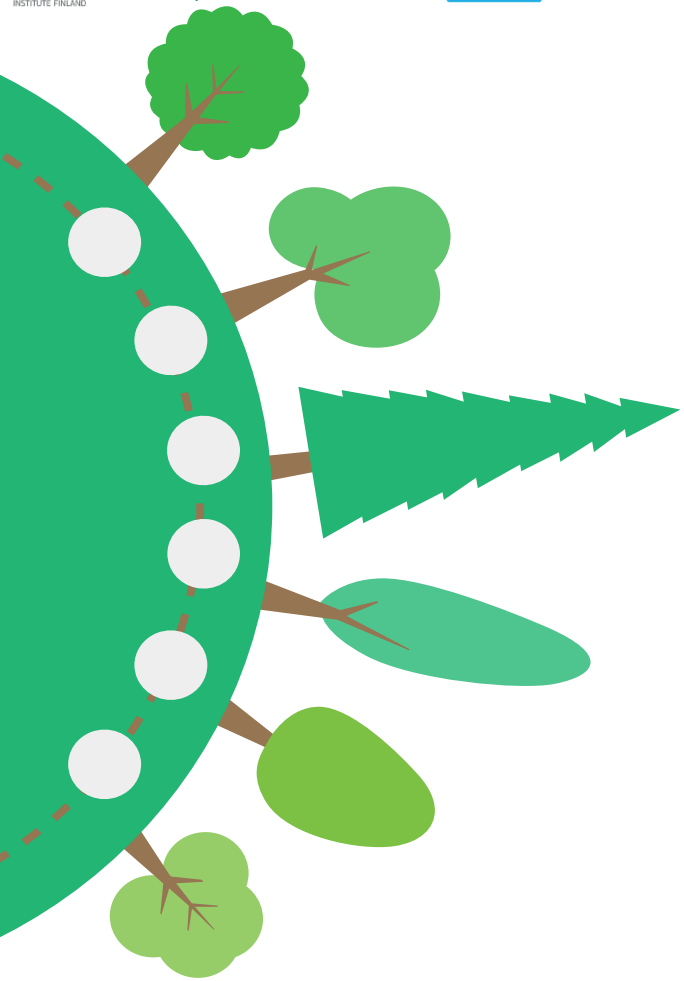

PathFinder

Mapping & Estimation Platform

Presenters:

Mari Myllymäki[1], Jukka Miettinen[2], Ivo Kohn[3] and Alessandro Cescatti[4]

[1]Natural Resources Institute Finland, Finland, [2]VTT Technical Research Centre of Finland, Finland, [3]Czech Forestry Institute, Czechia, [4]EC Joint Research Centre, Italy

PathFinder final conference
Brussels, 16 Jun 2026

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Outline

I

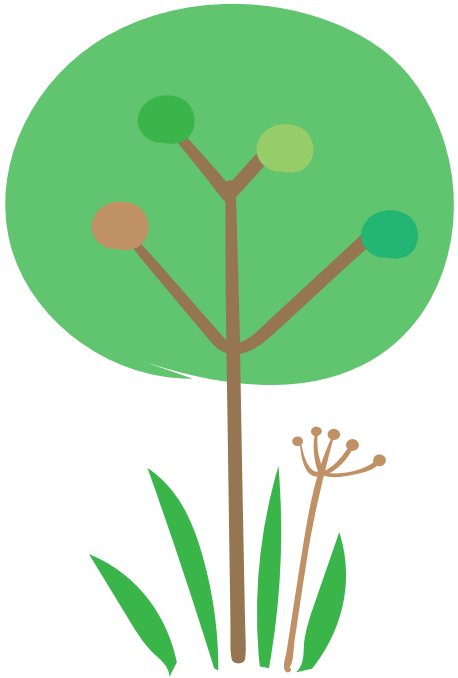
Overview

Role of the mapping & estimation platform in the PathFinder approach

II

Mapping

European wide forest information in 10 m spatial resolution



III

Estimation

Cross-border harmonized estimates based on existing NFIs

IV

EU policy support

Carbon farming baseline and forest area mapping

The research leading to these results has received funding from the European Union Horizon Europe (HORIZON) Research & Innovation programme under the Grant Agreement no. 101056907

Overview

Role of the mapping & estimation platform in the PathFinder approach

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Towards an Integrated Consistent European LULUCF Monitoring and Policy Pathway Assessment Framework

FOREST MONITORING

Surveys

Advanced field work

REMOTE SENSING & MAPS

Estimating

Mapping

Modelling

FORECASTING

Trade-off & synergy analysis

Biogeo-physical climate impacts

Land-use & forestry-management scenarios

POLICY

Co-design of forest management pathways

Climate target assessment

Forest monitoring & governance

The research leading to these results has received funding from the European Union Horizon Europe (HORIZON) Research & Innovation programme under the Grant Agreement no. 101056907. This output reflects only the authors' view, and the European Union cannot be held responsible for any use that may be made of the information contained herein.

For more info:
www.pathfinder-heu.eu

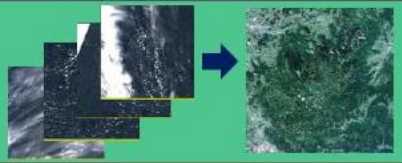
Integrated mapping and estimation concept

- Full description in D2.1 at: https://pathfinder-heu.eu/resources

PathFinder Mapping and Estimation Platform

Data pre-paration

Earth observation (EO) data pre-processing

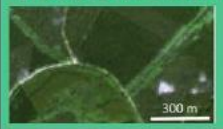


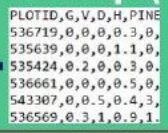
Decentralized field data pre-processing

- Plot level NFI calc.
- EO value extraction
- QC steps

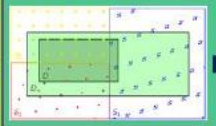
Mapping and estimation

Forest attribute map (10 m) creation





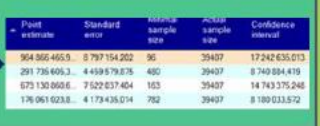
Statistical estimate production



$$\bar{y}_{d,g,sp} = \frac{\hat{t}_{d,g,sp}}{\lambda_{dg}}$$

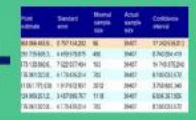
$$\hat{t}_{d,g,sp} = \sum_{k \in s_{2,dg}} \frac{t_{yak}}{\pi_k} = \sum_{k \in s_{2,dg}} a_{qk} t_{yak}$$

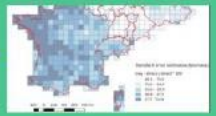
$$t_{yak} = \sum_{i=1}^{M_{ak}} y_{dgpi}$$



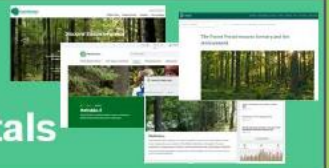
Dissemination and communication

Visualization and distribution of the results





Enable links to FISE and national portals

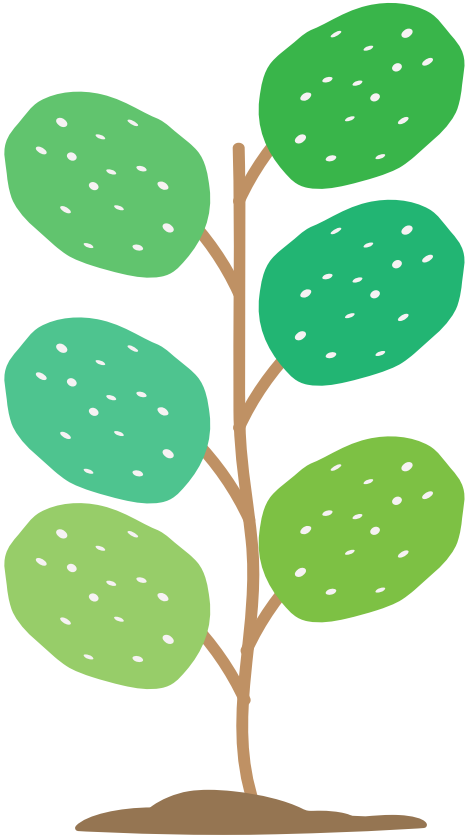


The research leading to these results has received funding from the European Union Horizon Europe (HORIZON) Research & Innovation programme under the Grant Agreement no. 101056907

Why is the integrated mapping and estimation important?

Benefits of the integrated mapping and estimation concept include:

- Maximising the benefits and potential of multisource data (including the long running National Forest Inventories)
- Controlled integration of EO based monitoring into existing reporting procedures
- Harmonized cross-border results throughout Europe
- Consistency of forest information from European to local levels
- Spatially explicit high resolution forest information to support CRCF and other key EU policies



The research leading to these results has received funding from the European Union Horizon Europe (HORIZON) Research & Innovation programme under the Grant Agreement no. 101056907

Mapping

European wide forest information in 10 m spatial resolution

The research leading to these results has received funding from the European Union Horizon Europe (HORIZON) Research & Innovation programme under the Grant Agreement no. 101056907

Mapping specifications in the platform demonstration

Satellite data:

- Sentinel-2 composite (10 m)
- Year 2020 (+2024, 4 layers)

Reference data:

- NFI plots, 6-14 countries, depending on the variable

Auxiliary features used:

- Copernicus 30 m DEM
- CLMS layers
- Chelsa (~1 km, 1981-2010): climatic data
- Maryland tree cover change product

Variables mapped:

- Growing Stock Volume
- Above Ground Biomass
- Conifer proportion (of biomass)
- *Species proportions (of biomass)*:
- Diameter (quadratic mean)
- *Basal area*
- *Height*
- *Gross annual increment (of biomass)*
- *Net annual increment (of biomass)*
- *Deadwood*

1. Betula + Carpinus + Fraxinus
2. Populus and Salix
3. Fagus
4. Quercus
5. Eucalyptus
6. Other_Broadleaf
7. Picea
8. Abies
9. Pinus
10. Other Conifers

PathFinder

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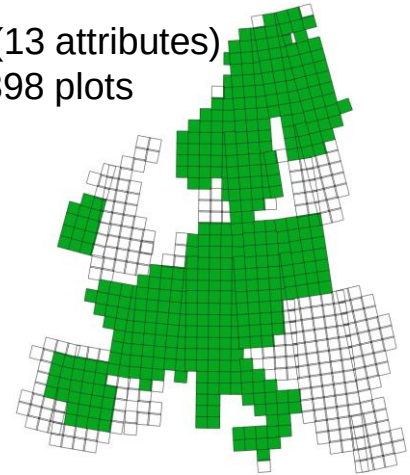
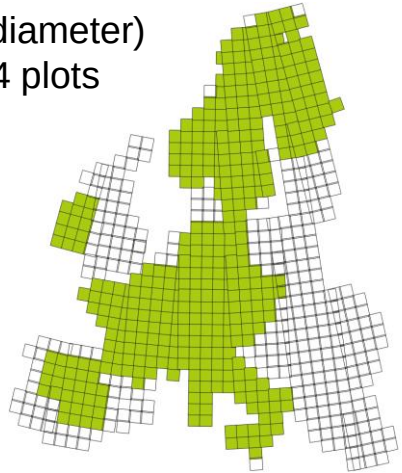
NFI field plot availability by attributes

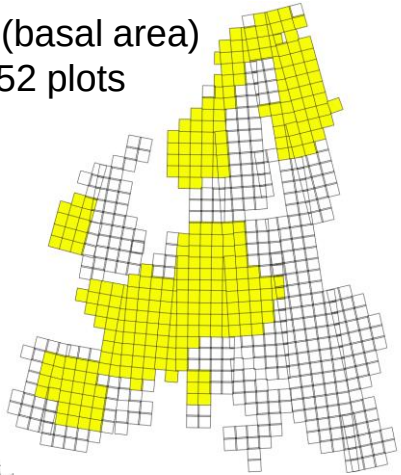
FB1 (13 attributes)
119 398 plots



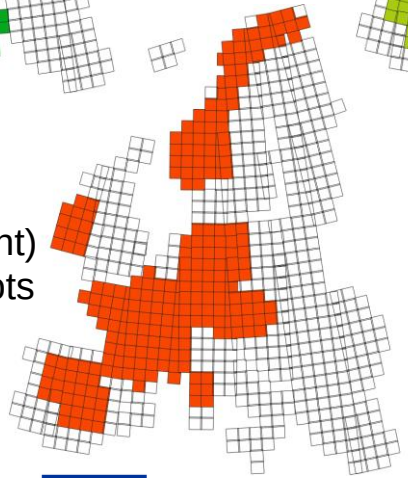
FB2 (diameter)
94 924 plots



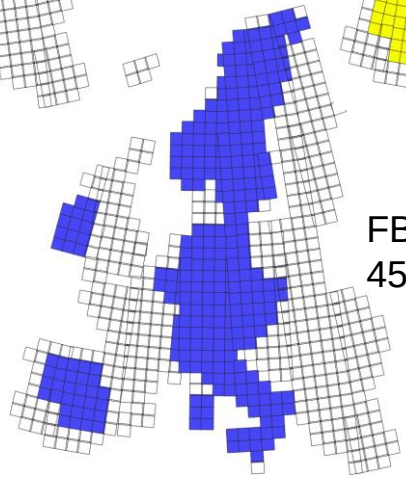
FB3 (basal area)
69 552 plots



FB4 (height)
45 361 plots



FB5 (GAI, NAI)
45 387 plots



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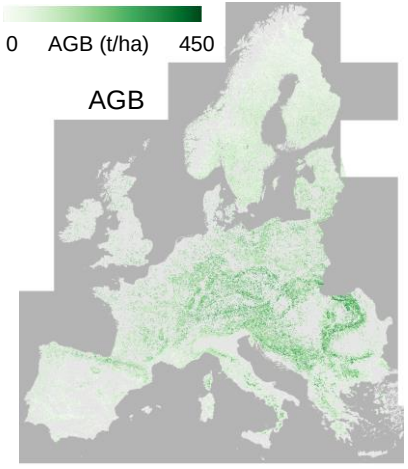
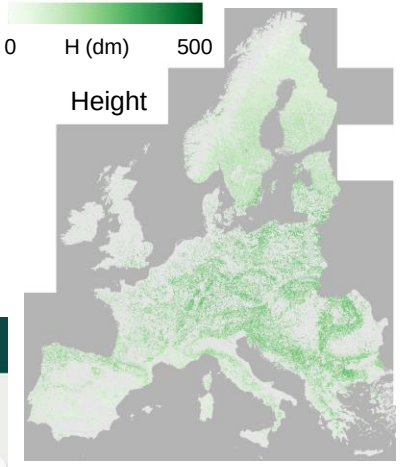
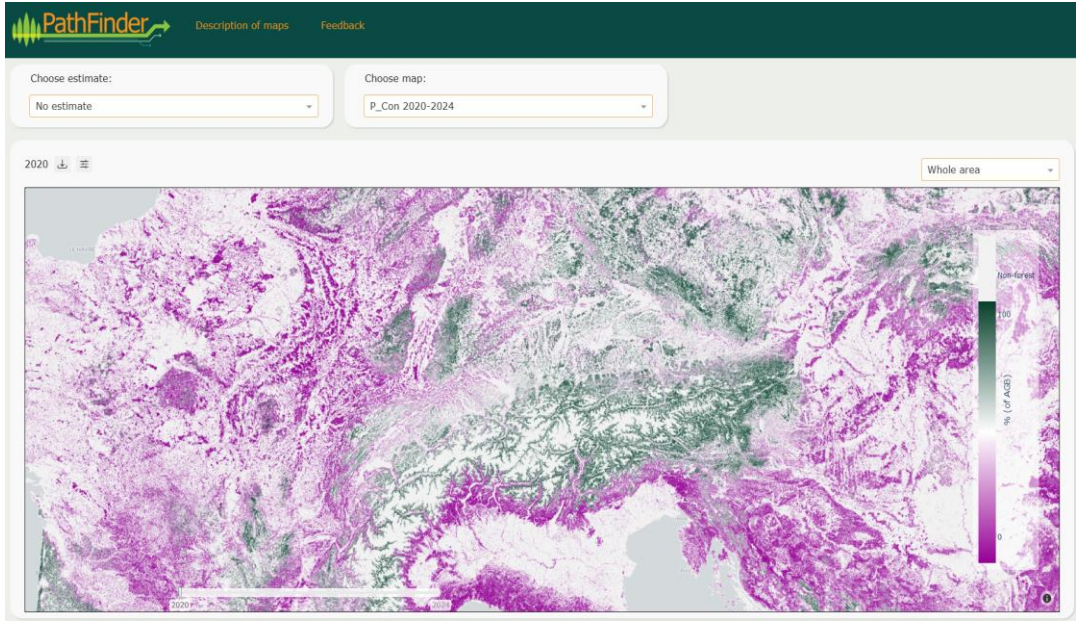
Maps are publicly available

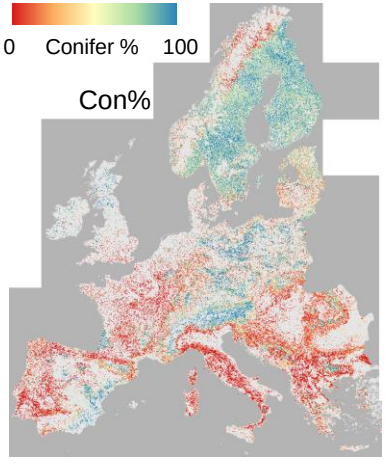


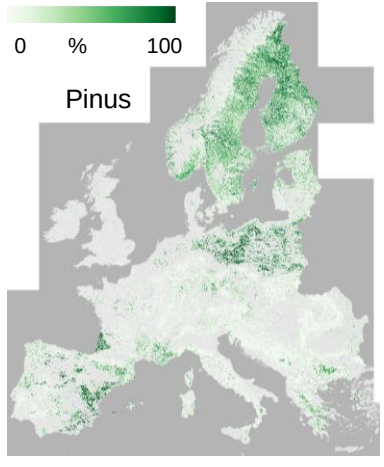
Live demo coming soon…

Visualization and download portal at:
https://portal.pathfinder-heu.eu/









Map accuracy I

- **RMSE and R^2 levels allow operational forest monitoring** (in combination with field plots!).
- **Bias is very small** – one of the benefits of k-NN method.
- **For tree species, these error metrics provide little information** due to the drastically varying (and often low) proportions of the species in a given area.
- Density scatter plots recommended as the most informative source of error information for the species proportion maps.

Error metrics calculated from all NFI plots

Variable	RMSE	RMSE%	Bias	Bias%	R^2
Growing Stock Volume	137.78	69.53	1.57	0.79	0.42
Above Ground Biomass	85.58	67.45	0.82	0.64	0.36
Conifer proportion (of AGB)	23.90	43.00	0.48	0.86	0.69
Quadratic mean diameter	9.43	45.34	-0.09	-0.43	0.31
Basal area	12.11	53.85	0.06	0.27	0.37
Height	49.31	31.23	0.19	0.12	0.63
Betula + Carpinus + Fraxinus	20.57	157.51	-0.25	-1.94	0.30
Populus and Salix	11.75	459.33	-0.37	-14.62	0.13
Fagus	15.11	256.98	-0.02	-0.37	0.41
Quercus	21.01	140.10	0.55	3.65	0.56
Eucalyptus	1.76	3234.64	-0.01	-12.85	0.37
Other_broadleaf	18.85	239.76	-0.37	-4.71	0.22
Picea	22.00	114.39	-0.60	-3.14	0.54
Abies	8.06	484.82	-0.06	-3.68	0.37
Pinus	25.58	78.72	1.20	3.69	0.61
Other conifers	10.50	478.32	-0.05	-2.47	0.23

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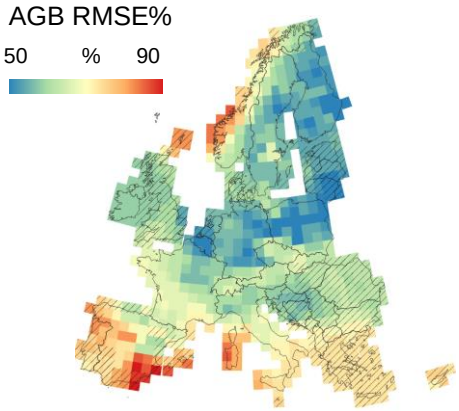
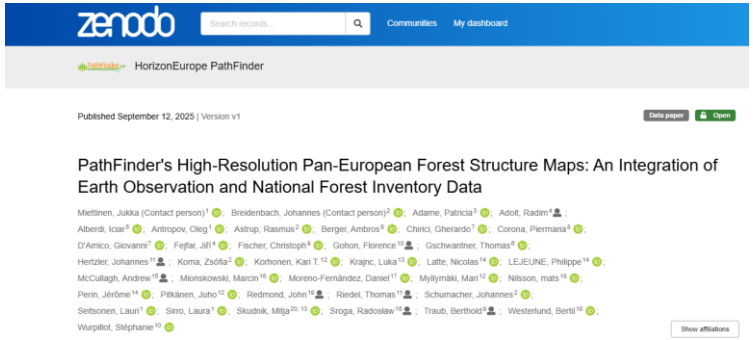
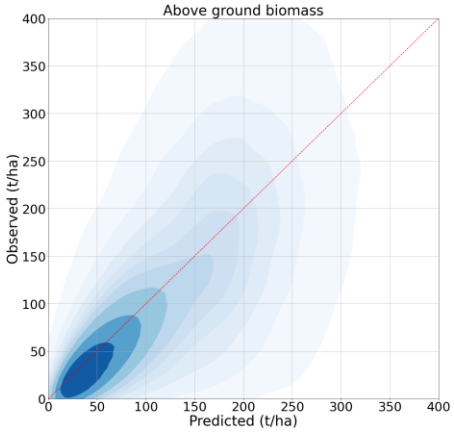
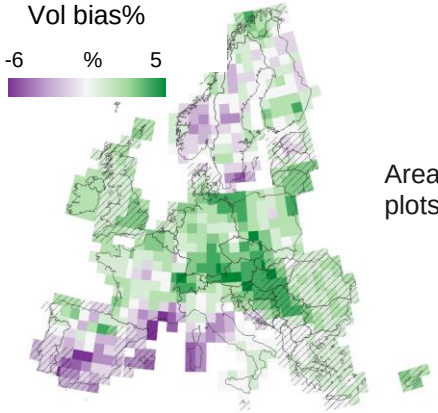
Map accuracy II

Full accuracy details at:
https://doi.org/10.5281/zenodo.17107267

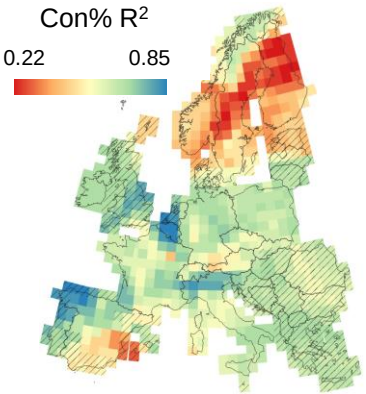


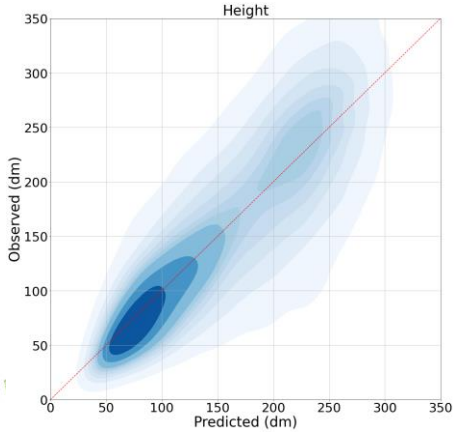


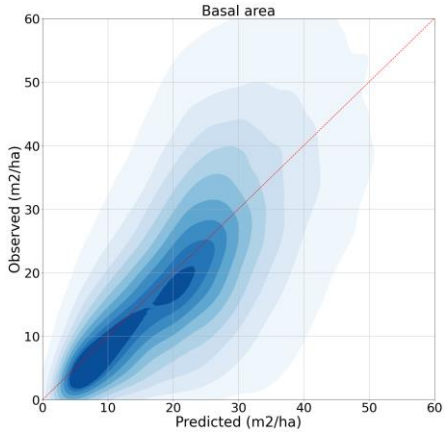




Areas without plots hashed







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Estimation

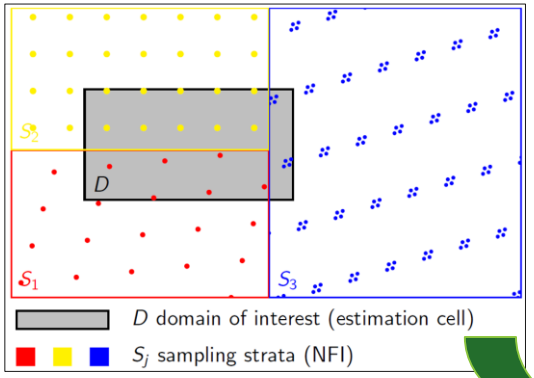
Cross-border harmonized estimates based on existing NFIs

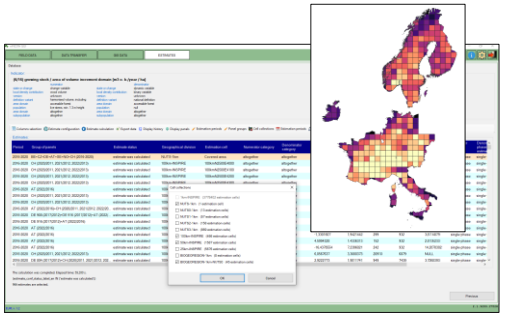
The research leading to these results has received funding from the European Union Horizon Europe (HORIZON) Research & Innovation programme under the Grant Agreement no. 101056907

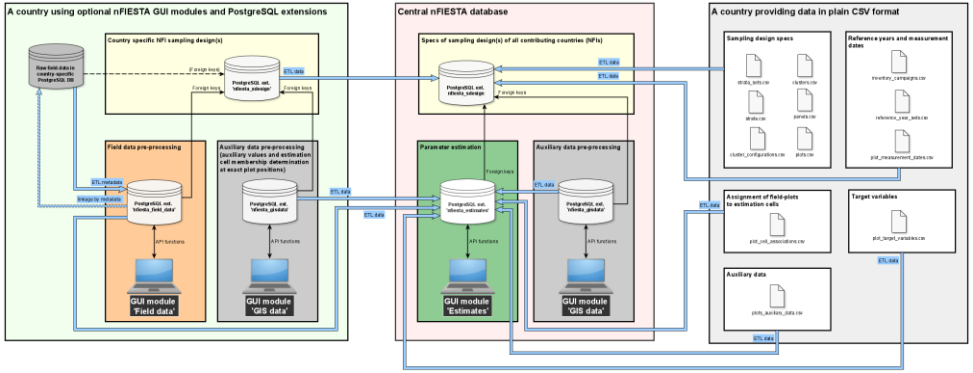
Estimates

nFIESTA = new Forest Inventory, Estimation and Analysis framework

- Developed by Radim Adolt et al. at Czech Forestry Institute (NLI) in DIABOLO, PathFinder and Monifun EU projects (nFIESTA · GitLab).
- Implements NFI best practices of producing forest related information for strategic planning and policy formulation.
- Statistically-sound estimates for **probability samples**, typically NFI data, **which may come from two or more countries using a different sampling designs.**
- Model based-estimates in areas with missing or insufficient field-plot data.







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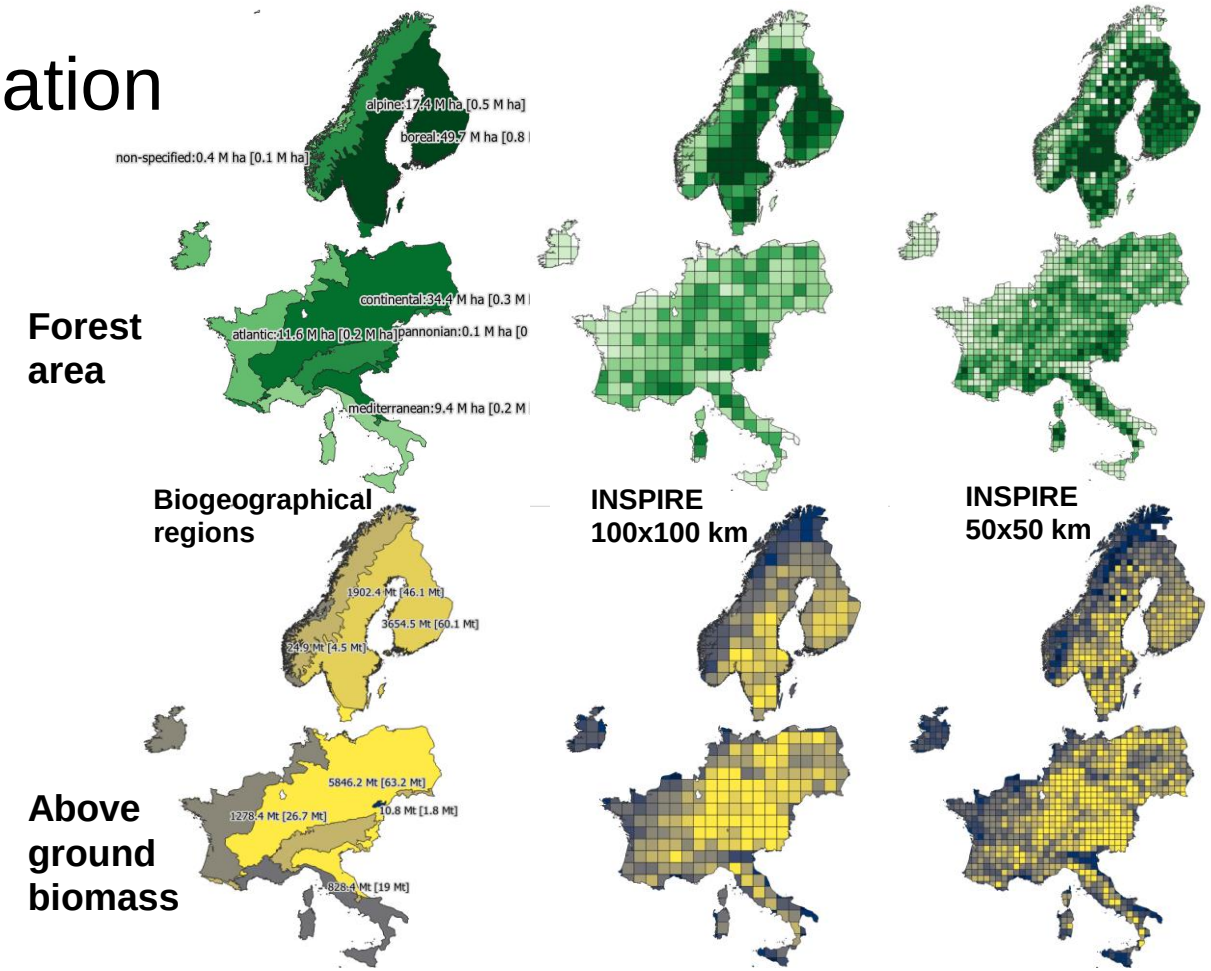
Design based estimation

Harmonized estimates across Europe derived from NFI datasets for:

- Total area
- Biogeographical regions
- INSPIRE cells in various levels (100 km, 50 km…)
- Arbitrary interest areas



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Consistent forest information across all levels

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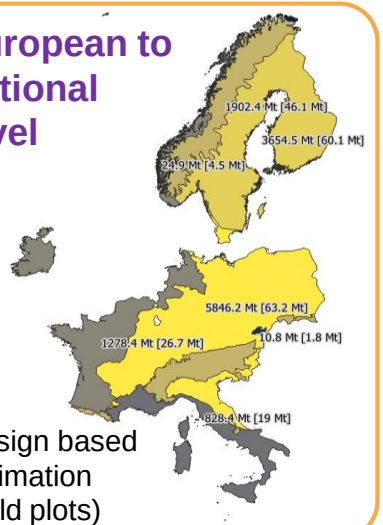
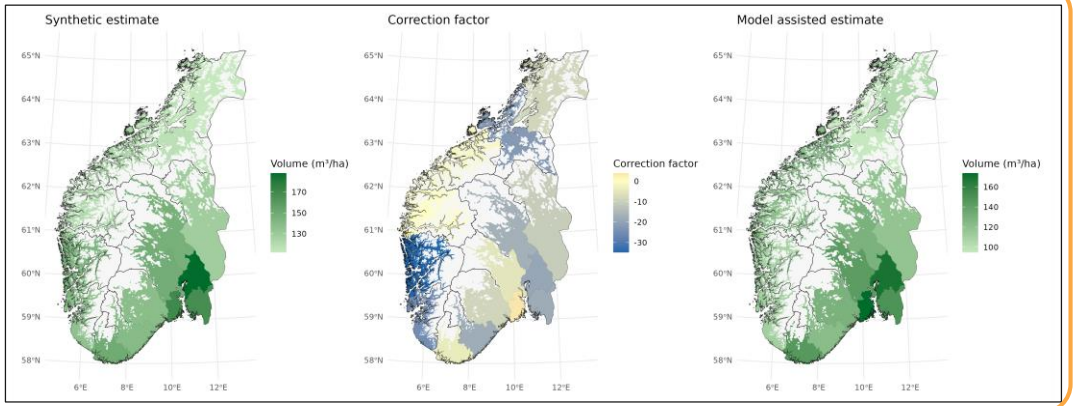
European to national level



Design based estimation (field plots)

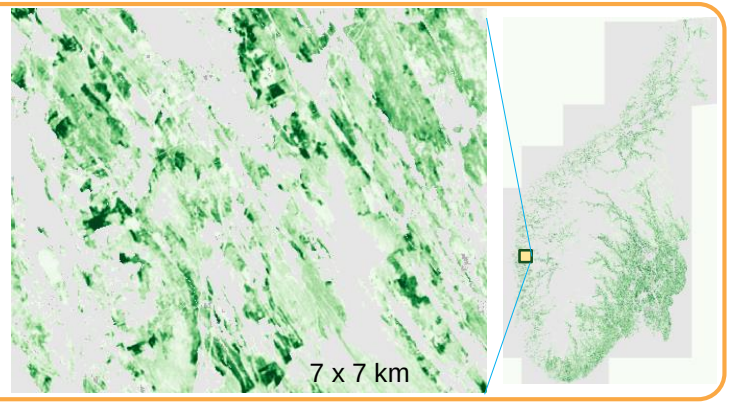
Provincial to municipality level

Model assisted estimation (NFI and maps combined)



Local level

Maps showing distribution in high detail

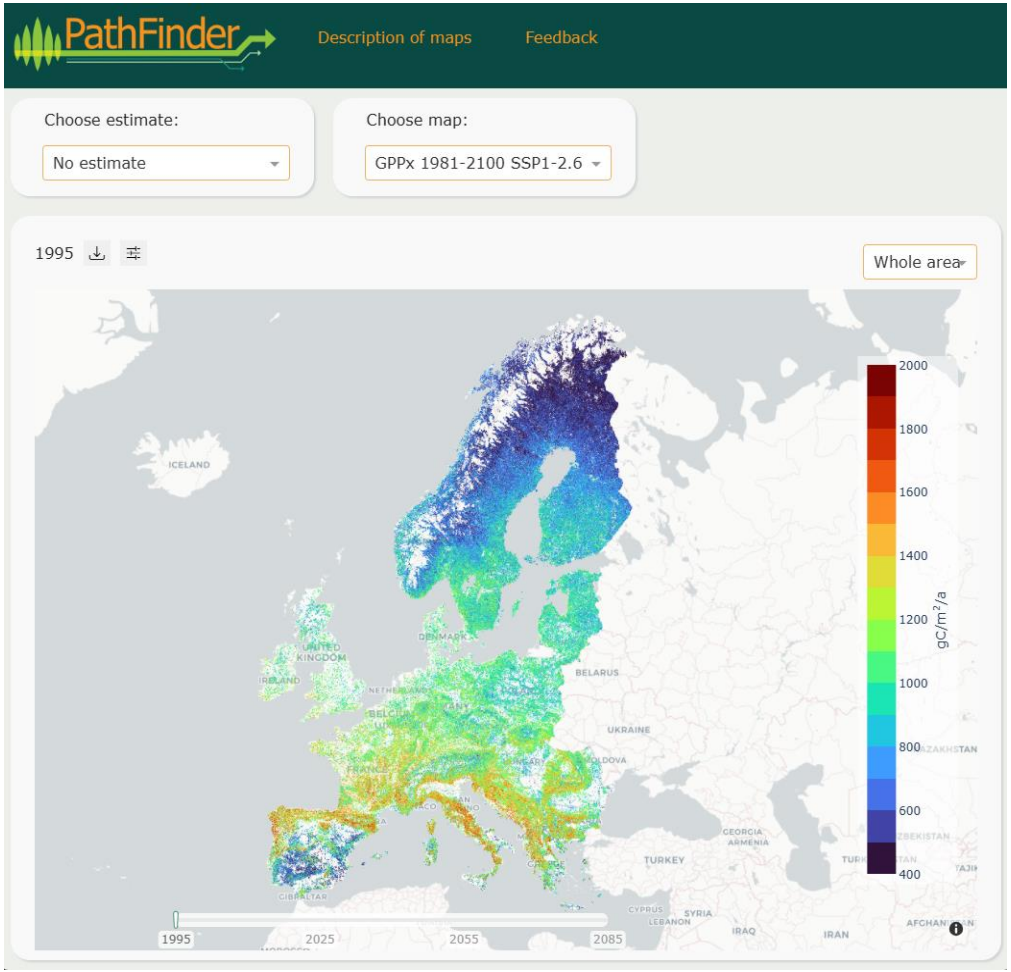


Key points:

1. All information based on the same input datasets: --> Consistency across levels
2. Enables integration of EO based mapping into existing reporting procedures
3. Reduces standard error for small areas
4. Provides fine-scale (10 m) information on relative distribution of forests on local level

PathFinder portal

- Where:
  - https://portal.pathfinder-heu.eu/
- What:
  - Maps
    - Forest attribute maps (x 18+3)
    - Deadwood map
  - Estimates
    - Single phase estimates
    - Model assisted estimates (Coming soon…)
  - Forecasts
    - GPPx forecasts (x 2) →2100
    - CLUMondo scenario forecasts (x 4) →2100
    - PixSim forecasts →2100 (Coming soon…)
- Why:
  - Visualization, download and links to sources.



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EU Policy Support

- Carbon farming baseline
- Forest area mapping

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EU policy support - Objectives

Supporting the EU Carbon Removals and Carbon Farming Regulation (CRCF, EU 2024/3012) and the Forest Monitoring Law (FML) proposal

- CRCF: develop MRV tools for the calculation of the standardized baseline and mapping net and gross annual increments of European forests

- FML: develop and validate a map of forest area as Land Use: validation of a European forest area map using National Forest Inventory (NFI) data

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Carbon farming baseline - Overview

Input data

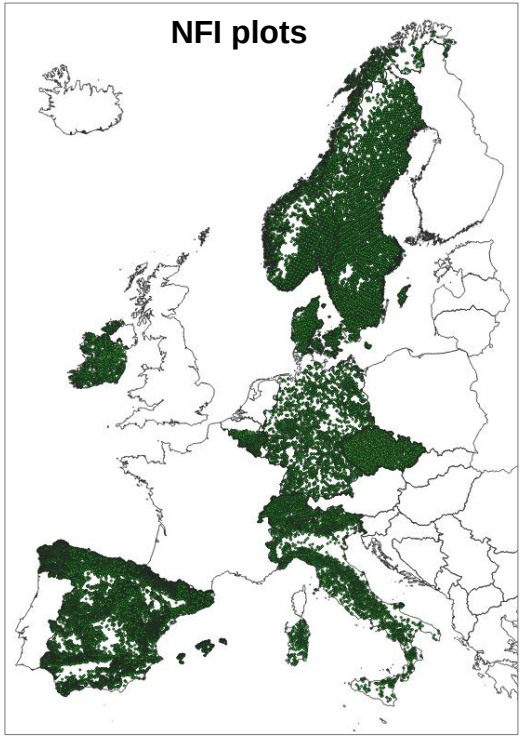
- NFI plots
  - 10 countries - 78,000 plots
- Maps
  - 73 predictors

Modelling approach

- Data driven (Decision trees, Xgboost)
- 1 country = 1 model

Aim

- Net Annual Increment
- Proxy of carbon removal
- Business-as-usual scenario



Variables

NFI Plots	Maps
• Forest Type	• Sentinel-2
• Tree Diameter	• Forest Type
• Biomass	• Forest Loss
• Species	• Tree Cover
• Interventions	• Tree Diameter
	• Tree Height
	• Biomass
	• Main Species
	• Biodiversity index
	• Productivity index
	• Disturbances
	• Management

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Carbon farming baseline - Results

Variable to predict

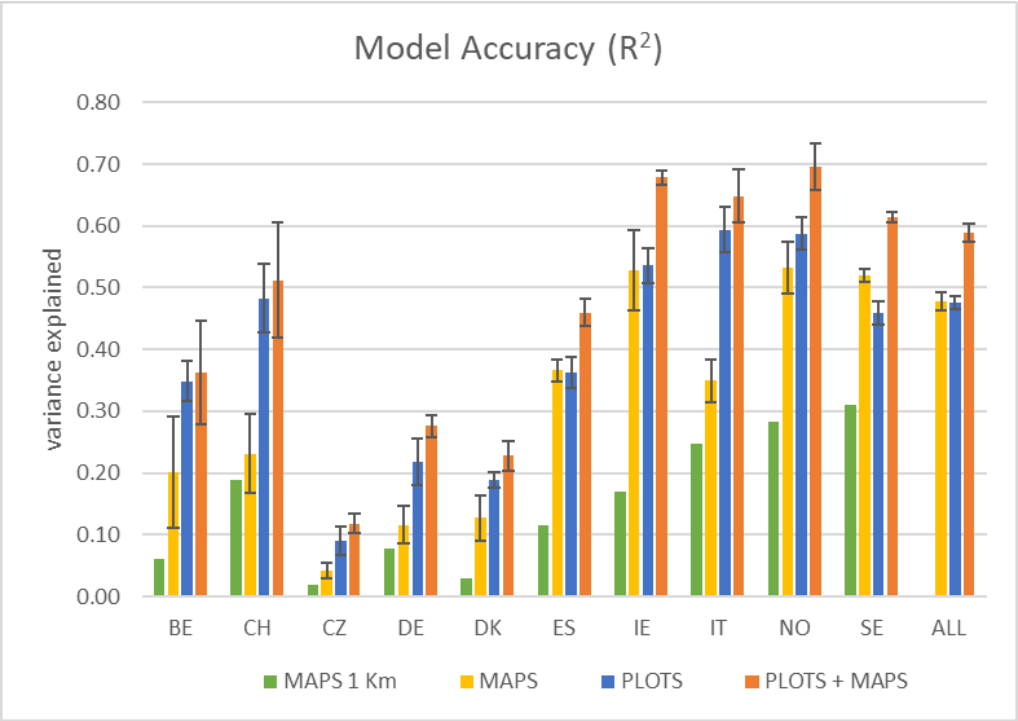
- Net Annual Increment

Predictors

- PLOTS: only NFI field variables
- MAPS: only satellite-based variables
- PLOTS + MAPS: field + satellite variables

Results

- Accuracy varies by country
- Relevance of map - plot colocation
- Integration PLOTS + MAPS = best results



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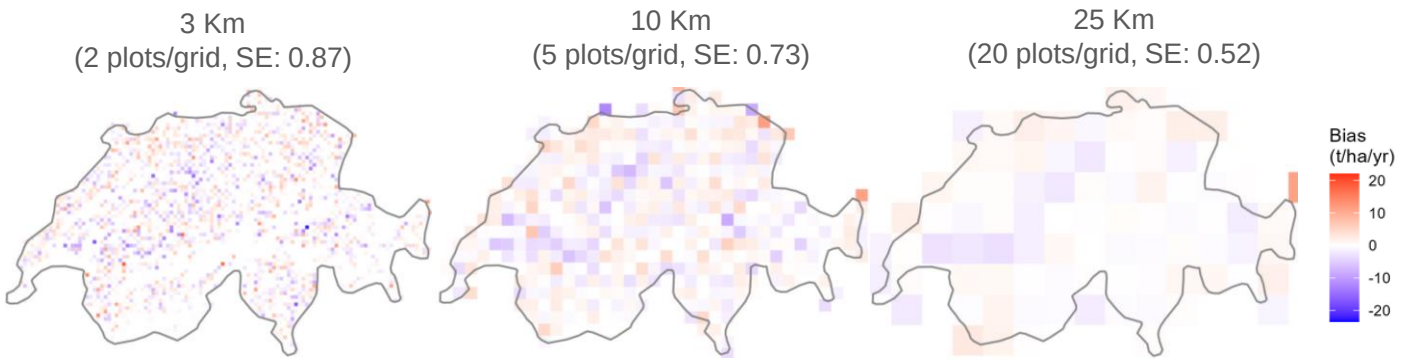
Carbon farming baseline - Results

Prediction error

- Local mean error and its standard error (SE) reduce when aggregating the predictions
- Better estimates for larger areas

Prediction mean error at varying spatial scales



Mean errors for model PLOTS + MAPS – Example for Switzerland

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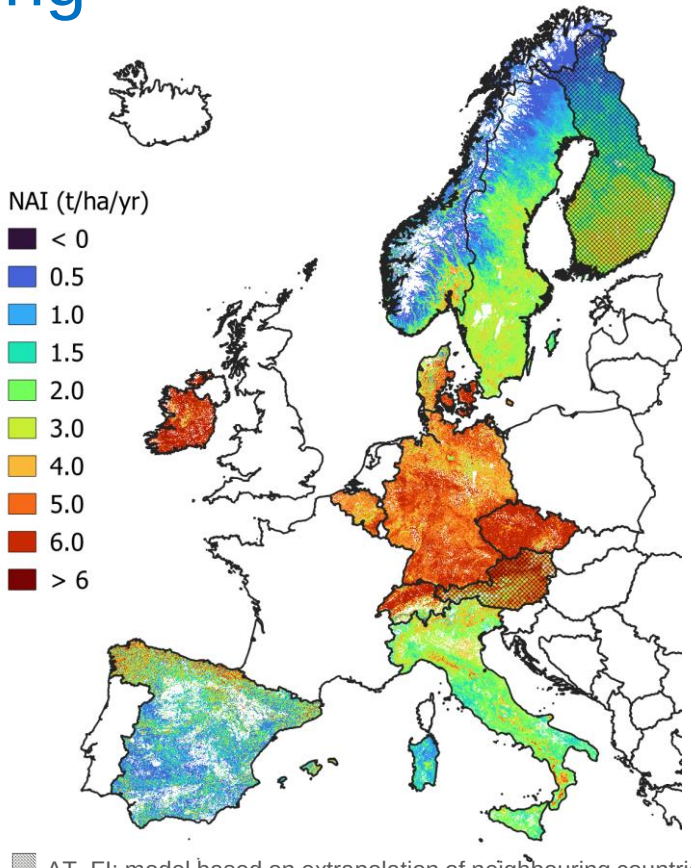
Carbon farming baseline - Mapping

Mapping forest increment

- Predictors: EO maps
- Based on country-specific models
- Map for demonstration only (resolution: 1 Km)

Concept

- Apply the method to develop national / local models and maps of forest growth and carbon removal
- Calibrated predictive models are applicable without updated NFI data



AT, FI: model based on extrapolation of neighbouring countries

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Carbon farming baseline - Conclusions

Results

- Data-driven approach for the standardized baseline
- Relevance of integrating NFI field and EO data
- Models applicable at various scales and periods

Limitations

- Accuracy varies by country; spatial aggregation of predictions reduces uncertainty
- Limited data on disturbances and management

Future directions

- Refine models at country scale
- Transform a research study into an operational MRV tool for the participating countries

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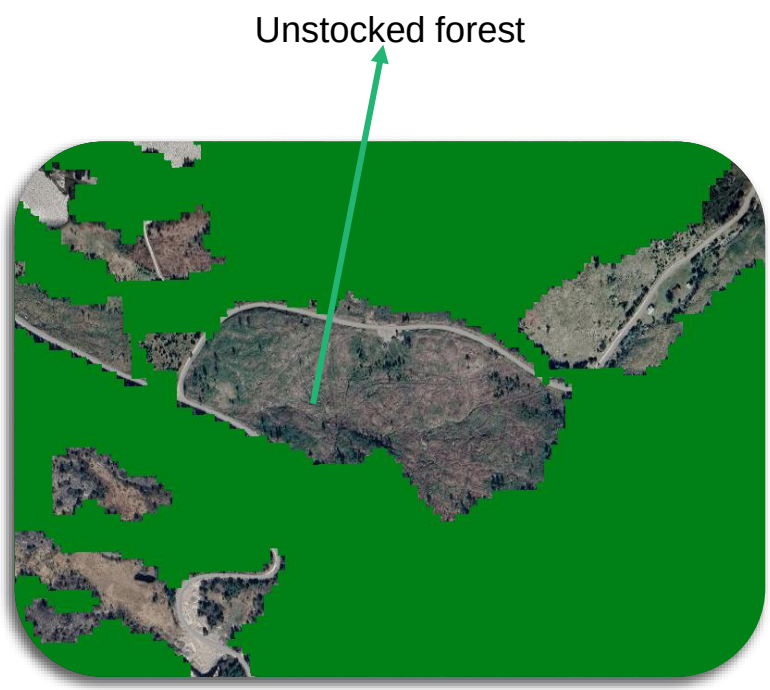
Forest Area Mapping



The requirement

- Forest land-cover ≠ forest land-use
- Temporarily unstocked forest can be mistaken for non-forested land
- This leads to mismatch between national statistics and satellite based assessment

Remote sensing (Copernicus HRL forest cover map)
Validation with National Forest Inventories (NFI)

How to identify unstocked forests:

- Use **time series analysis** to assess past and present conditions.
- Detect changes in land use over time.

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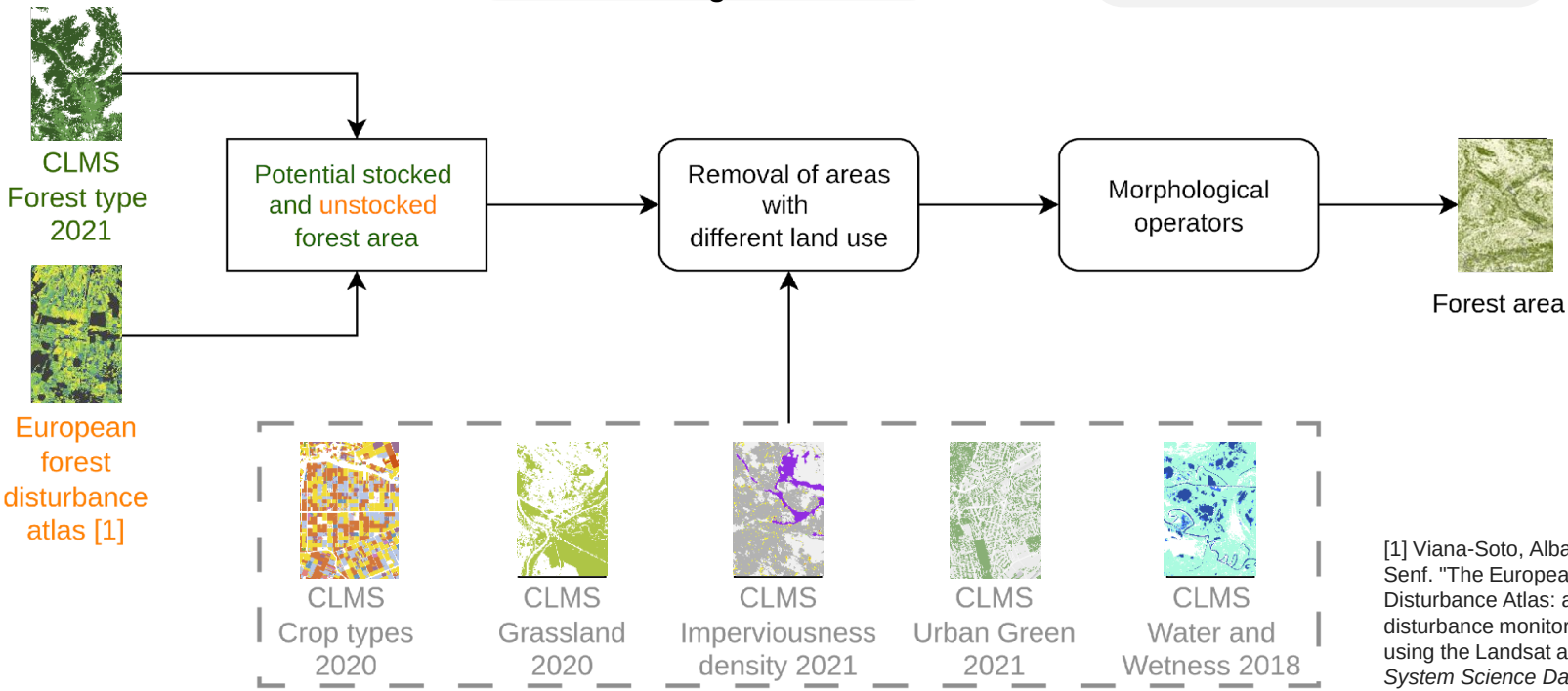
1 currently **stocked forest** as mapped by the CLMS forest type product.

2 forests **disturbed in the last 30 years** are potentially unstocked forests or areas subject to land use change.

3 disturbed forest areas under **different land-cover** by CLMS products are removed



[1] Viana-Soto, Alba, and Cornelius Senf. "The European Forest Disturbance Atlas: a forest disturbance monitoring system using the Landsat archive." *Earth System Science Data,* 2025.

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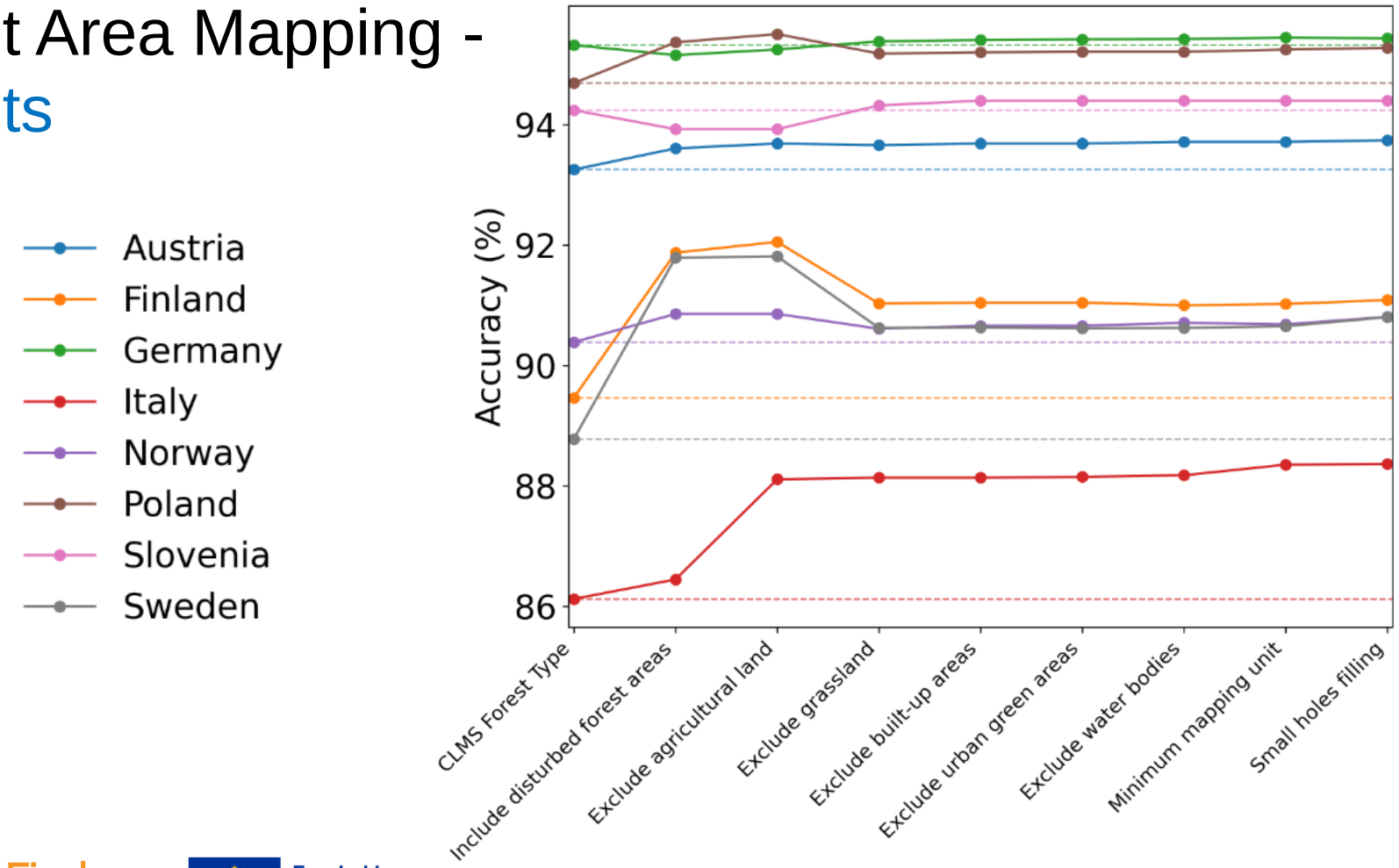
Forest Area Mapping - Results



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Forest Area Mapping - Results

Accuracy = (TP+TN) / (TP+TN+FP+FN) **Precision** = TP / (TP+FP) **Recall** = TP / (TP+FN)

Metric	Austria	Finland	Germany	Italy	Norway	Poland	Slovenia	Spain	Sweden
Accuracy	93.74	91.09	95.44	88.37	90.81	95.28	94.40	85.60	90.80
Precision	93.74	93.42	88.30	90.20	93.94	91.98	93.11	86.50	93.34
Recall	92.70	92.93	97.25	88.98	87.40	94.34	97.89	64.82	91.10

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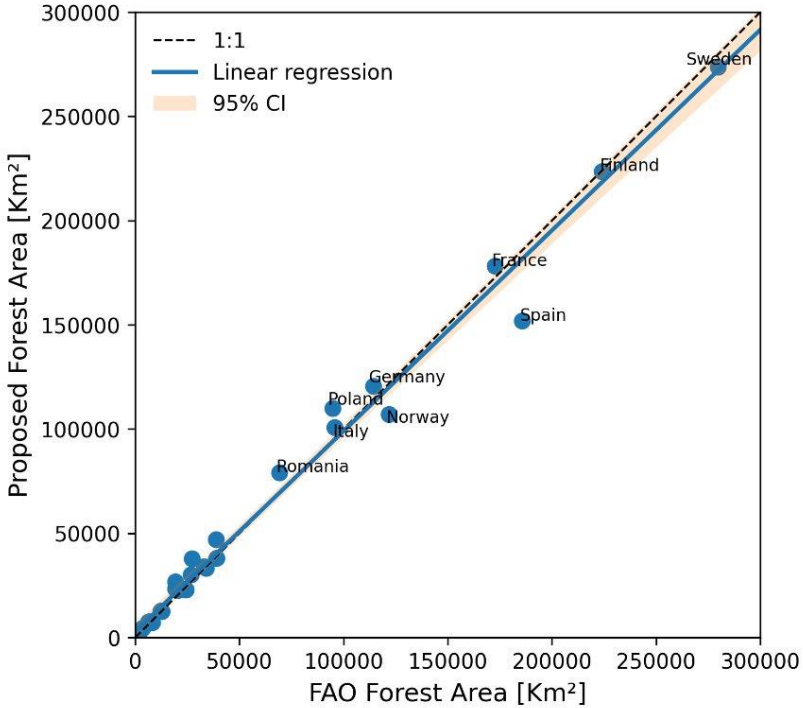
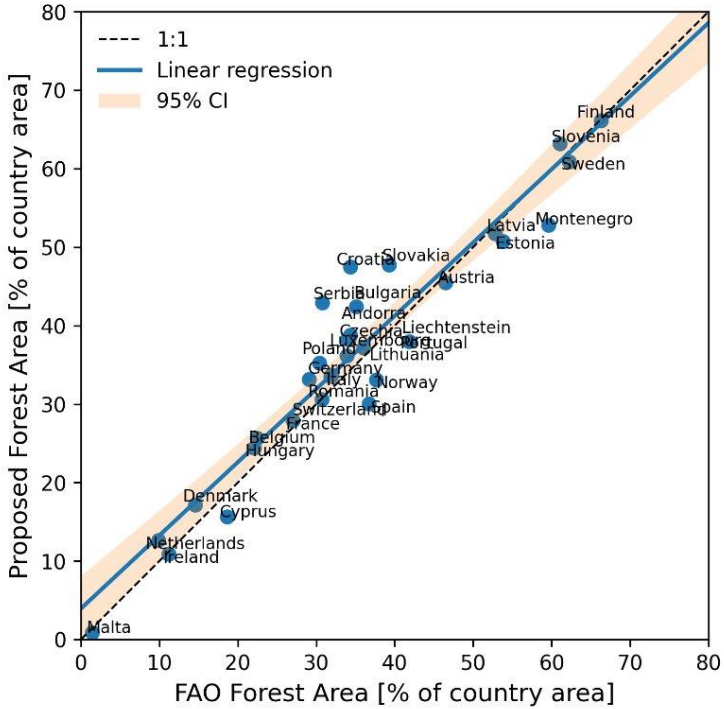
Forest Area Mapping - Results





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Forest Area Mapping - Conclusions

- Developed a framework to **map forest area** (both stocked and unstocked) by integrating temporal information through a historic disturbance product.

- The estimated forest area shows a **+2.6% increase** compared to existing forest cover products, improving recall while keeping stable precision.

Limitations

- Results are dependent on the **quality of input datasets**.
- Land cover products (e.g., grassland) can introduce systematic errors.
- The disturbance Atlas 30 m resolution often misses small disturbed areas.

Future Developments

- The framework is modular and can be easily updated as new datasets become available.
- Integrating **higher-resolution disturbance data** (e.g., Sentinel-2).

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Thank you for your attention!

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