REPUBLIC OF ESTONIA
ENVIRONMENT AGENCY

ENVIRONMENTALLY CONSCIOUS IN ANY WEATHER

Remote Sensing Solutions for Estonian Forest Monitoring: Forest Boarder Map Development for LULUCF Monitoring and Clear-Cut Detection, Reporting and Verification

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Current situation

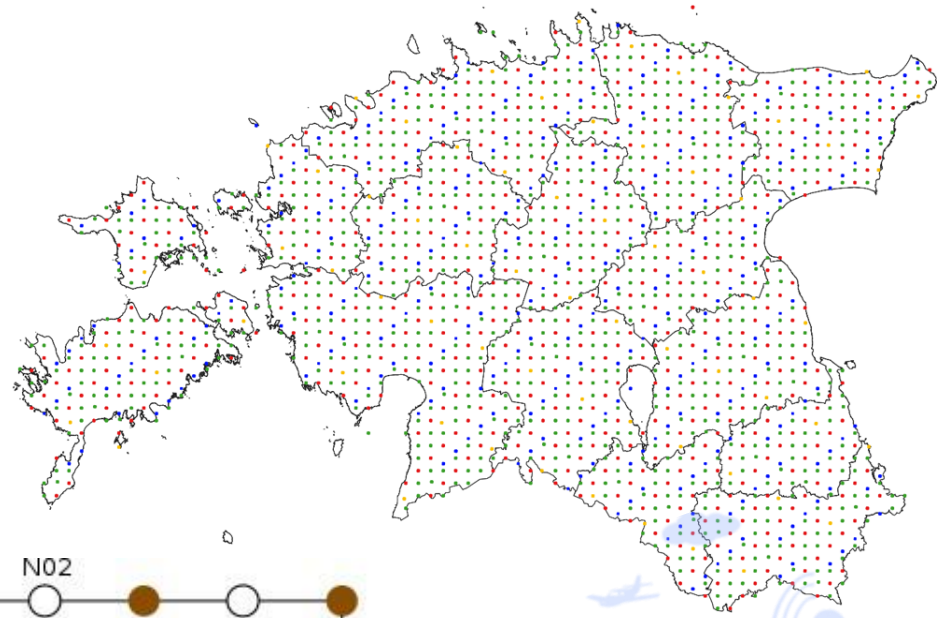
- Most of forestry and LULUCF data is based on plot based NFI

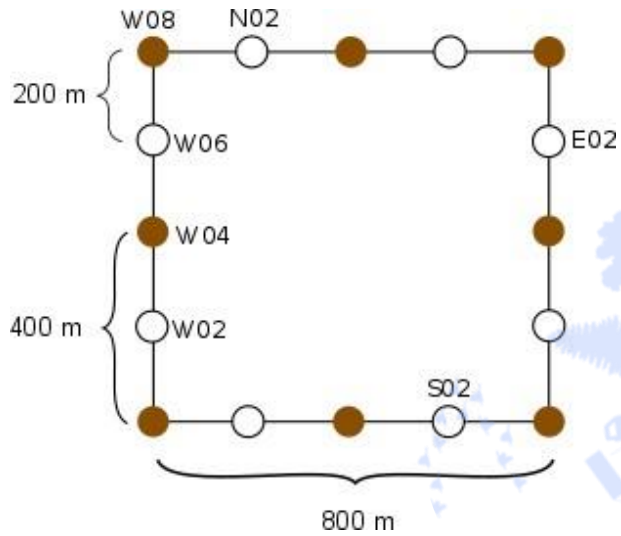
  Note: NFI is spatially explicit!

- In Estonia NFI is the only source for determining forest area based on the Estonian or FRA definition

- The goal of developments should be accuracy

- A large number of one-off pilot remote sensing developments that are impossible to use as a unified system





Forest Border Map Development- Why?

- The definition of forest area varies (FRA, diferent Estonian definitions), which leads to different calculated areas
- We have a layer of wooded areas (ETAK) which is digitized manually from LiDAR data, but it does not fully align with Estonian or international forest definitions
- The goal of developing the forest border map is to identify forest areas according to different definitions using remote sensing data

Forest Border Map Development- Why?

- Forest land is a **land-use** category
- Forest land may be temporarily without trees (after clear-cutting or natural disturbances)
- Woody vegetation (ETAK) is a **land-cover** category
- Not all wooded land qualifies as forest land

Forest Border Map Development- How?

Detecting Forest Land - Estonian University of Life Sciences

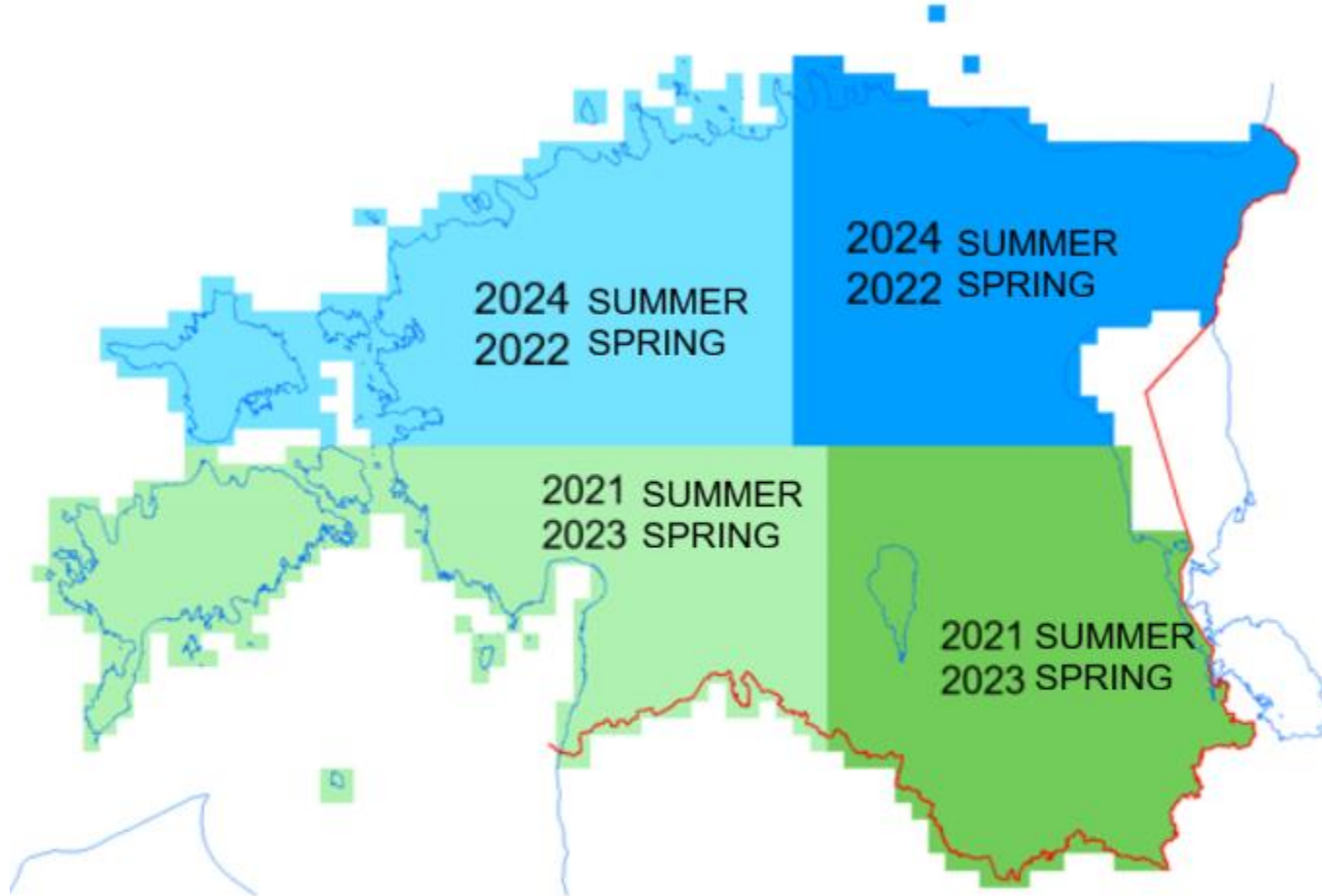
- Annual satellite-imagery based detection: probability of woody vegetation presence from spectral data (Sentinel-2)
- **Problems**: 1) areas temporarily without or with very sparse trees are not classified as forest. 2) a small shift in the forest boundary has a large overall impact
- **Solution**: use of 15 year time-series of LiDAR data and felling and deforestation documentation to refine classification

Airborne Laser Scanner

- Twice a year, ¼ of Estonia is scanned
  - Entire Estonia covered in 2 years – spring + summer
  - Entire Estonia covered in 4 years – spring only or summer only
  - Data density

    2008-2016, Leica ALS50-II with 0.25 p m^{-2}
    2016-2024, Riegl VQ-1560i with 0.8 p m^{-2}
    2025-…, RIEGL VQ-1460 with >1 p m^{-2}

Assumptions: good weather, equipment functioning, **no GPS interference (!!!)**



https://geoportaal.maaamet.ee/est/ruumiandmed/korgusandmed/aerolaserskaneerimise-korguspunktid/als-iv-ring-2021-2024-p855.html

Forest Mask Development- How?

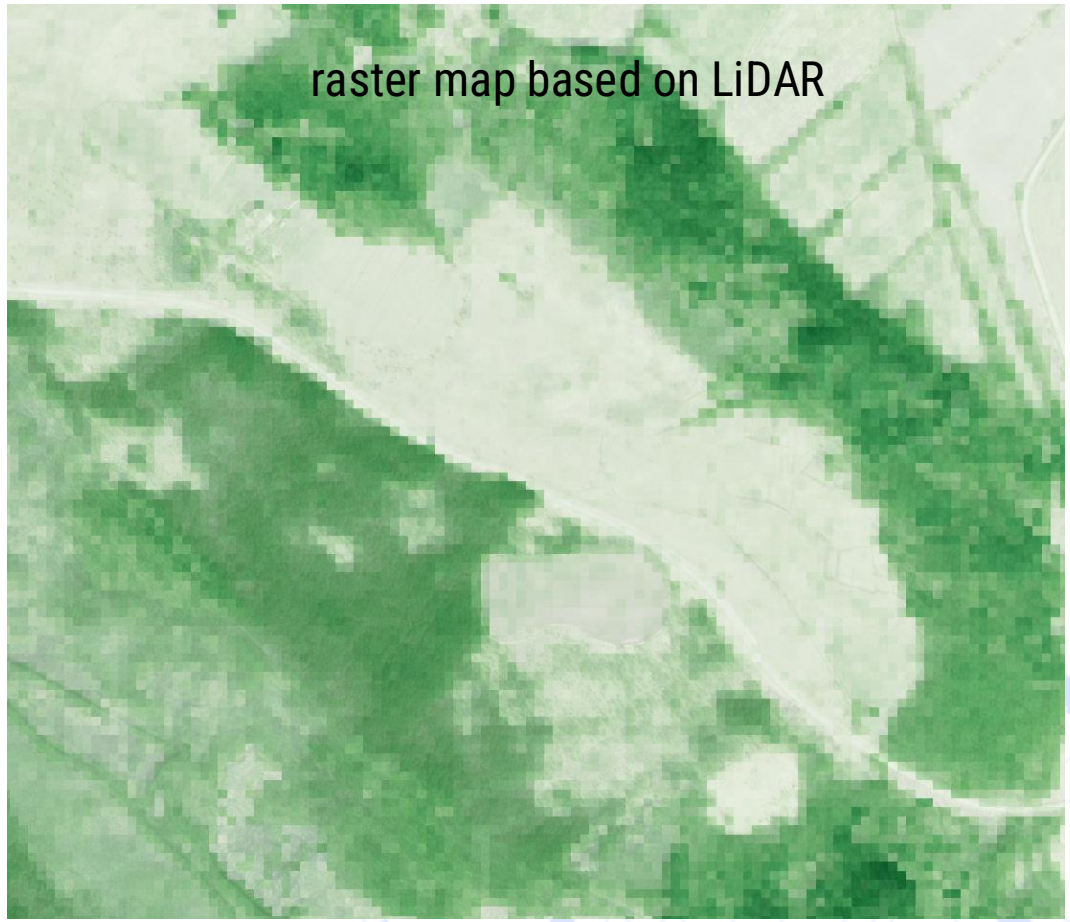
Detecting Forest (from LiDAR)

Forest is identified based on tree height and canopy cover

Problems:

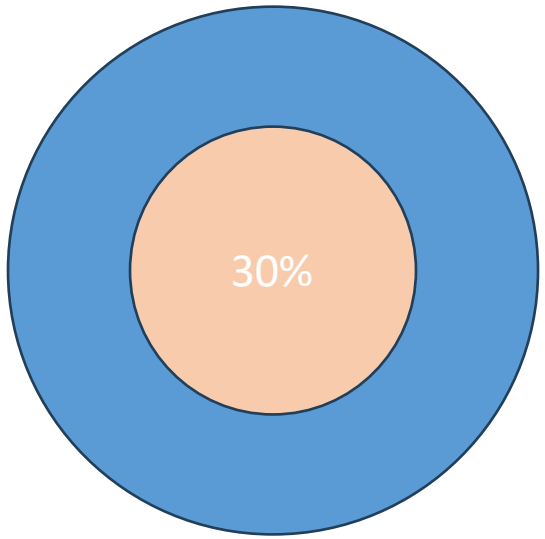
- Gaps in forests not classified
- Sparse stands leave unclassified spaces between trees
- Buffering enlarges total forest area incorrectly

Solution: pixel-to-pixel triangulation within a 25 m radius to fill gaps up to 1 pixel wide. Roads mistakenly classified as forest are later excluded.
Additionally, pixels can be filtered by canopy cover before triangulation to align with different forest definitions

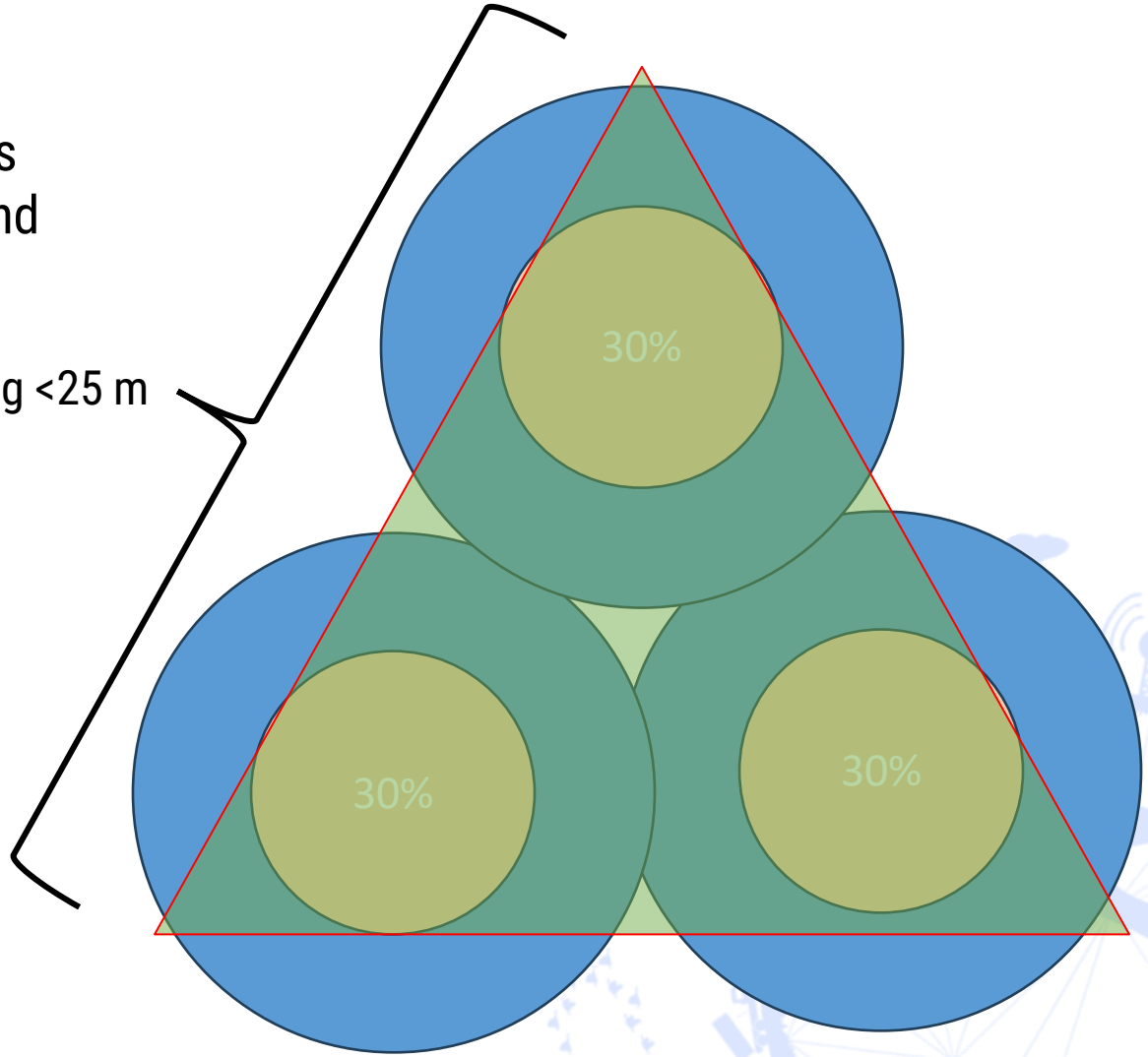


Triangulation

Forest should be defined as the area between trees (transparent green), not as individual buffers around each tree (blue)



5x5 pixel spacing <25 m



Triangulation

- Pixels with canopy cover above a given threshold (e.g. 30%) are selected

- Triangulation is performed between these points (grey lines)

- Polygons which length of the side does not exceed the distance between two pixels (<25 m) are classified as forest land

- Additional intra-pixel distribution is performed using LiDAR (red grid border in the figure)

Forest Border Map Usage

- Updated yearly (including the longest possible timeline back in time)
- Input to the LULUCF land use calculations
- Digital forest variable maps
  - Height
  - Volume
  - …
- Calculation of NFI estimates using the map
- Forest area based on Estonian and international definitions
- etc

Other

- wetlands
- croplands
- grasslands

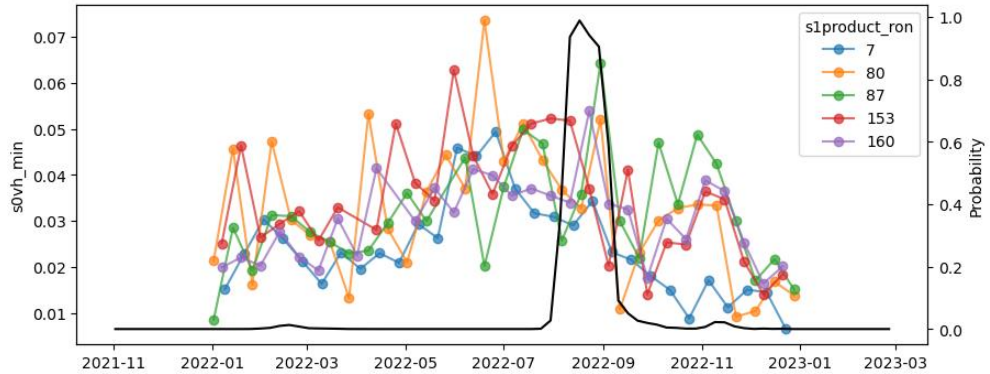
Operational felling assessment

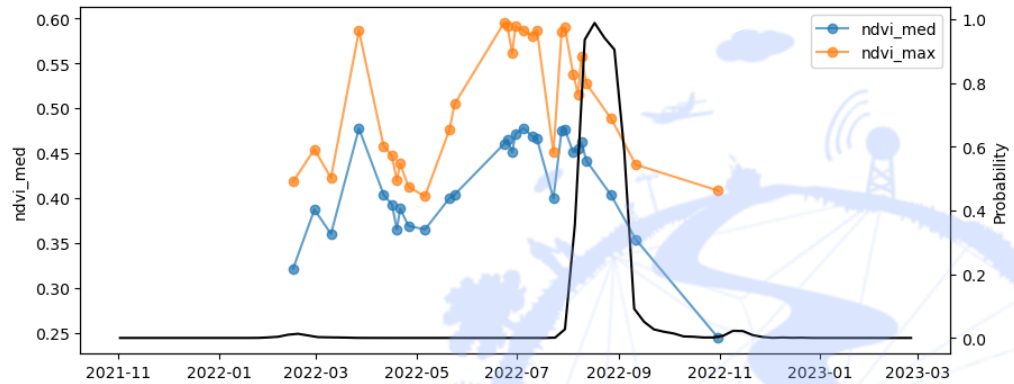
Why do we need operational felling information?

- **Support for permits** – The Environmental Board needs timely data when issuing felling notices (in private land)
- **Nationwide overview** – Enables rapid country-wide assessments (≈80% of cuttings are clear-cuts)
- **Damage monitoring** – Provides early information on large-scale forest damages
- **Actual timing for felling activities** – A felling notice is valid for two years, the state has no information if and when the felling actually takes place
- **LULUCF** – input to the gain-loss methodology

Clearcut detection combining Sentinel 1 and Sentinel 2 data

- **Model based on Artificial Neural Networks (1D-CNN architecture)**
- Clear-cut areas can be detected monthly by combining Sentinel-1 and Sentinel-2 data (with longer intervals in winter)
- Training data (clear-cut areas) comes from the State Forest Management Centre (RMK)
- Model detects clear-cuts reliably as small as 0.5 ha (f-score >0.9)
- Development has been done by KappaZeta





Operational felling assessment

- Outputs: shapefiles with both clear-cut and non-clear-cut events, including the time of clear-cut and the probability of occurrence
- Implemented in the EstHub processing environment
- ESTHub is Estonia's national data centre for storing, sharing, and processing Copernicus satellite data, established under the Land and Spatial Development Board. It provides access to Sentinel-1, Sentinel-2, Sentinel-3, and Landsat-8 imagery covering Estonia

KESKKONNAAGENTUUR

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Thank you!