

Pan-European forest structure maps and estimates integrating Sentinel-2 and National Forest Inventory data

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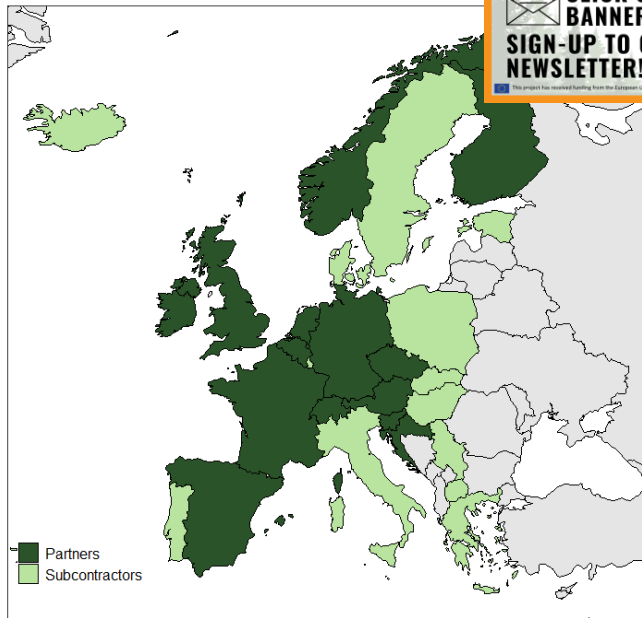
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Towards an Integrated Consistent European LULUCF Monitoring and Policy Pathway Assessment Framework



Coordinator:
Johannes Breidenbach

- Start: September 2022
- Duration: 4 years
- 23 Partners
- 17 supporting organizations (ICP Forests and NFIs)




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1. Innovative forest monitoring & pathway assessment system for EU GHG reporting of LULUCF
2. Advanced pathway assessments
3. Policy implementation

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement/ 101019907



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

FOREST MONITORING

Surveys Advanced field work

Mapping Estimating Modelling

REMOTE SENSING & MAPS

FORECASTING

Trade-off & synergy analysis Biogeophysical climate impacts

Land-use & forestry-management scenarios

Co-design of forest management pathways

Climate target assessment Forest monitoring & governance

POLICY



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

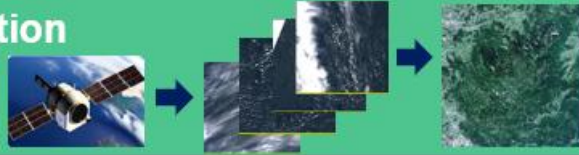


- Full description in D2.1 at: <https://pathfinder-heu.eu/resources>

PathFinder Mapping and Estimation Platform

Data pre- paration

Earth observation
(EO) data pre-
processing

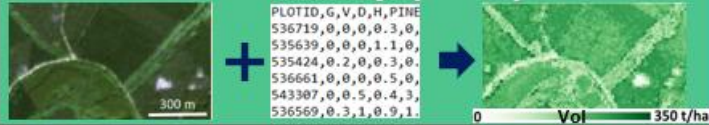


Decentralized field data pre-
processing

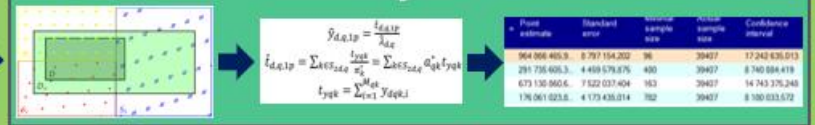
- Plot level NFI calc.
- EO value extraction
- QC steps

Mapping and estimation

Forest attribute map (10 m) creation

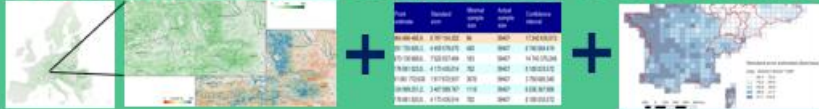


Statistical estimate production



Dissemination and communication

Visualization and distribution of the results



Enable links
to FISE and
national portals



Mapping specifications



Satellite data:

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

Reference data:

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

Features used in the k-NN model:

- Sentinel-2 (2020/2021)
- Copernicus 30 m DEM
- Chelsa (~1 km, 1981-2010): Mean annual temperature and precipitation

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)*

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



Mapped forest attributes

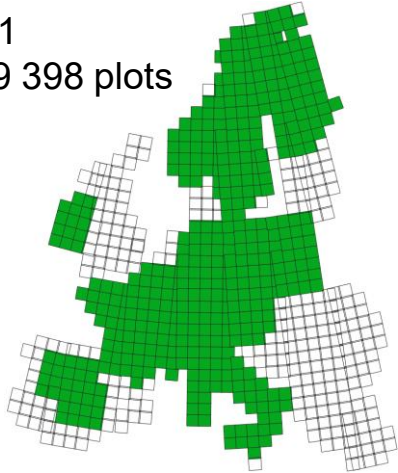


Variable	Code	Unit	Years	N of countries
Growing Stock Volume	Vol	m ³ /ha	2020 + 2024	14
Above Ground Biomass	AGB	t/ha	2020 + 2024	14
Conifer proportion (of AGB)	P_Con	% (of AGB)	2020 + 2024	14
Betula + Carpinus + Fraxinus	P_Bet_Car_Fra	% (of AGB)	2020	14
Populus and Salix	P_Pop_Sal	% (of AGB)	2020	14
Fagus	P_Fag	% (of AGB)	2020	14
Quercus	P_Que	% (of AGB)	2020	14
Eucalyptus	P_Euc	% (of AGB)	2020	14
Other_broadleaf	P_OthBL	% (of AGB)	2020	14
Picea	P_Pic	% (of AGB)	2020	14
Abies	P_Abi	% (of AGB)	2020	14
Pinus	P_Pin	% (of AGB)	2020	14
Other conifers	P_OthCon	% (of AGB)	2020	14
Quadratic mean diameter	DBH	cm	2020	12
Basal area	BA	m ² /ha	2020	9
Height	H	dm (!)	2020	6
Gross annual increment (of AGB)	GAI	t/ha/a (x100)	2020	10
Net annual increment (of AGB)	NAI	t/ha/a (x100)	2020	10

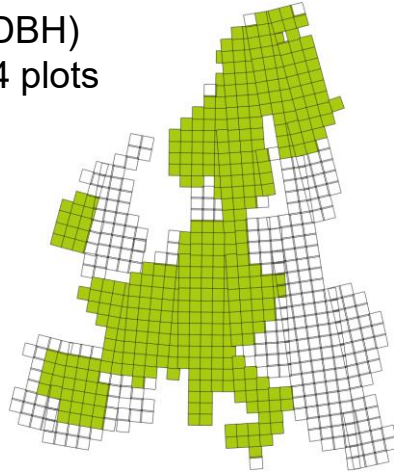
Plot availability by attributes



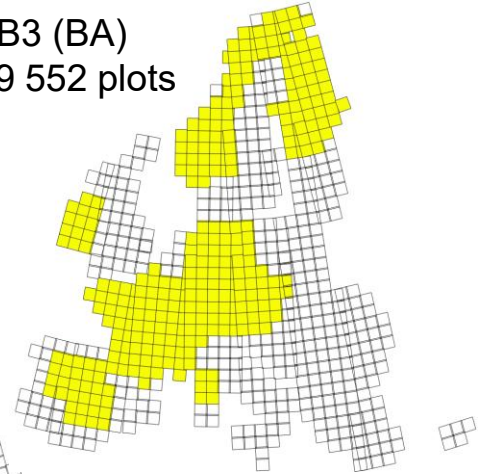
FB1
119 398 plots



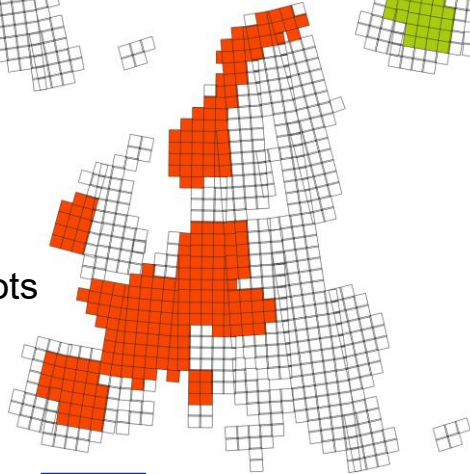
FB2 (DBH)
94 924 plots



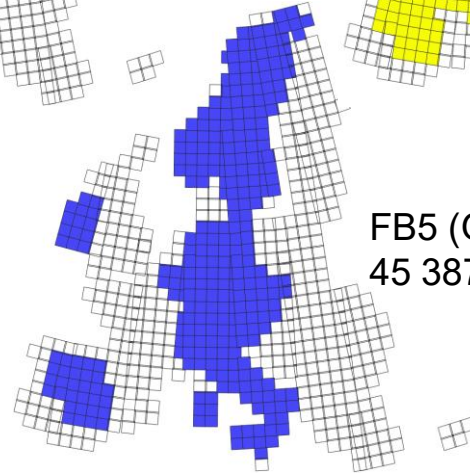
FB3 (BA)
69 552 plots



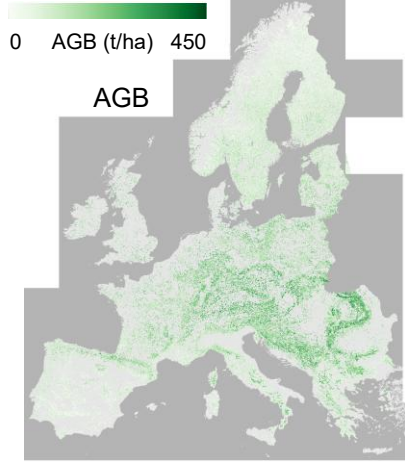
FB4 (H)
45 361 plots



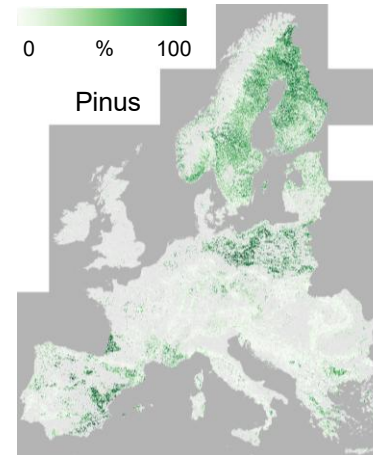
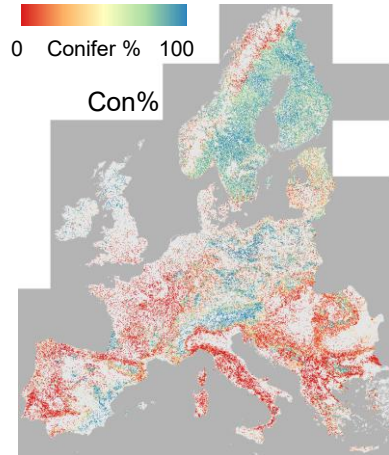
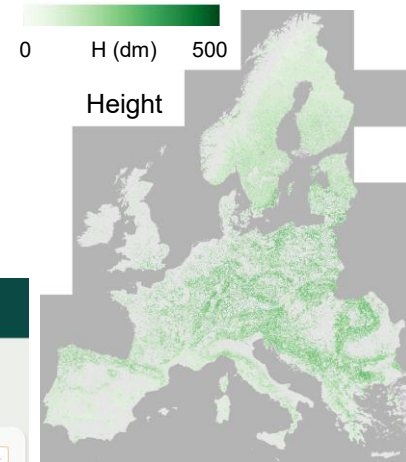
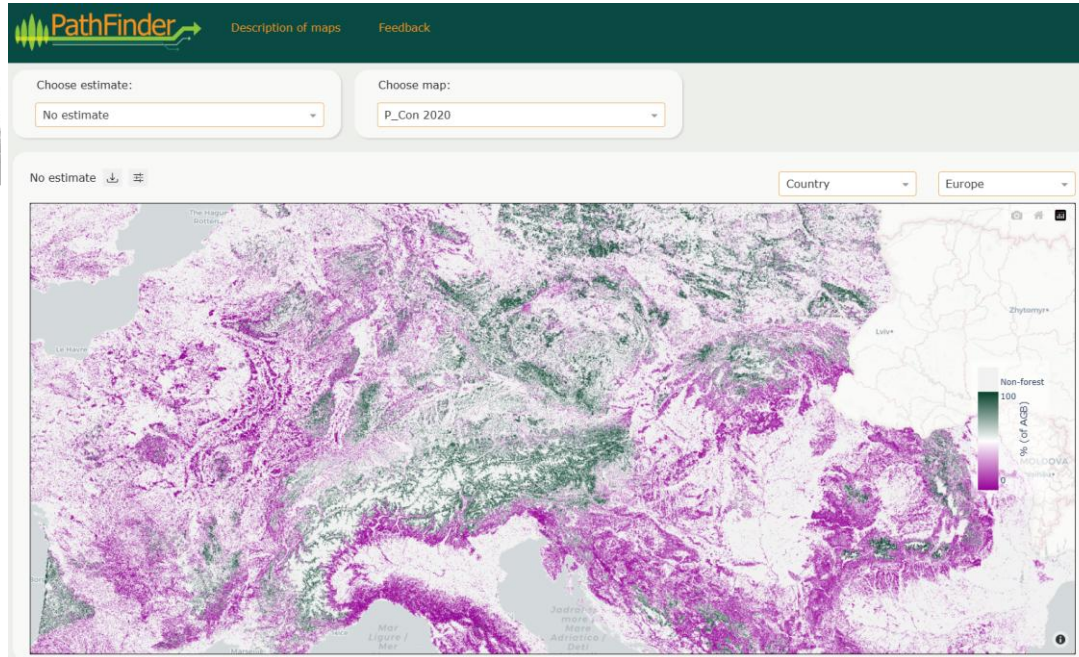
FB5 (GAI, NAI)
45 387 plots



Maps are now available! (Estimates to follow soon...)



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



Map accuracy I



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
Gross annual increment (of AGB)	276.88	78.75	-0.55	-0.16	0.50
Net annual increment (of AGB)	270.13	80.53	-0.41	-0.12	0.49
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

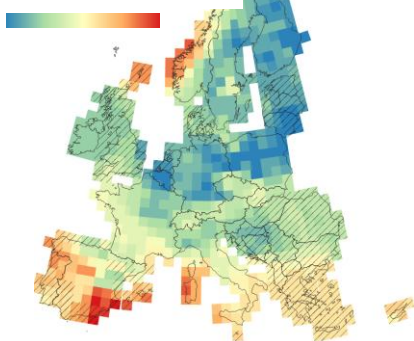
- RMSE and R² values (apart from tree species) on similar levels as have been reported in earlier studies.
- Bias very small – one of the benefits of k-NN method. But varies between areas. (next slide)
- For tree species, error metrics provide little information due to the drastically varying (and often 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.

Map accuracy II

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

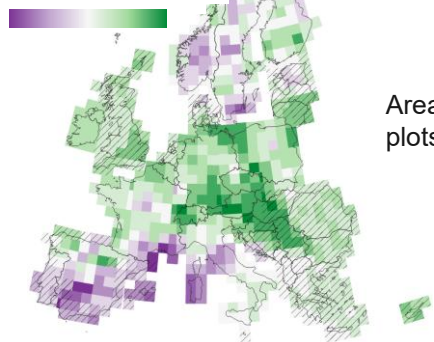
AGB RMSE%

50 % 90



Vol bias%

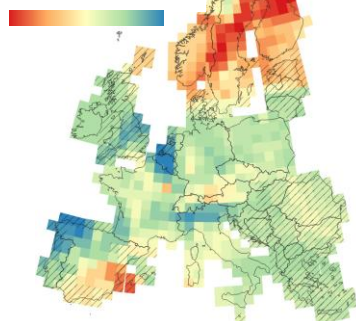
-6 % 5



Areas without plots hashed

Con% R²

0.22 0.85



zenodo Search records Comments My dashboard

HorizonEurope PathFinder

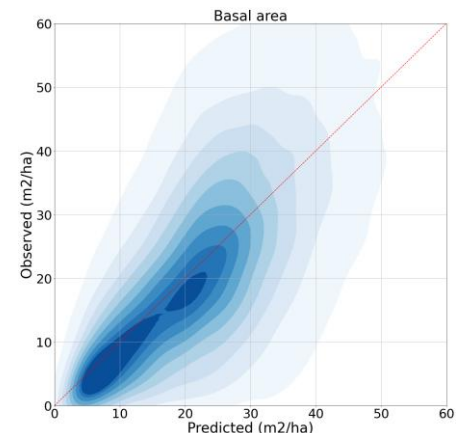
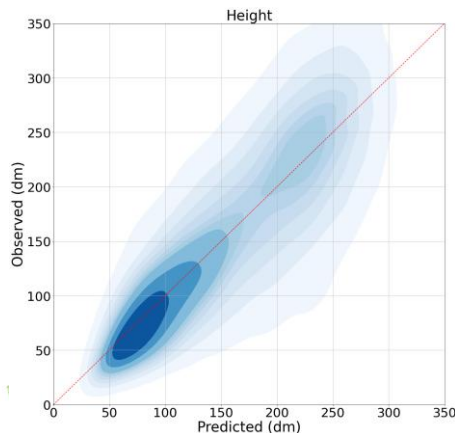
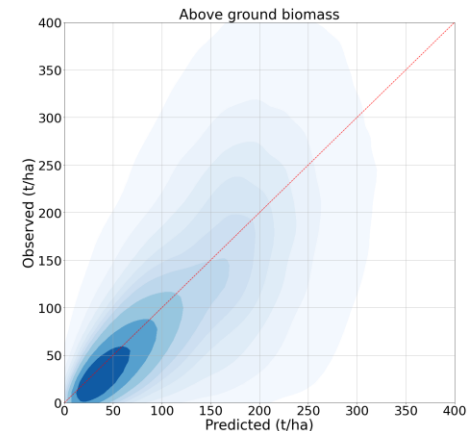
Published September 12, 2025 | Version v1

Data paper Open

PathFinder's High-Resolution Pan-European Forest Structure Maps: An Integration of Earth Observation and National Forest Inventory Data

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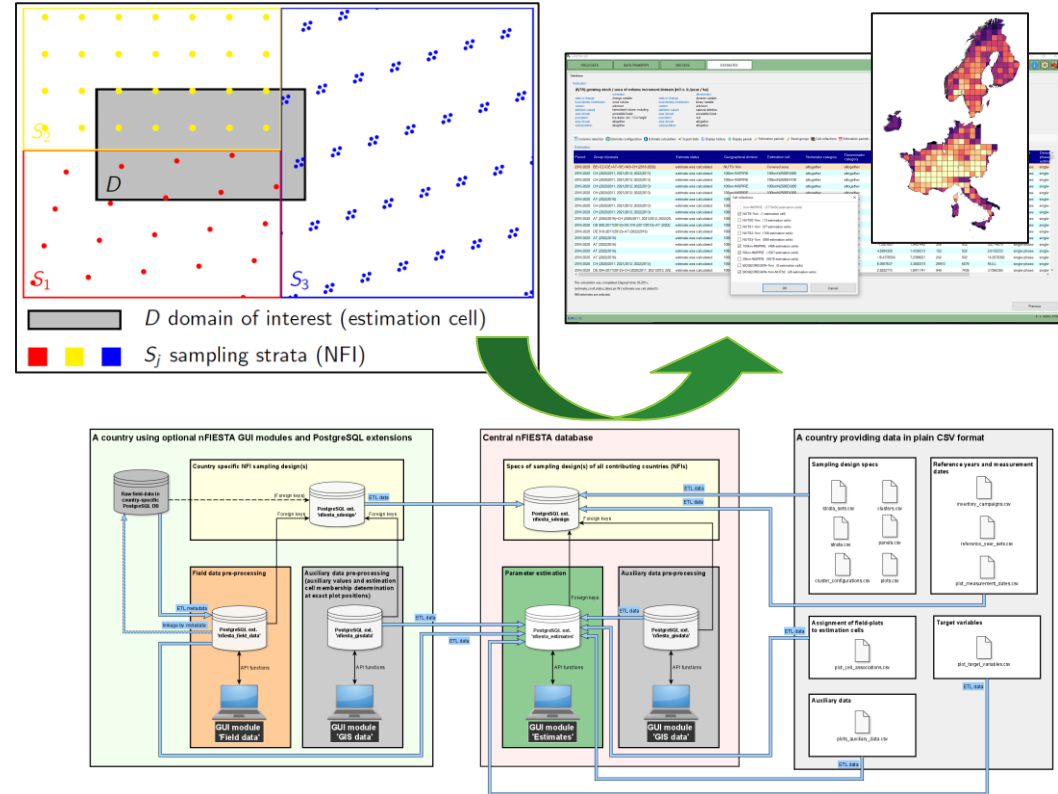
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Estimates



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.



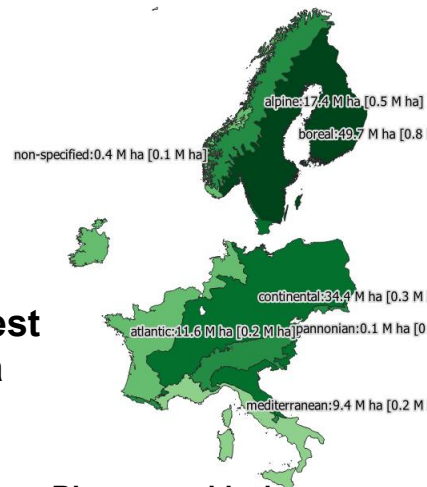
Estimates

– Preliminary examples

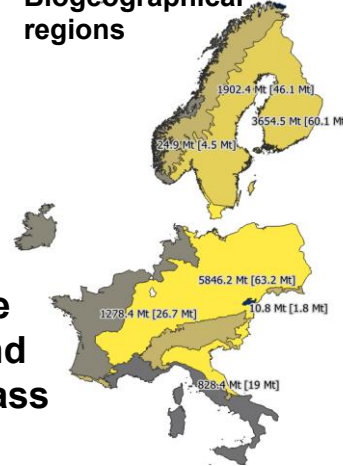
Harmonized design-based estimates across Europe for:

- Total area
- Administrative areas
- Biogeographical regions
- INSPIRE cells in various levels (100 km, 50 km...)
- Etc.

Forest area

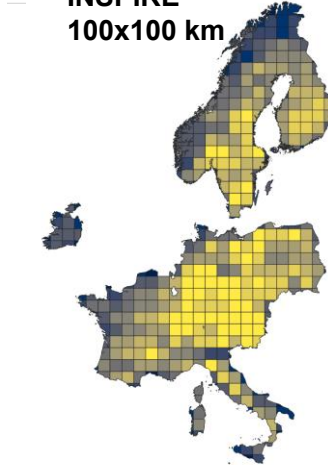


Biogeographical regions

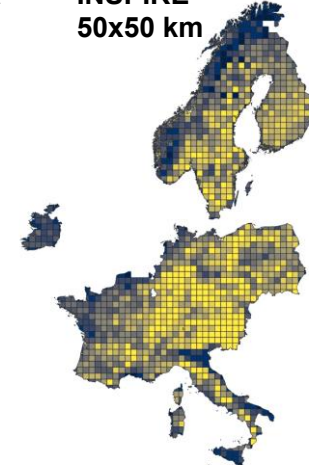


Above ground biomass

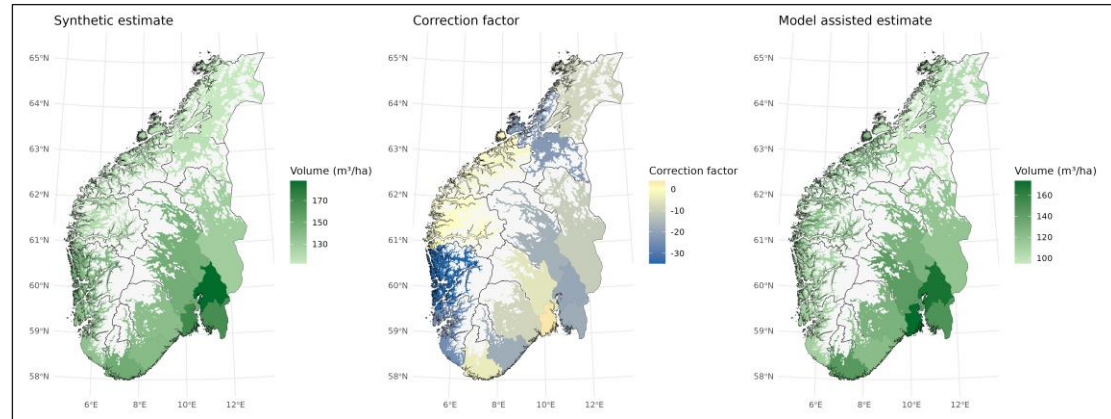
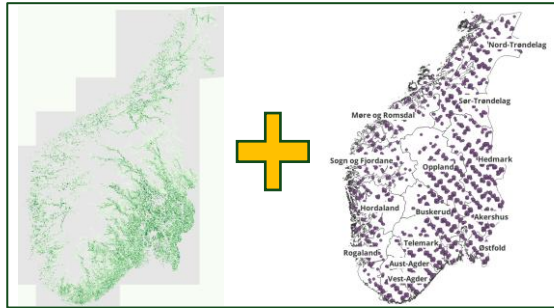
INSPIRE 100x100 km



INSPIRE 50x50 km

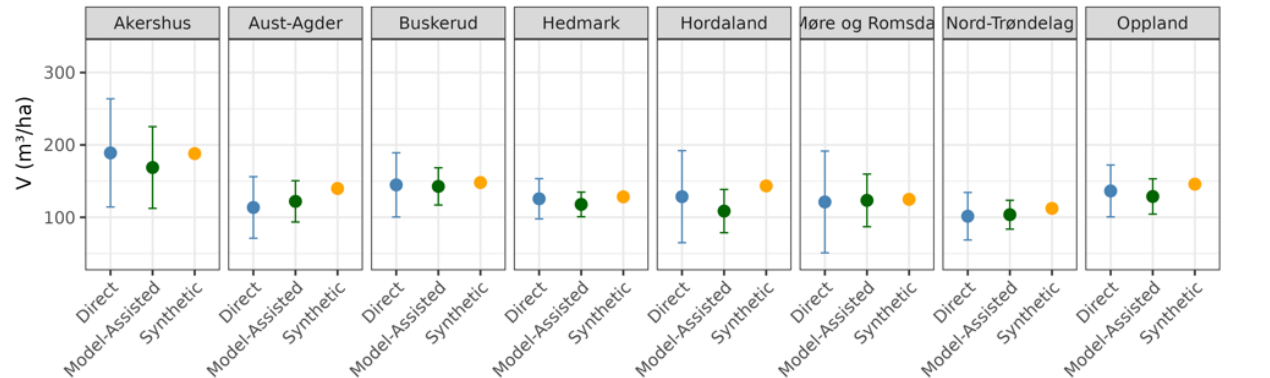


Model-assisted estimation



1. EO-based forest map – synthetic estimate (pixel counting) – no uncertainty for estimates
2. NFI plots (direct estimate) used to calculate correction factor and determine model assisted estimates
3. Outcome: Improved estimates with uncertainty metrics

Comparison of Estimates per County for V



Conclusions



- Combination of probabilistic sampling and EO based mapping allows:
 - Integration of EO based mapping into existing reporting procedures
 - Provision of consistent outputs from field and EO based approaches
- Model-assisted estimation:
 - Reduces standard error compared to direct (NFI-plot based) estimate
 - Allows bias correction of the maps

→ Improved accuracy with detailed spatial distribution
- LULUCF-concept: Map-based change estimates for improved timeliness followed by recalculations with model-assisted estimates once field-reference data are available.
- Outputs to be used also in analysis of approaches for CRCF (conducted by JRC):
 1. Mapping of net and gross annual increments for the development of the standardised baseline and quantification tools
 2. Comparison of EO and field-based models



Thank you for your attention!

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- WP2 overall

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