</u>**"

Implications:

1. We should use **unbiased** estimators
2. We should be capable of estimating and documenting the **precision** (variance) of the estimates and produce a confidence interval
3. The estimates should have a high precision

   Two "but's":

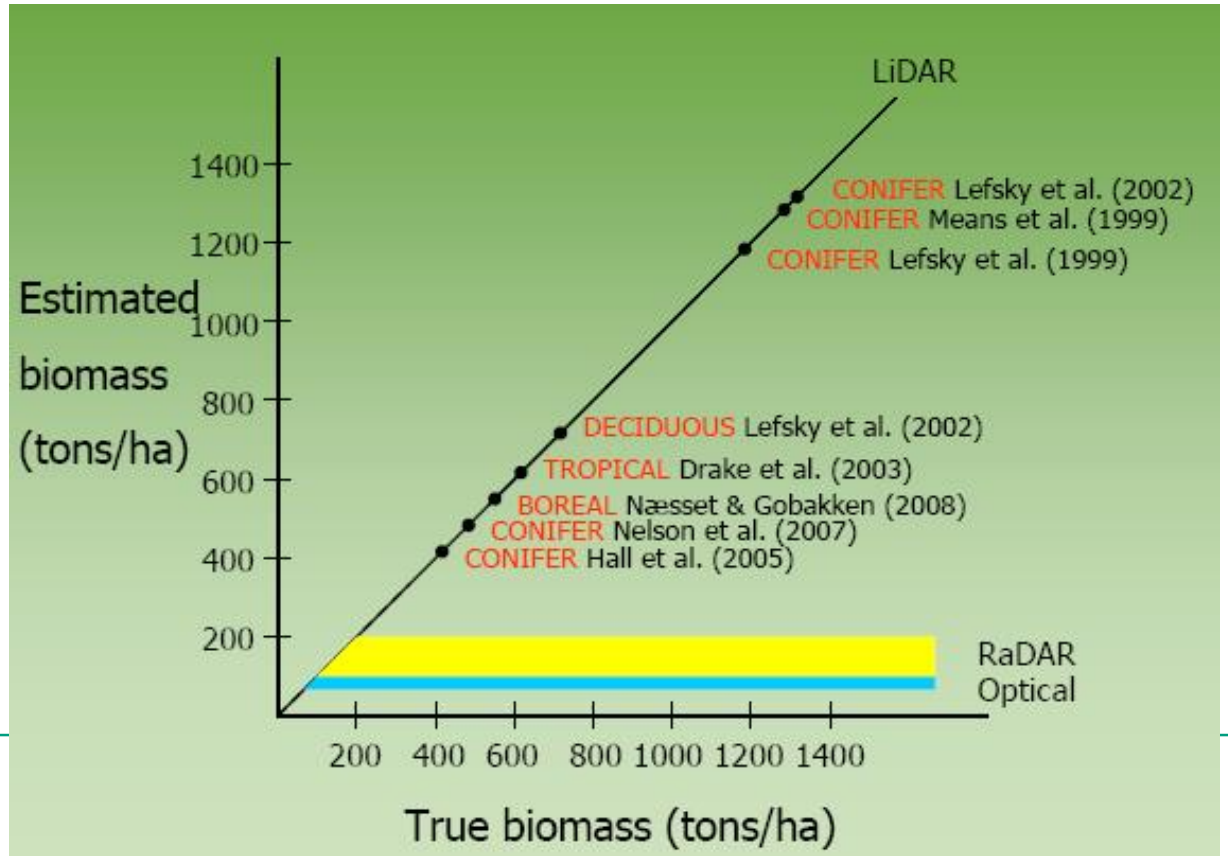
   - Will a REDD+ country be rewarded with higher credits per ton carbon for a more precise estimate?
   - Will a REDD+ country receive credits for non-significant changes from reference level?

Can advanced technologies contribute to higher precision and reduced costs for biomass and biomass change estimates in rainforests and miombo woodlands of Tanzania?

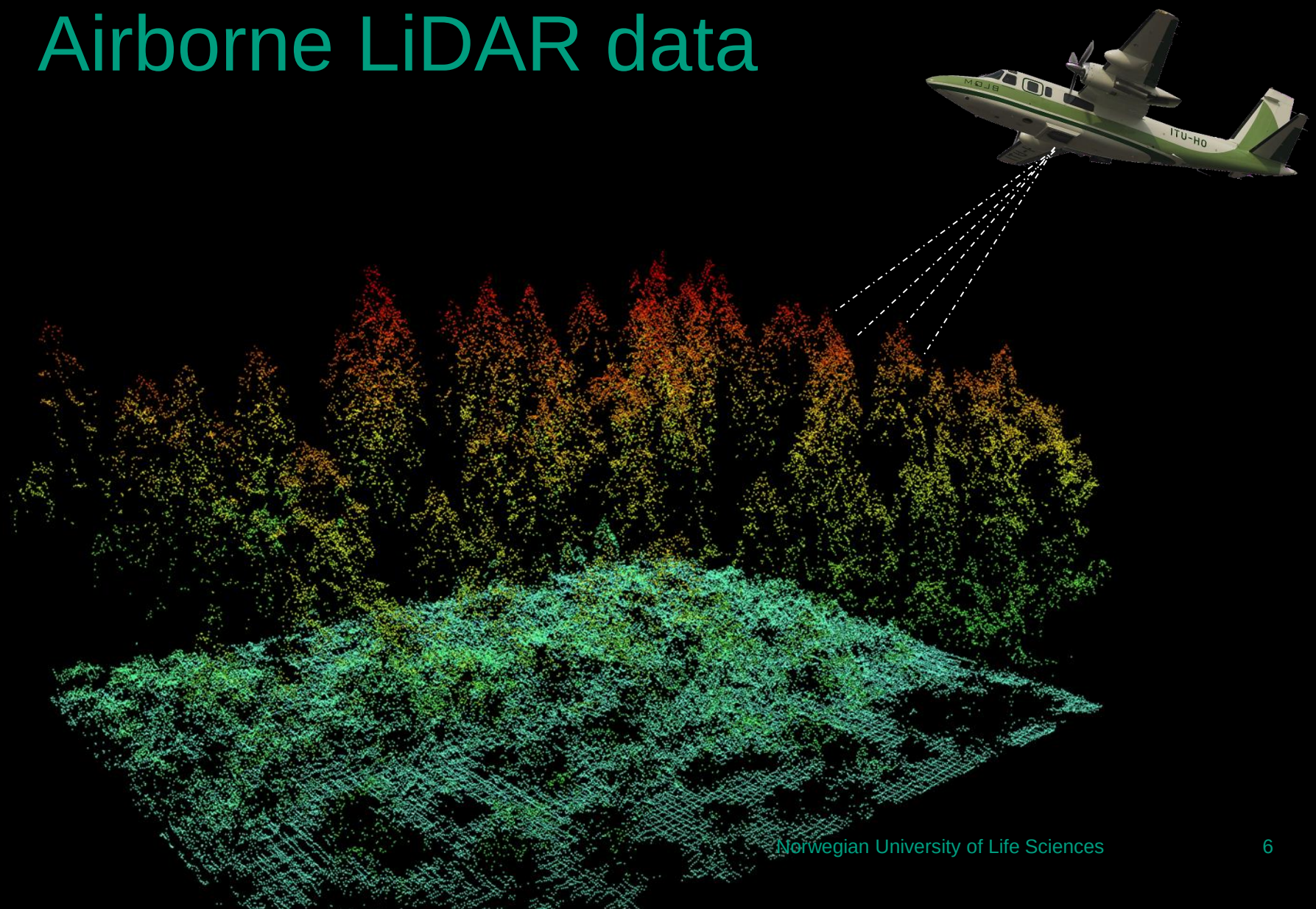
Airborne LiDAR data over large geographical areas

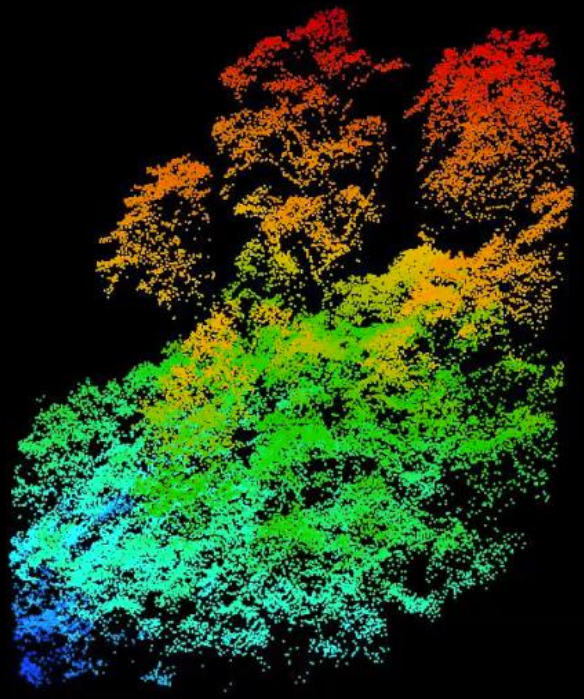
Why is LiDAR superior to all other remote sensing techniques?

-No saturation problems (Does not display any asymptotic tendencies in biomass estimation for biomass quantities up to >1300 tons/ha)

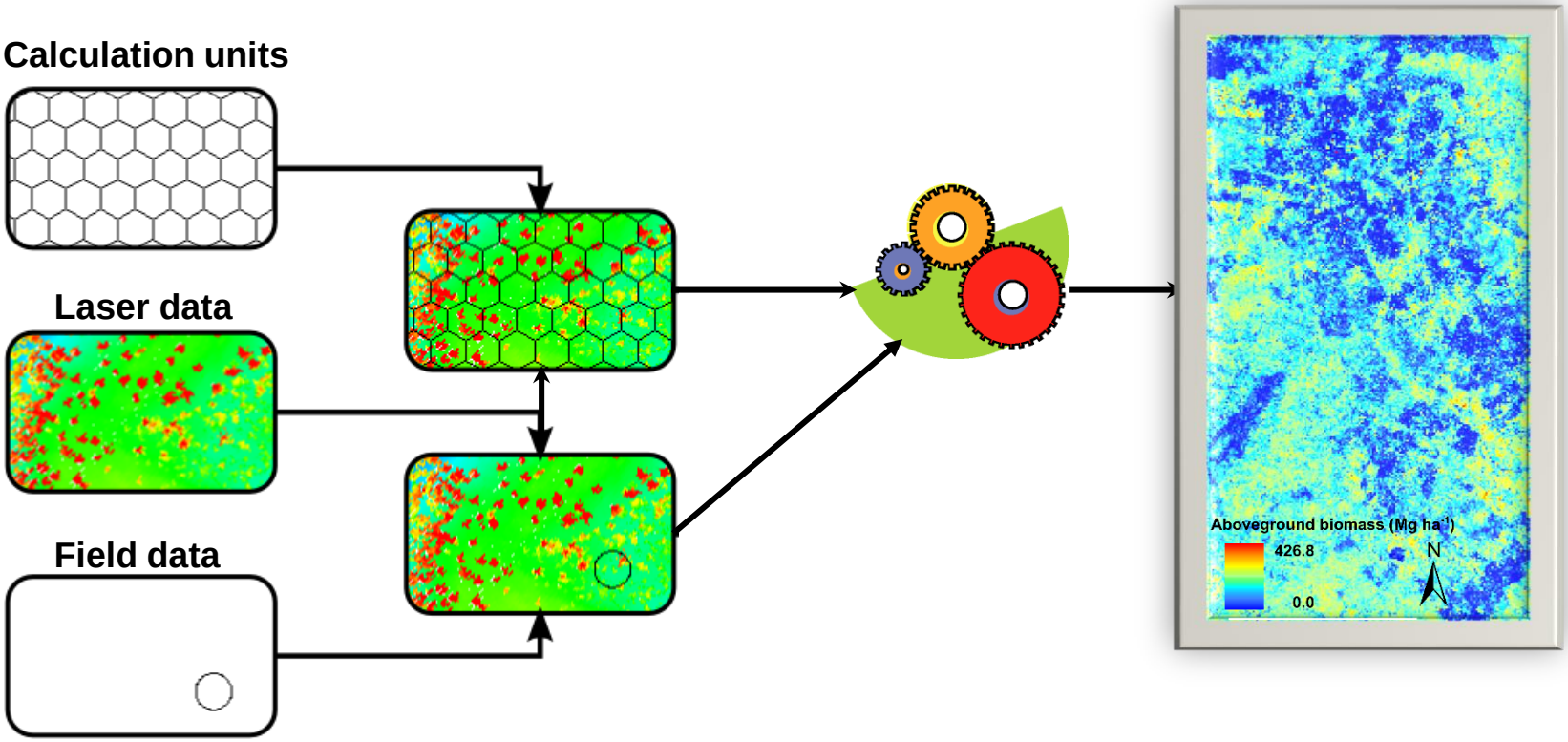


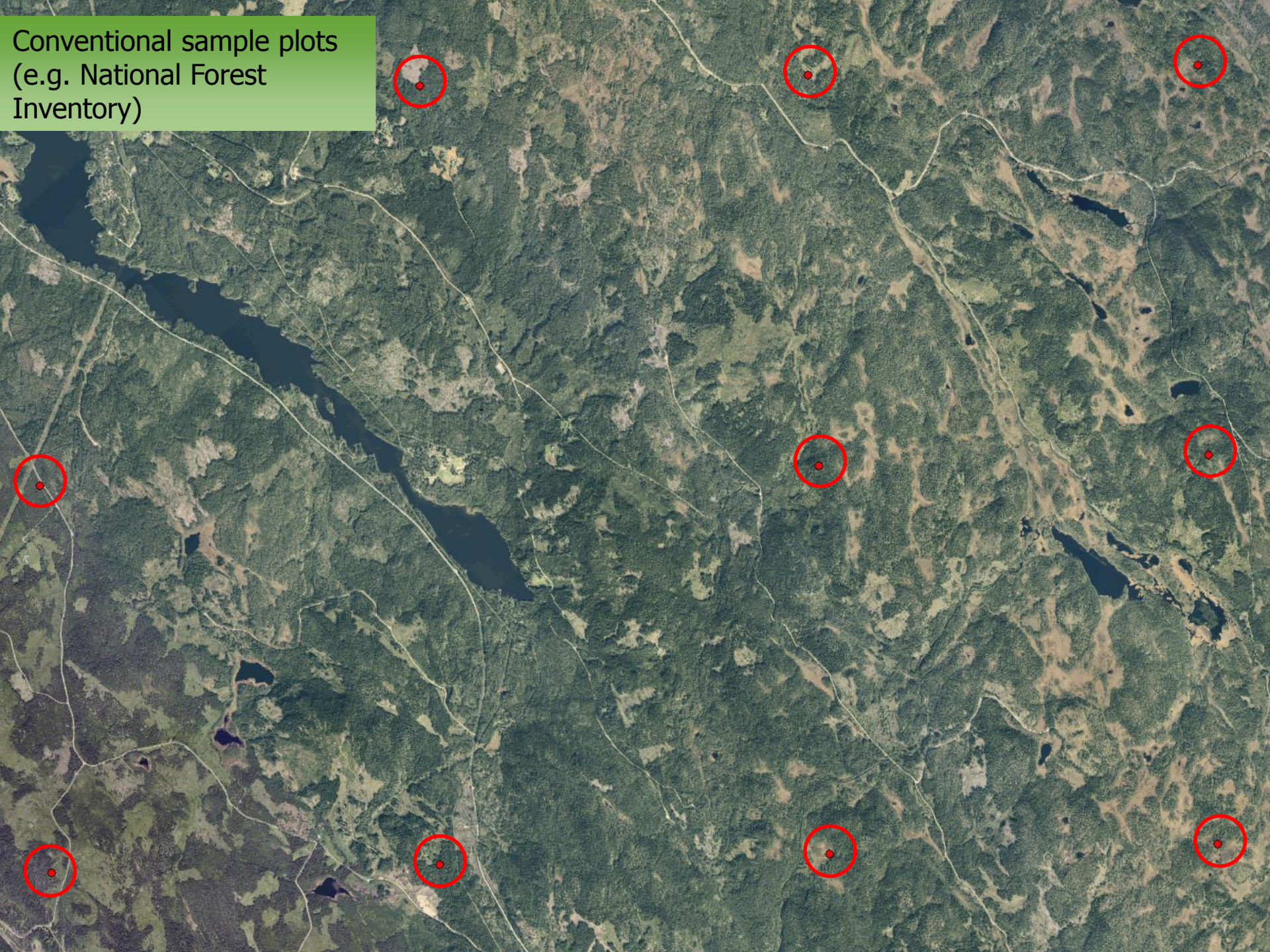
Airborne LiDAR data





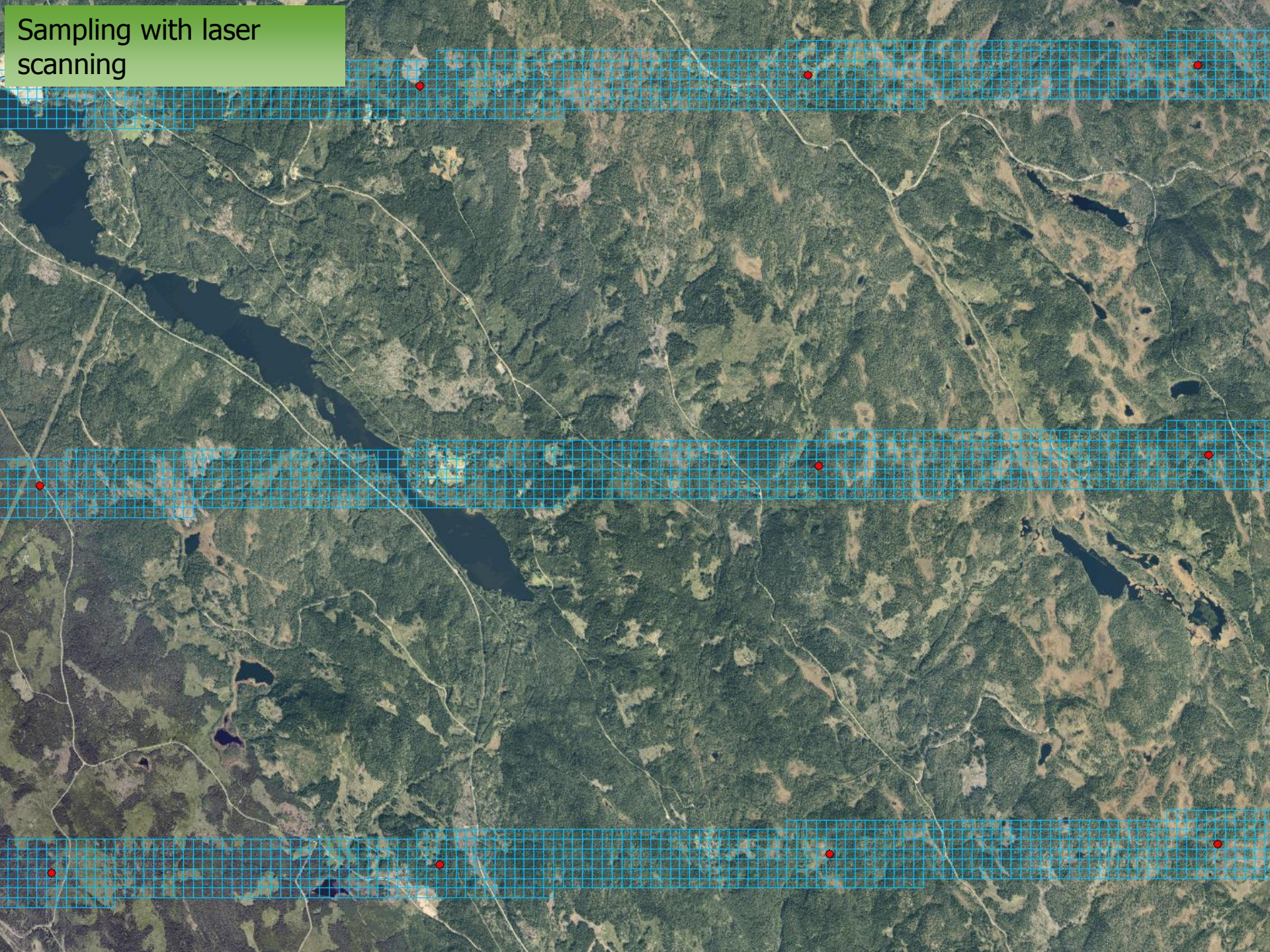
The ALS forest inventory



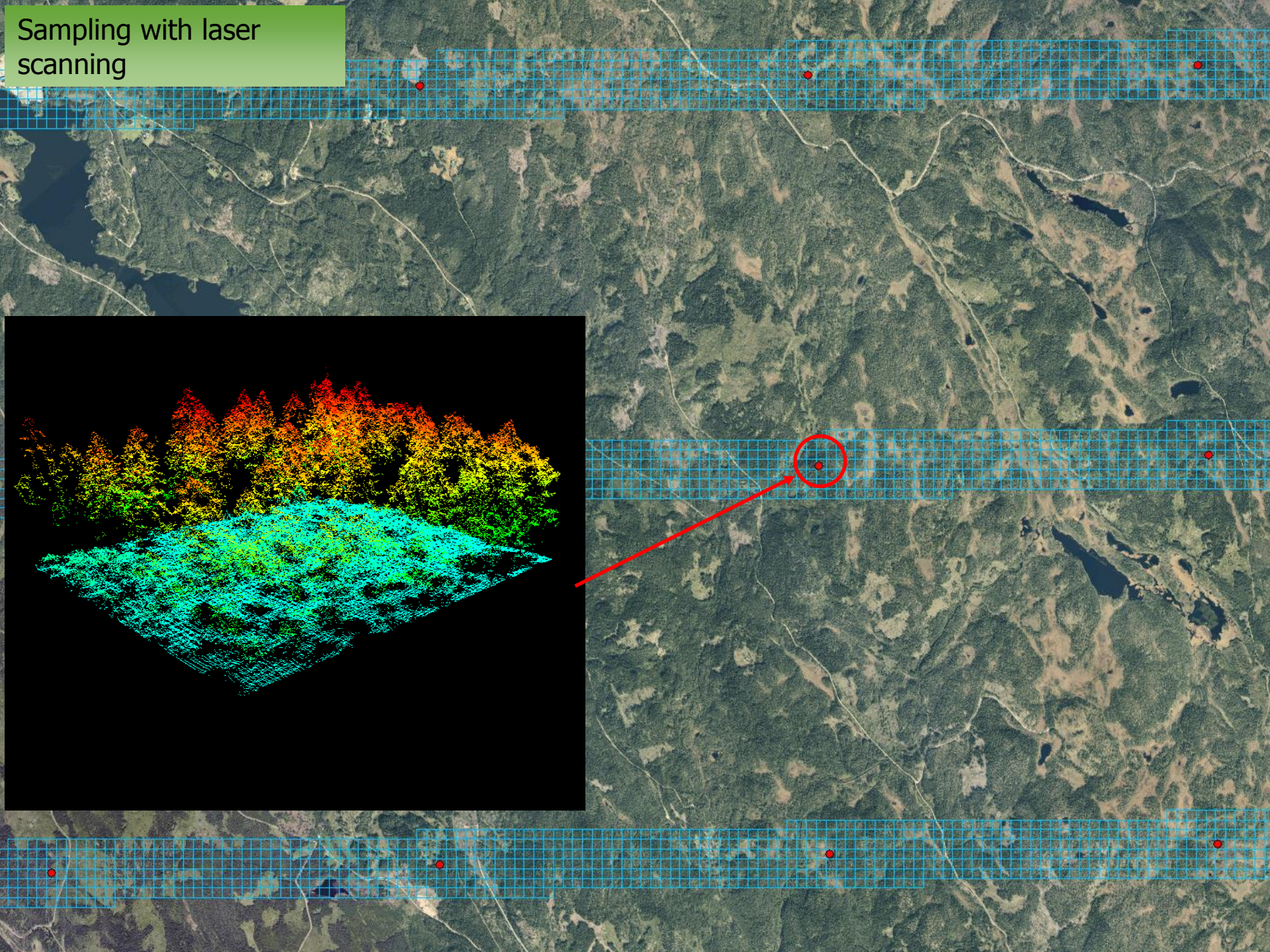

Conventional sample plots
(e.g. National Forest
Inventory)

Wall-to-wall inventory with laser scanning

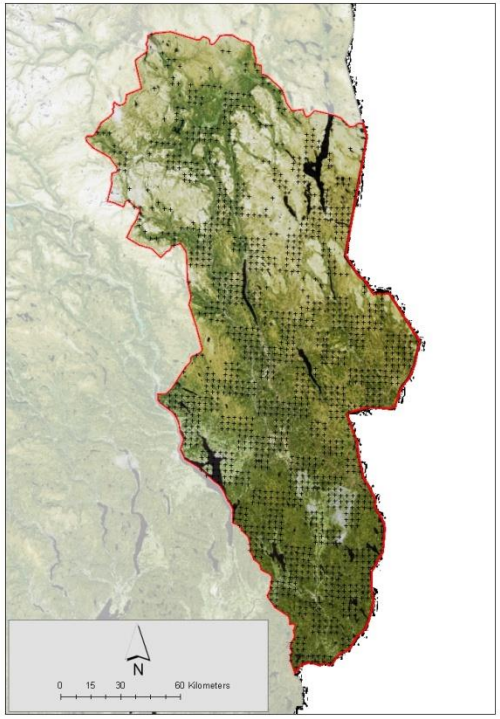
Sampling with laser scanning

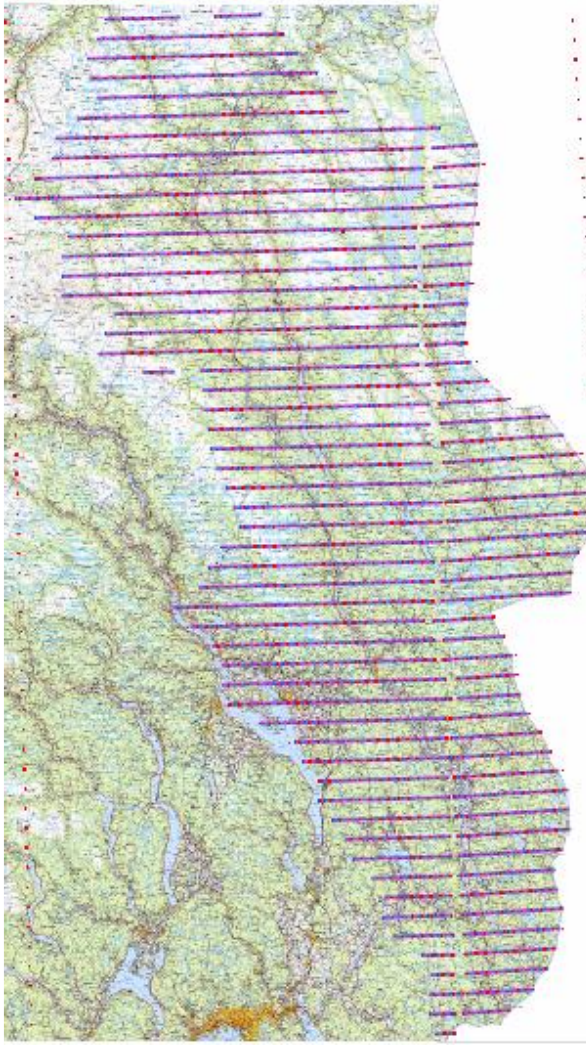


Sampling with laser scanning

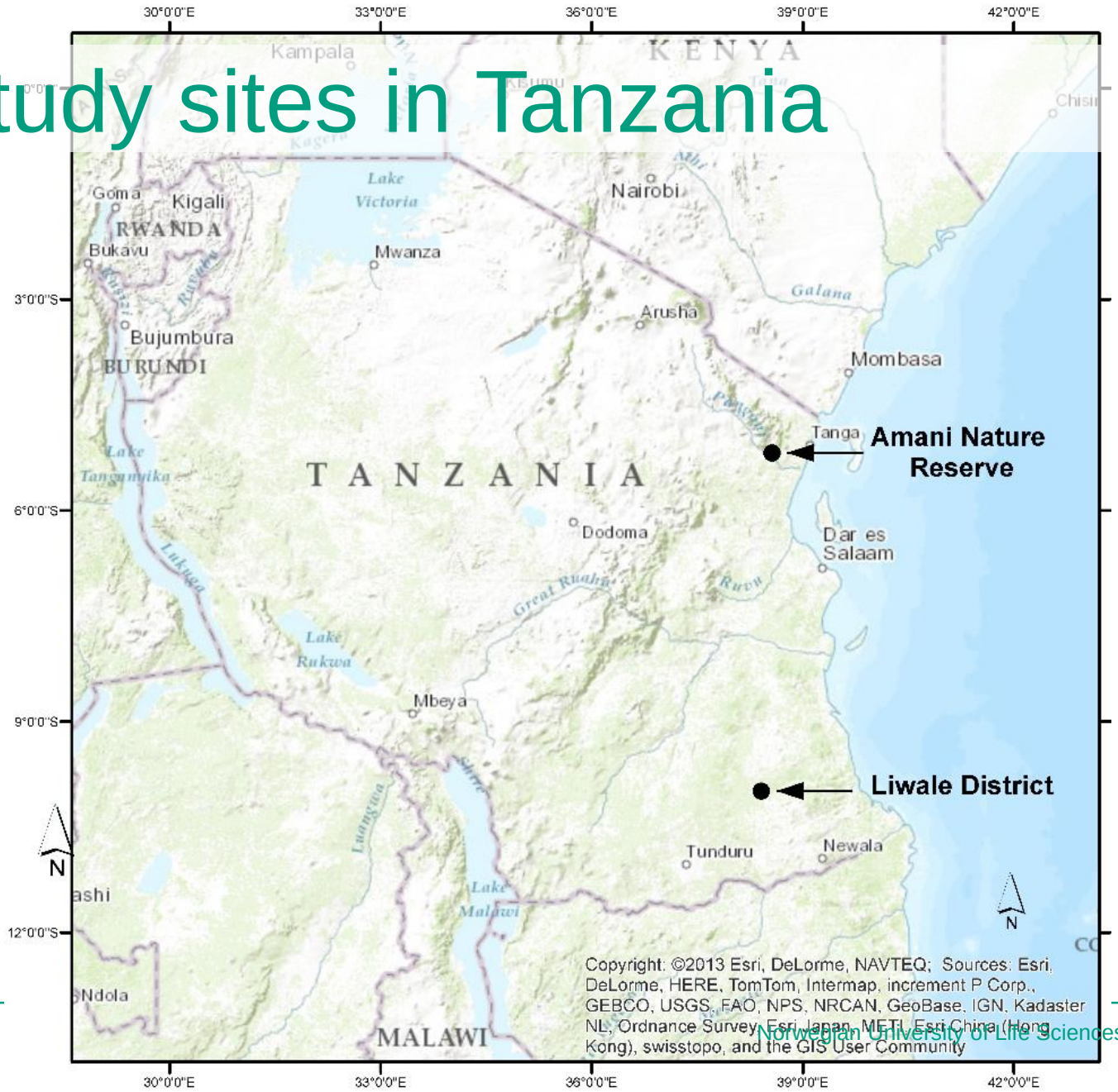


Examples of sample-based LiDAR surveys





Study sites in Tanzania

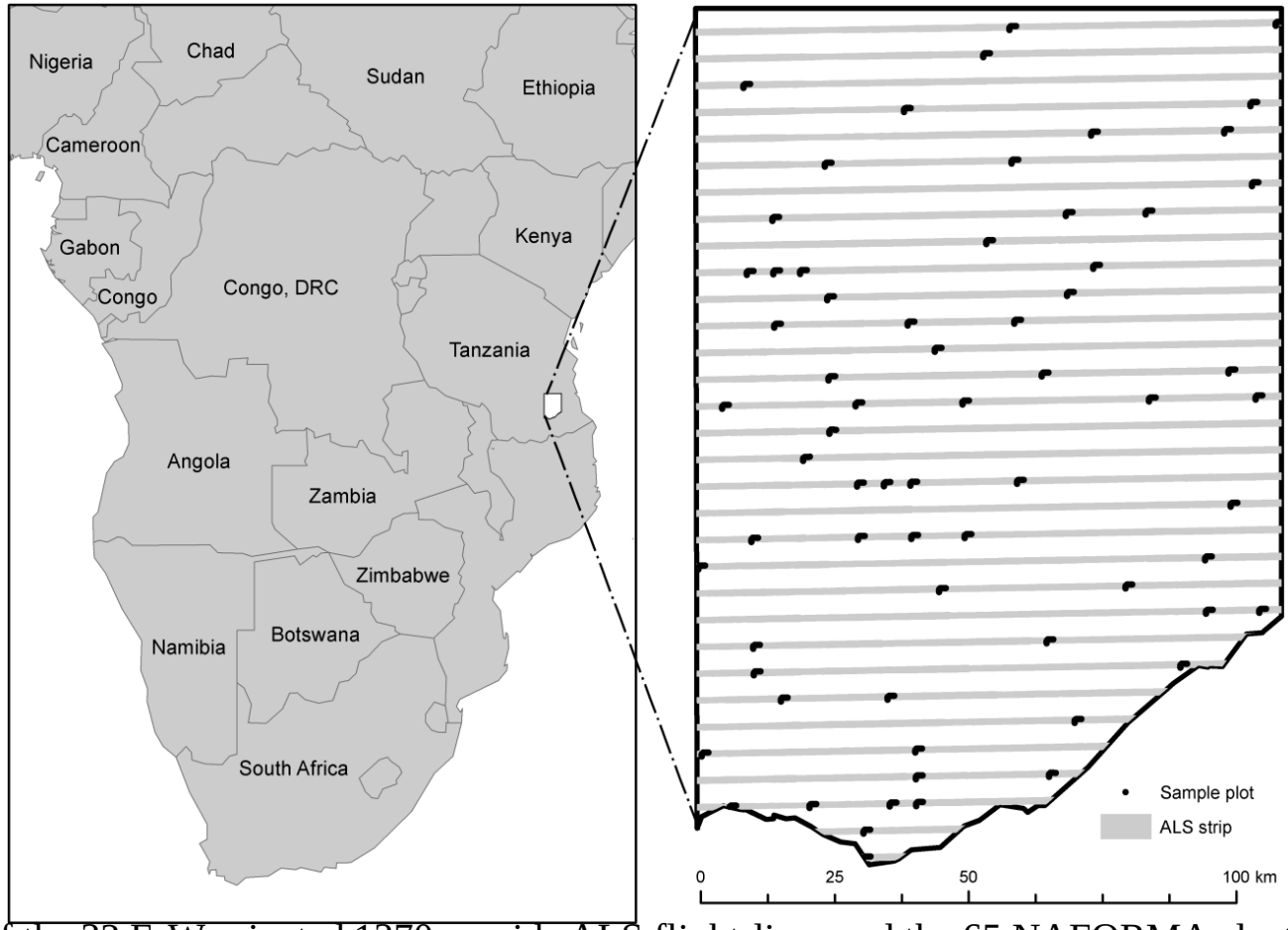


ALS acquisition in Tanzania

The ALS contract

- Procurement following standard EU regulations (Jan. - Sept. 2011)
- 13 companies pre-qualified (African and European)
- 3 invited to negotiations (price, technical solution)
  - All were Scandinavian companies
  - Prices differed by almost 2X
- Final contract (Liwale): ca 3 M NOK (ca 500 NOK km^{-1})
- Flights in 2012 and 2014.

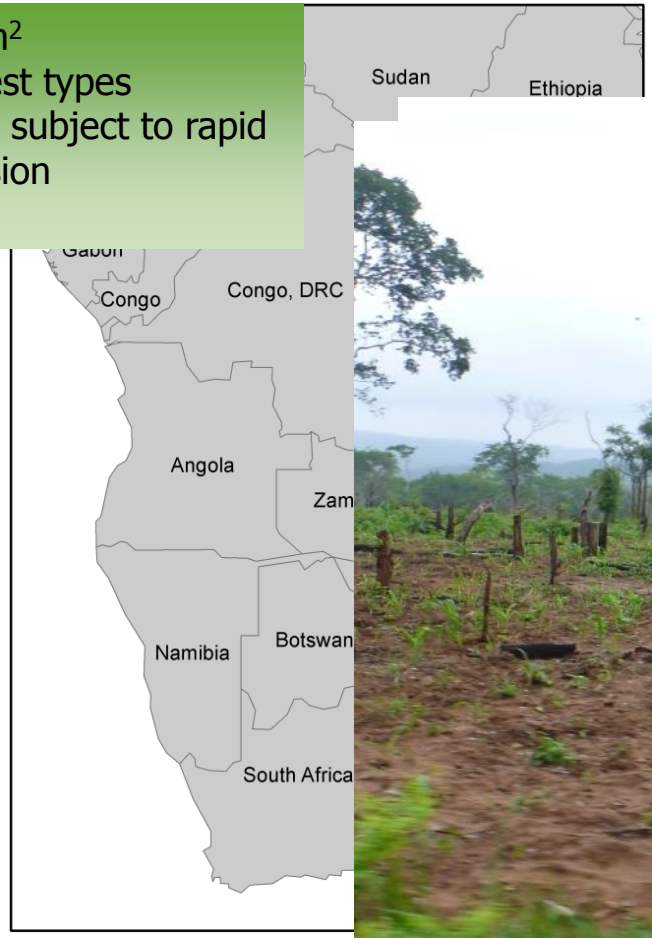
ALS sampling in Tanzania



Distribution of the 32 E-W oriented 1370 m wide ALS flight-lines and the 65 NAFORMA clusters in Liwale.

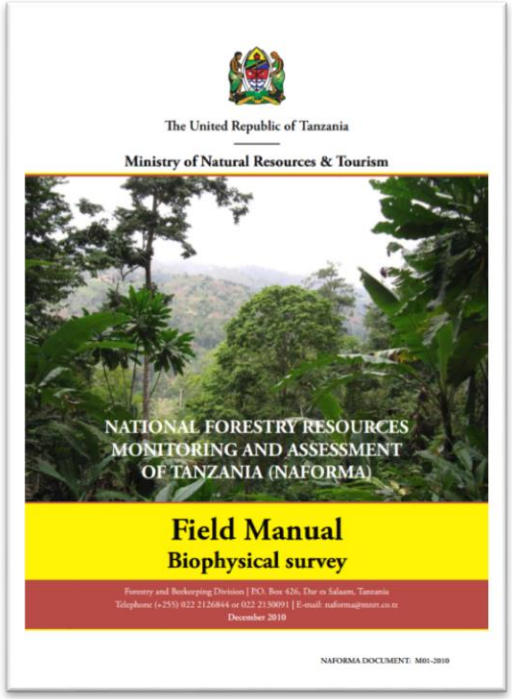
Liwale District

-~16,000 km^2
-Various forest types
-Some areas subject to rapid land conversion



Photos: Endre Hofstad Hansen

Liwale District



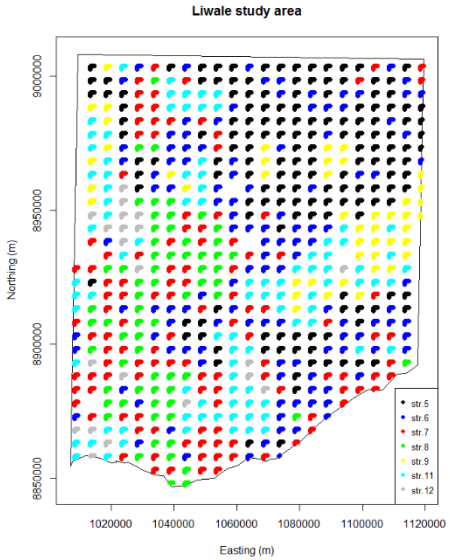
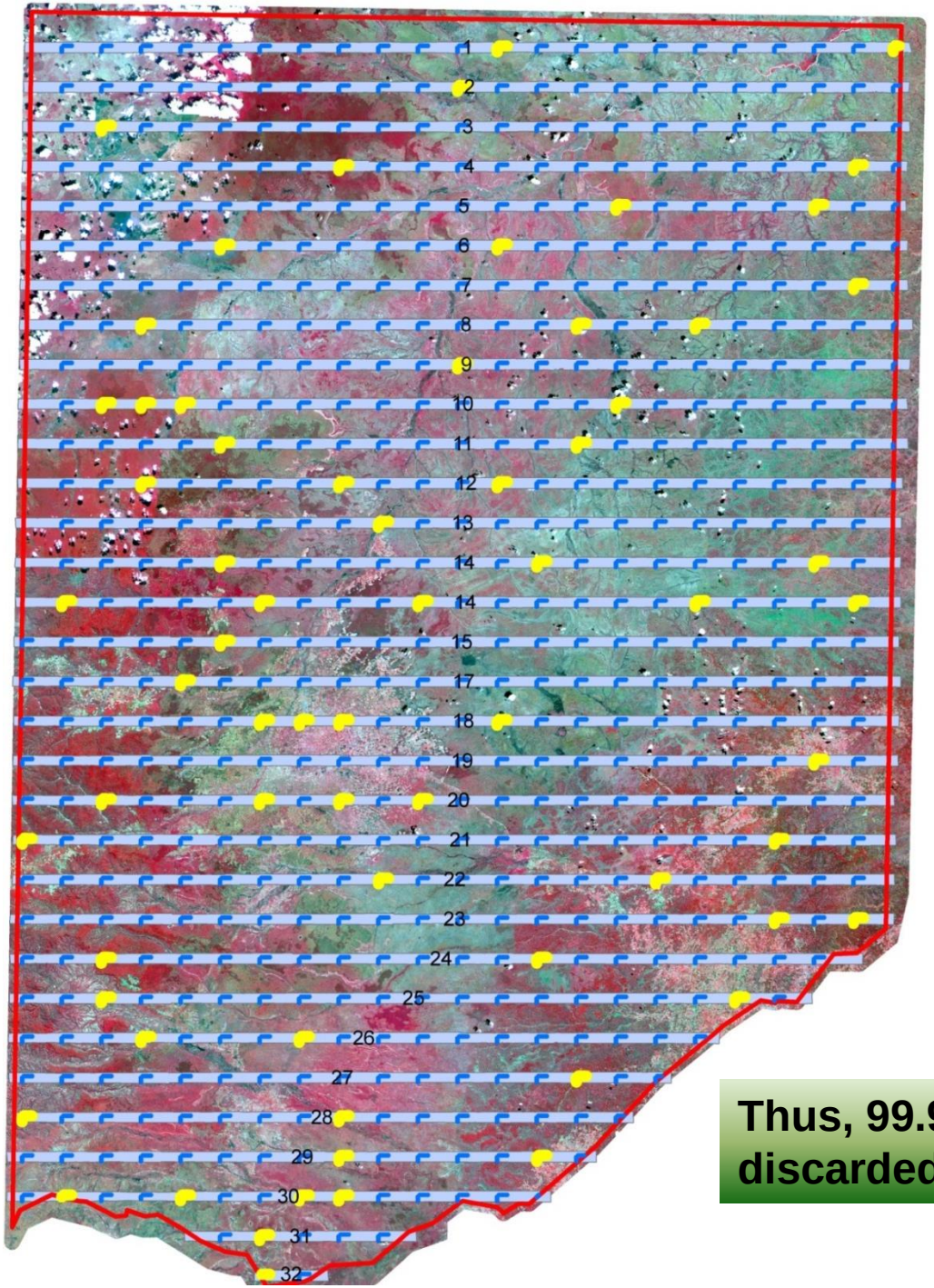


Table 1. Variables employed in composing NAFORMA strata

Strata No.	Time (minutes)	Mean volume on land (m^3/ha)	Slope (%)	Number of plots/cluster	Land area represented (mill. ha)
1	0–480	0–27	0<=10	10	83
2	0–480	27<=61	0<=10		
3	0–480	61<=118	0<=10		
4	0–480	118<–	0<=10		
5	480–960	0–27	0<=10		
6	480–960	27<=61	0<=10		
7	480–960	61<118	0<=10		
8	480–960	118<–	0<=10		
9	>960	0–27	0<=10		
10	>960	27<–61	0<=10		
11	>960	61<–118	0<=10		
12	>960	118<–	0<=10		
13	0–960	0–61	10<=20	8	4.6
14	0–960	61<–	10<=20		
15	>960	0–61	10<=20		
16	>960	61<–	10<=20		
17	0–	0–118	20<=slope	6	0.5
18	0–	118<–	20<=slope		

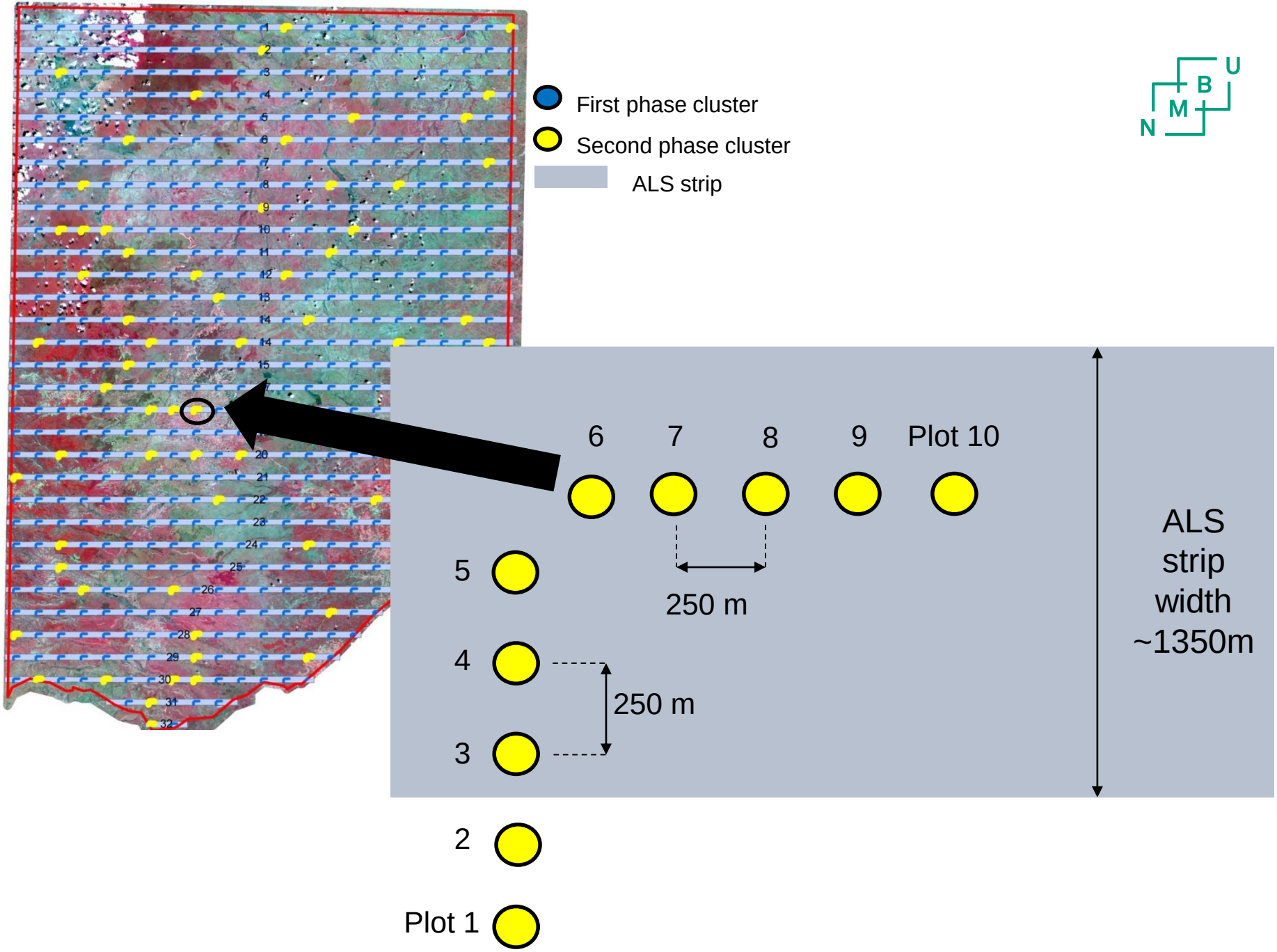


First phase cluster

Second phase cluster

ALS strip

Thus, 99.92% of the ALS data were discarded, in the stratified estimation.


First phase cluster
Second phase cluster
ALS strip
6
7
8
9
Plot 10
5
4
3
2
Plot 1
250 m
250 m
ALS strip width ~1350m

Available data

- 513 NFI field plots (65 clusters)
  - 2012
  - 2014
- Strip sample of ALS data (32 strips)
  - 2012
  - 2014

Objectives:

Calculate the mean biomass, the biomass change and the variance of these estimates.

Compare the estimates and look at cost efficiency

$$= \frac{1}{m}\sum_{h=1}^{H}\sum_{k=1}^{H}\frac{W_h W_k}{\overline{A}_n \overline{A}_k}\frac{\sum_{i=1}^{m}(G_{ih}(\hat{\alpha}) - \hat{R}_h A_{ih})(G_{ik}(\hat{\alpha}) - \hat{R}_k A_{ik})}{m-1} +$$

$$+ \sum_{h=1}^{H}\sum_{k=1}^{H}\frac{W_h W_k}{\overline{A}_h \overline{A}_k}\sum_{j_1}^{p_h}\sum_{j_2}^{p_k} C\hat{o}v(\hat{\alpha}_{j_1 h}, \hat{\alpha}_{j_2 k})\,\hat{\overline{G}}'_{j_1 h}\,\hat{\overline{G}}'_{j_2 k}$$

Photo: Endre Hofstad Hansen

Relative efficiency of remote sensing-assisted estimates of biomass

Relative efficiency:

$$\mathrm{RE} = \frac{\hat{V}_{\mathrm{field}}}{\hat{V}_{\mathrm{RS}}}$$

Under simple random sampling:

n_{field}=RE * n_{RS}

A naive example:

RE=3

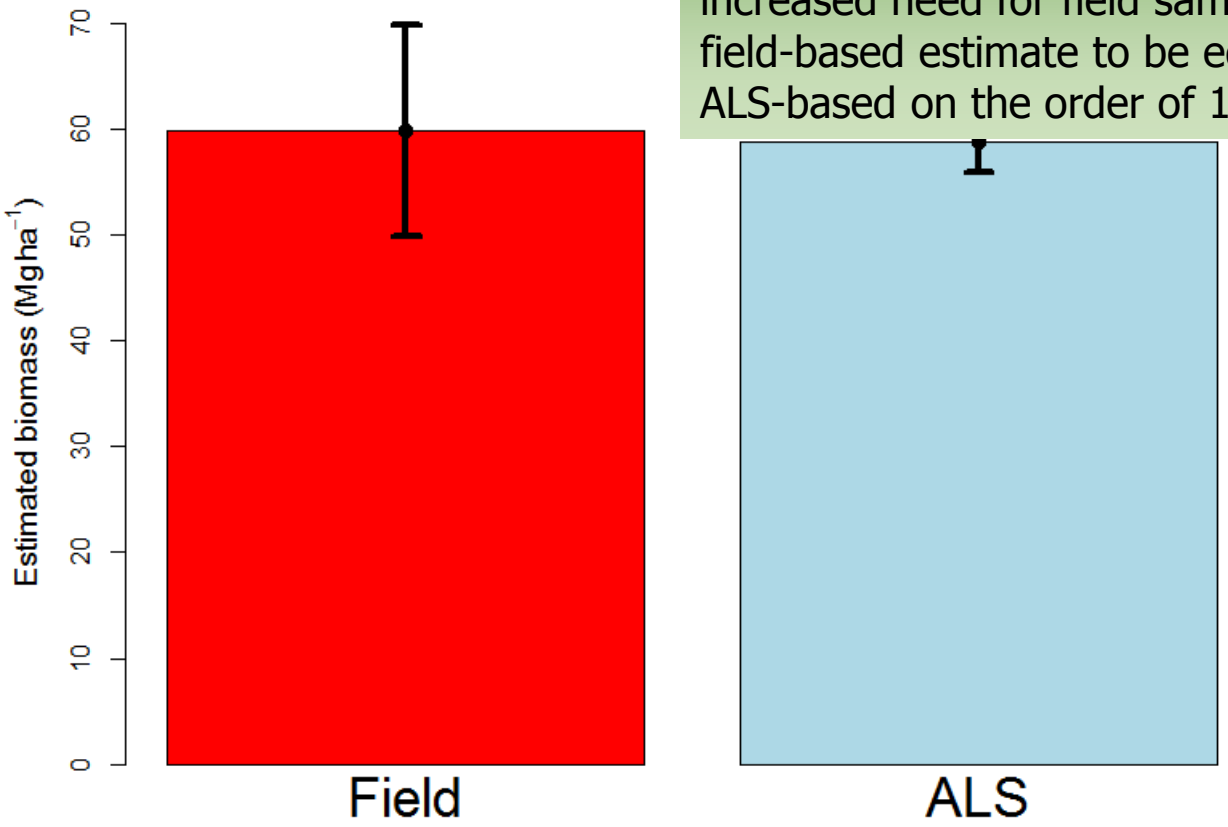
n_{field}=900 field plots

We would need only 300 plots when using remote sensing data to enhance the estimates

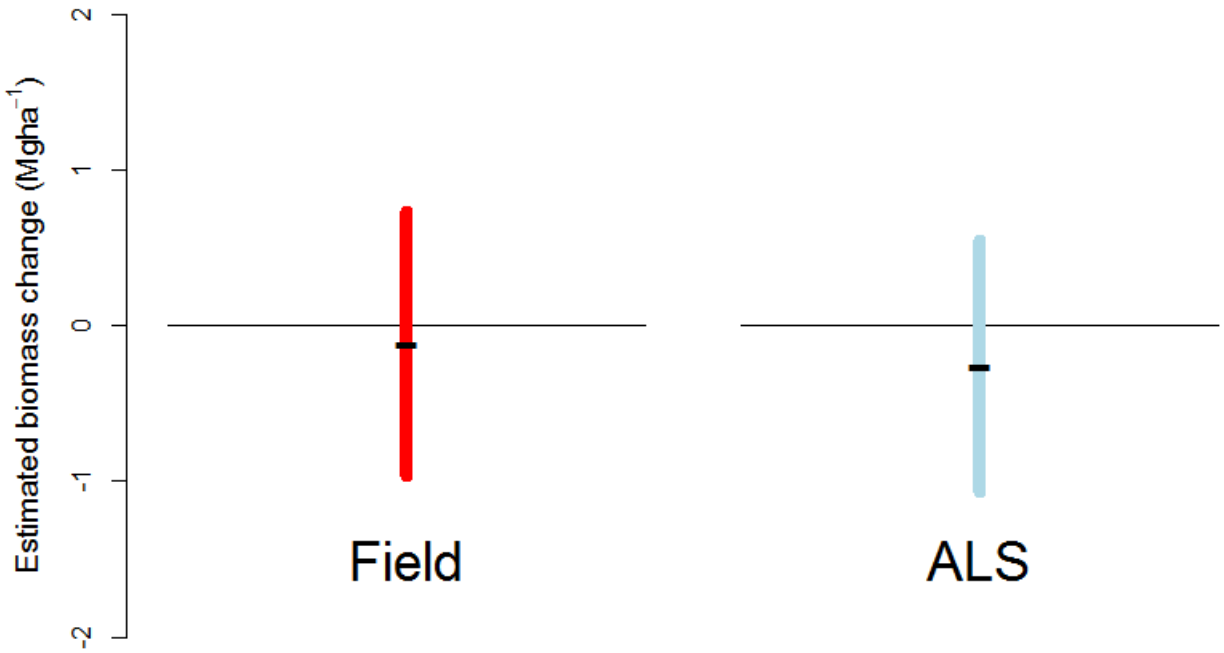
We may compare the costs of 600 plots versus the costs for the remote sensing data

Estimating biomass in 2012

If the design was simple random sampling rather than double sampling, the gain in precision by use of ALS would translate to an increased need for field samples for the pure field-based estimate to be equally precise as the ALS-based on the order of 11.5.



Estimating biomass change from 2012 to 2014

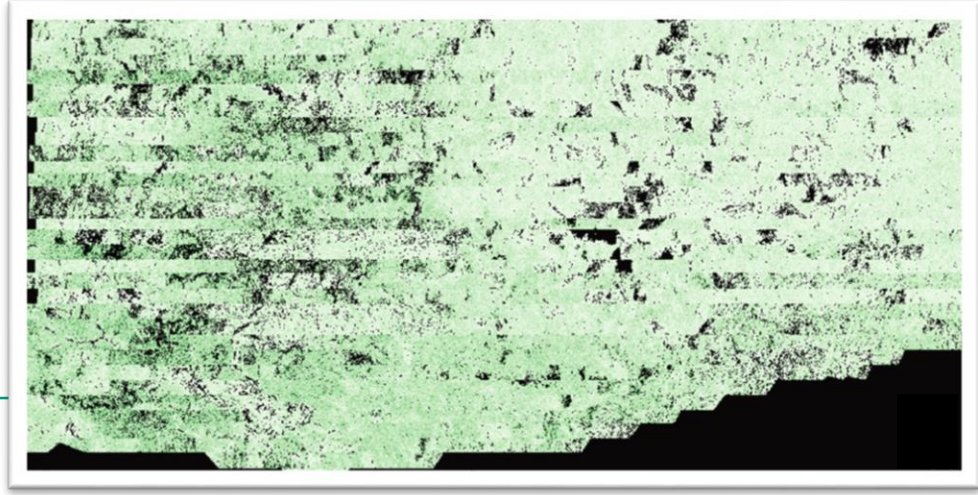


Cost-efficiency of ALS-assisted surveys

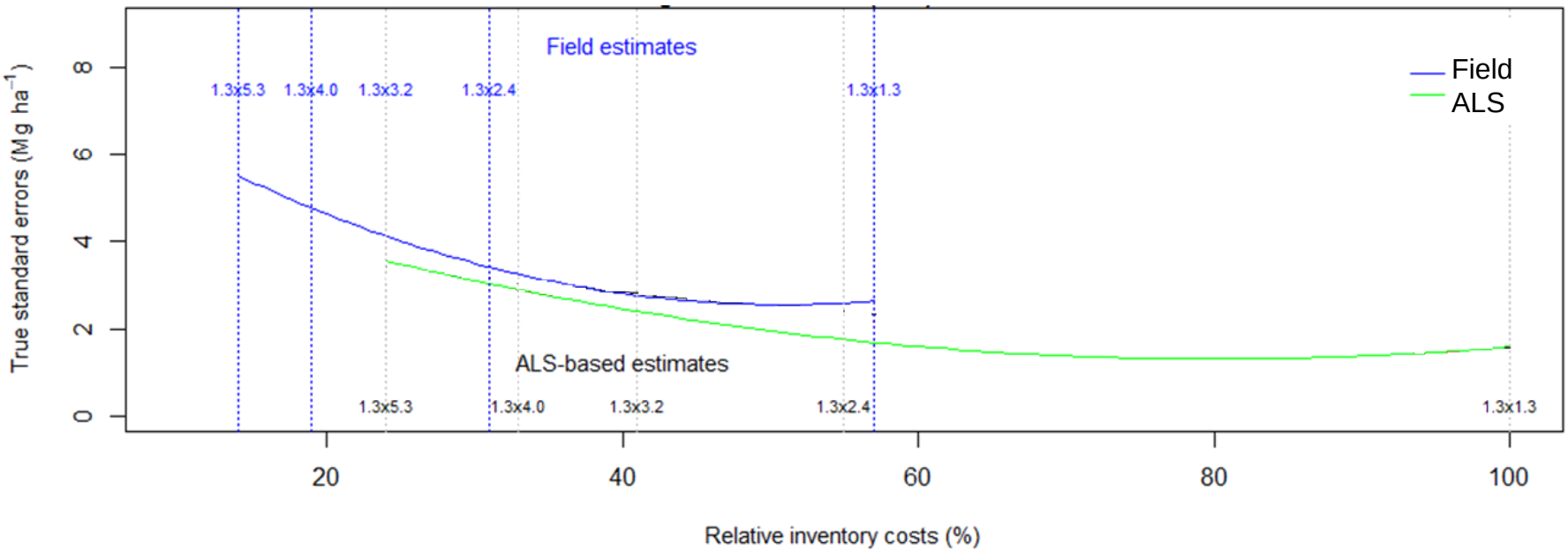
- Different designs and their respective cost-efficiencies may be analyzed by sampling simulations.

- Assumed a cost of 1000 USD per field cluster and 60 USD per strip-kilometer with ALS data.
  - The costs assumed to remain proportional to the original survey

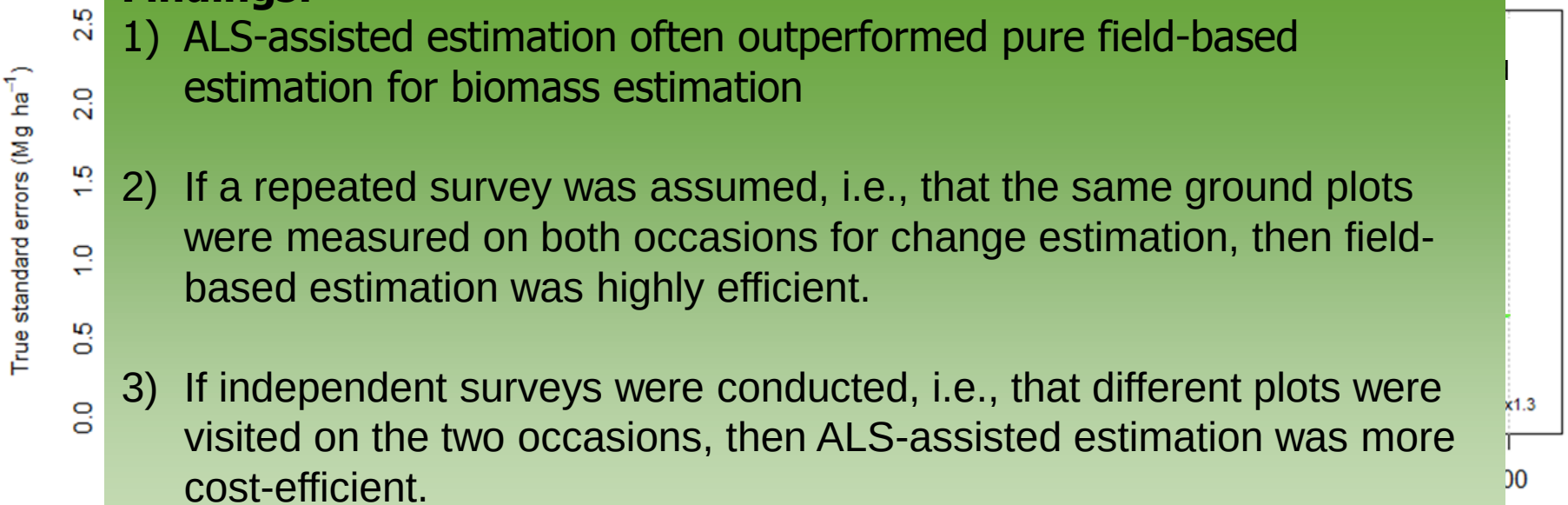
- Artificial population
  - Based on 32 ALS strips



Single time estimation (2012)



Change estimation longitudinal survey



Findings:

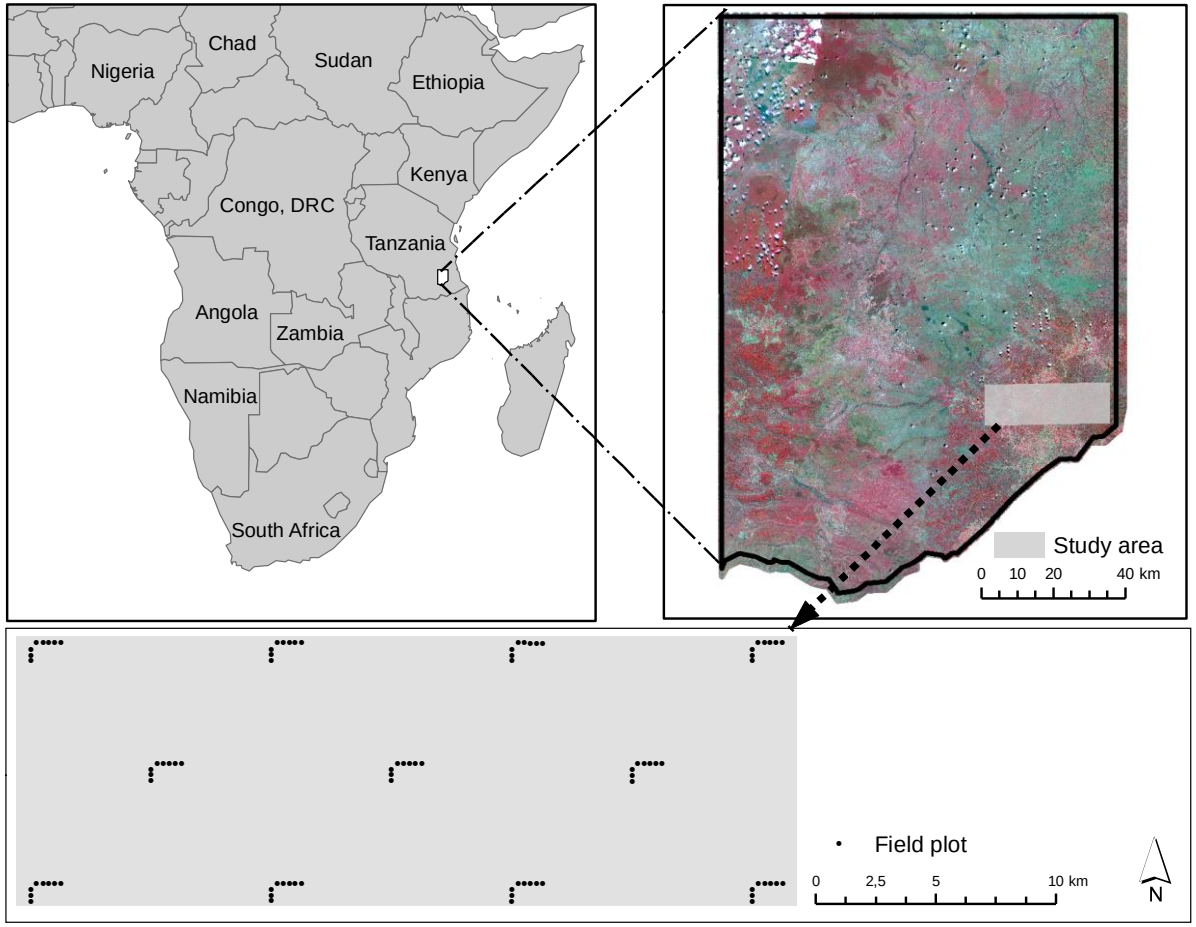
1) ALS-assisted estimation often outperformed pure field-based estimation for biomass estimation

2) If a repeated survey was assumed, i.e., that the same ground plots were measured on both occasions for change estimation, then field-based estimation was highly efficient.

3) If independent surveys were conducted, i.e., that different plots were visited on the two occasions, then ALS-assisted estimation was more cost-efficient.

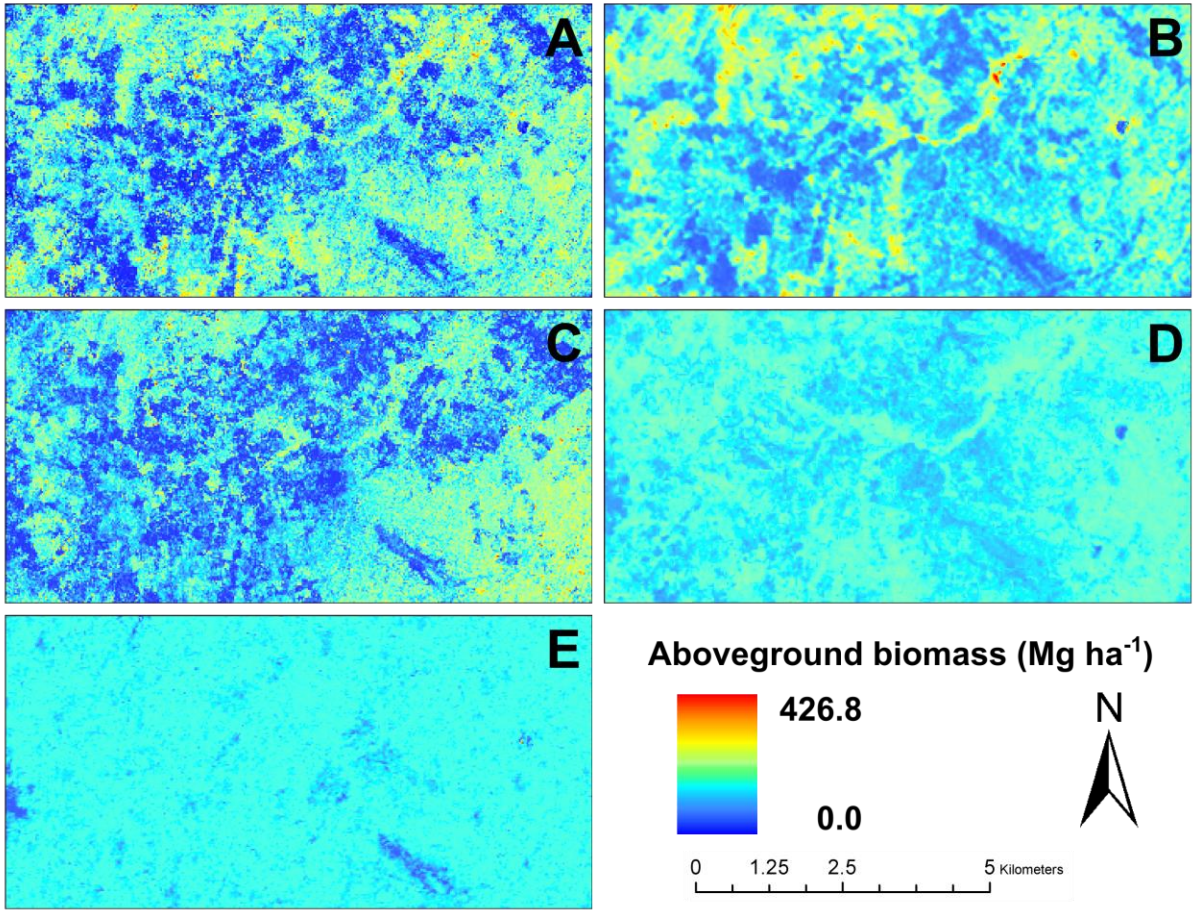
The results are sensitive to changes in cost structure.
It is likely that ALS surveys may have greater potentials for improvements.

Comparison of various remote sensing techniques for biomass estimation



Location of the small 365 km^2 study area within the larger Liwale area.

Biomass estimates



A: ALS

B: InSAR

C: RapidEye

and global forest map products:

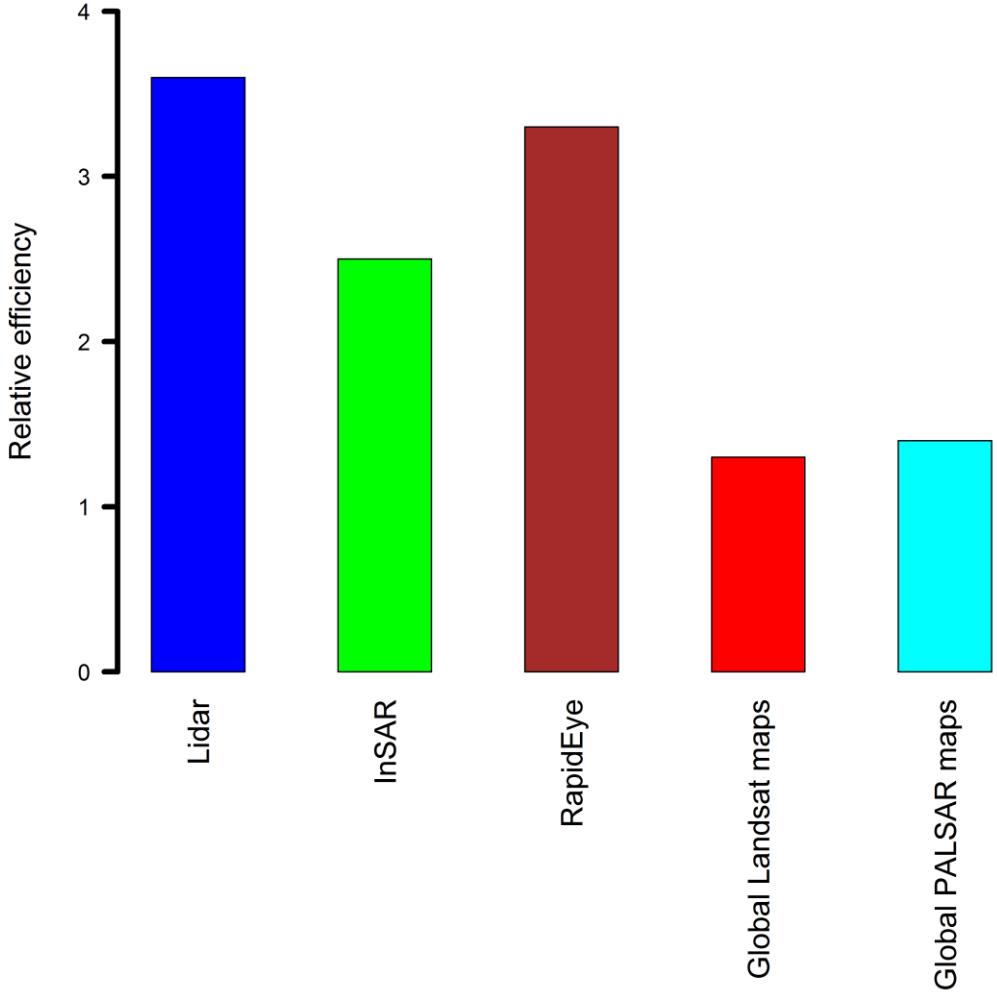
D: Global Landsat maps

E: Global ALOS PALSAR maps.

Biomass maps for a minor part of the 365 km^2 study area based on the five remotely sensed datasets

Biomass estimates

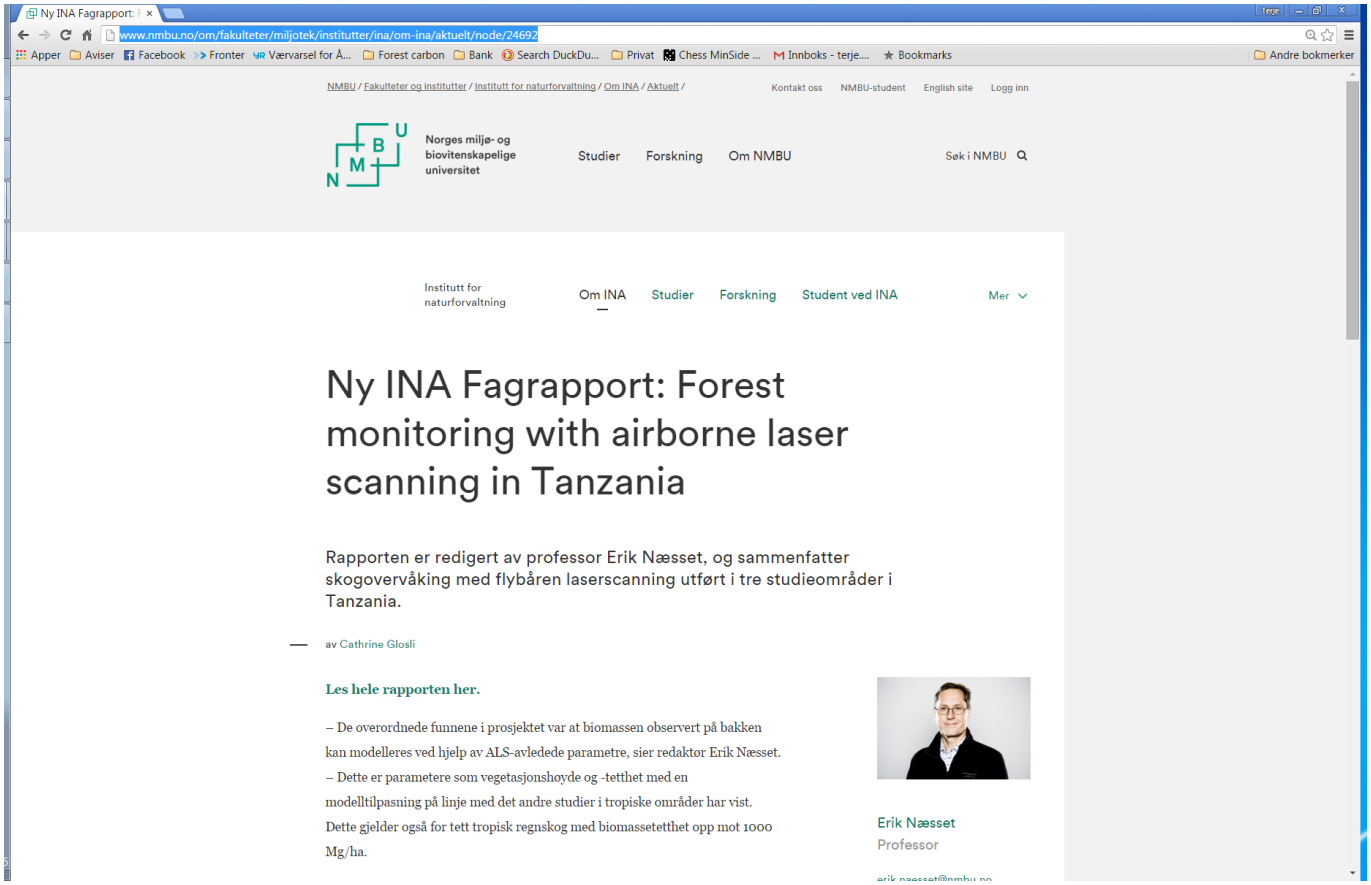
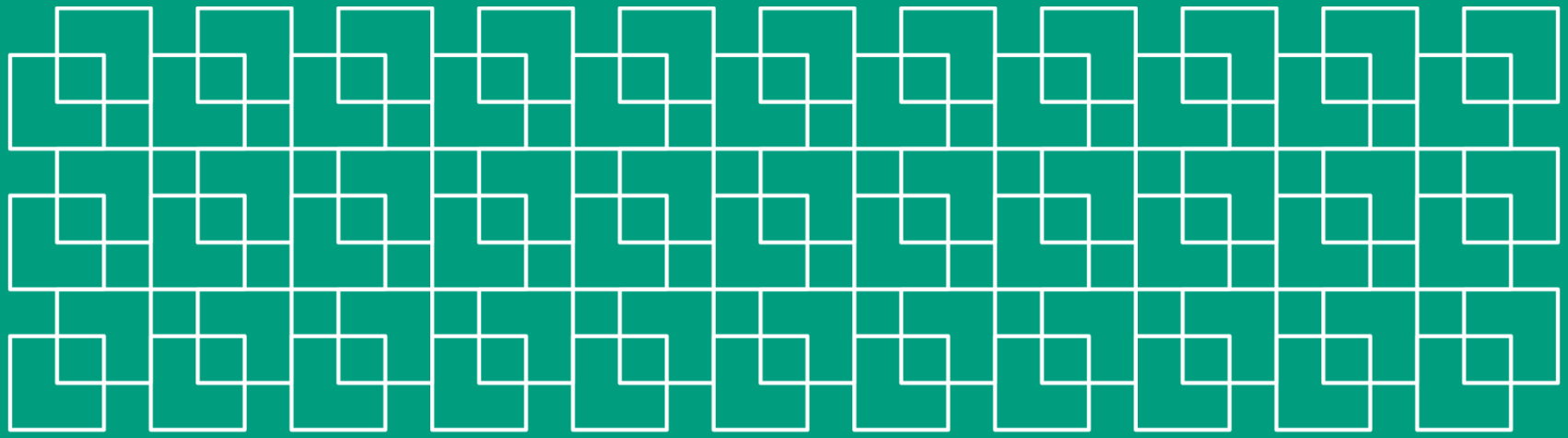
Relative efficiency of remote sensing-assisted estimates of biomass



Concluding remarks

- The studies demonstrate that ALS data can improve precision of biomass estimates beyond what a pure field survey can provide.
- The contribution of ALS data to improve biomass change estimates was moderate, depending on how the samples were collected.
- Cost-efficiency studies are of fundamental importance in assessing different sampling designs and approaches to estimation.
- The design of the NAFORMA field survey is highly efficient for estimation of current resources based on the field data alone, but this design is not the most efficient when used in combination with remotely sensed data.
- A complete-cover stratum map consistent with the stratification in NAFORMA would mitigate this problem and enable improved efficiency of use of all types of remotely sensed data.

INA report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