Contribution to D3.6: Open access harmonised maps

Holistic management practices, modelling and monitoring for European forest soils, HoliSoils

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Deliverable DX.X: Deliverable title (use short version if necessary)		
Brief description of your deliverable (75 – 100 words)		
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OTHER	Software, technical diagram etc.	
Ethics	Ethics deliverables	

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Contents

1. Introduction

This report summarises the procedures for producing maps of soil properties for European Forest soils within the HoliSoils project. It briefly describes the input data, both observations and environmental layers, and the methodology. Subsequently, there is a short summary of the main results. The report, which is a contribution to HoliSoils Deliverable D3.6 "Open access harmonised maps" coordinated by Thünen Institute, ends with a short discussion and conclusion. The data availability section explains where the maps can be found and how they can be accessed.

2. Input data

Input data covers both the soil observations (i.e. point measurements) and the environmental layers used to produce the maps.

2.1 Observations

The soil observations used for mapping were queried from the WoSIS database, which was augmented with datasets provided in the context of the HoliSoils project :

- HoliSoils provided datasets (Wellbro*ck* et al., 2021) that include:
    - ICP Forest Level I and Level II (ICP Forests 2021),
    - A compilation of forest soil data for Poland (Brozek, et al. 2019)
    - French soil monitoring system (RQMS 2021), which considers multiple land covers besides forests, and
- Forest soil data for Europe held in WoSIS (Batjes, Calisto, and Sousa 2024).

The data shared in the framework of the HoliSoils projects, and their licences, are visualised in a dashboard, for details see Batjes and Calisto (2023). Out of these 7,200 'profiles' about 3,500 are under EU Corine 2018 land cover (see below). Complemented with the existing WoSIS forest 'profiles' this yielded about 27,825 profiles under Corine 2018 land classes for the mapping work (Figure 1).

Thus, to represent ~227 million ha forest soils in Europe, only observations within Corine forest land cover were considered. To select the observations, the following criteria were used:

- Belong to a dataset for which all observations were collected in forest (for example ICP Forest)
- Be in a forest land cover category as defined in the Corine land cover (European Union's Copernicus Land Monitoring Service information 2018) including: 3.1.1 Broad-leaved forest, 3.1.2 Coniferous forest and 3.1.3 Mixed forest.

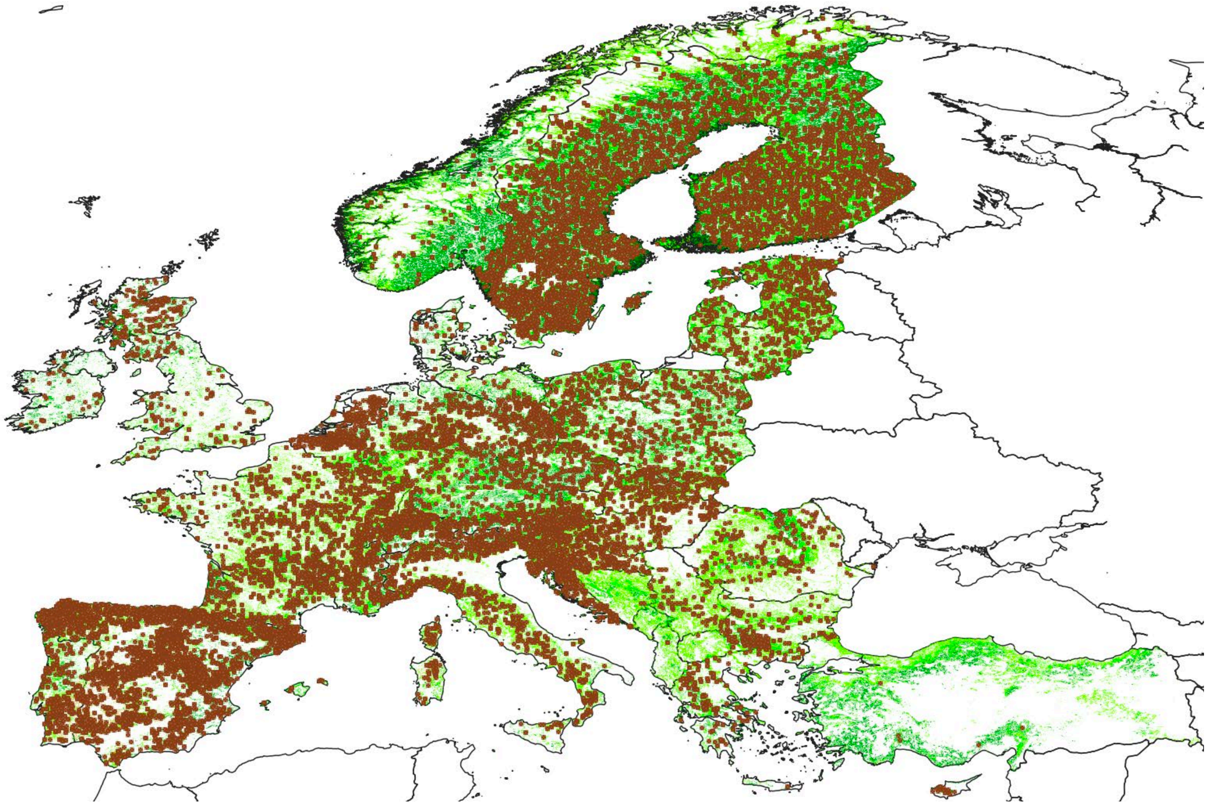


Figure 1. Distribution of forest soil 'profiles', in Corine 2018 land cover classes, considered in the HoliSoils mapping work.

It proved cumbersome to unambiguously 'flag' organic surface layers at the top of mineral forest soils in view of inconsistencies/differences of recording between countries and classification systems (e.g. Gobezie et al. 2024; Batjes et al. 2024). Alternatively, for organic (i.e. peat) soils the whole depth was considered. We are aware that this impacts the organic carbon stocks calculations, with possible effects on e.g. subsequent 'forest soil vulnerability' assessments for HoliSoils. Surface layers above mineral soil potentially are a large pool of organic carbon, especially in boreal and temperate forest (Ziche et al. 2019). This aspect will be investigated in further comparative studies.

2.1.1 Depth distribution

Most observations are available for the topsoil only (<60 cm). The table below is an example of the depth distribution of the observations for soil organic carbon (SOC). It is representative of the other properties as well as considered a best case scenario.

Depth interval (cm)	Number	Proportion
0-5	217	0.01
5-15	14074	0.71
15-30	5311	0.27
30-60	94	0.00
>60	None	None

2.1.2 Modelled properties

The following primary soil properties, as determined following discussions with HoliSoils partners, were modelled:

Property	Description	Units
Soc	Soil organic carbon content	g/kg
phh2o	pH in water	pH
nitrogen	Total nitrogen	g/kg
Bdod	Bulk density, oven dry	kg/dm3
Cfvo	Coarse fragments, volumetric	cm3/100cm3
Sic	Soil inorganic carbon content	g/kg
Sand	Sand	g/100g
Silt	Silt	g/100g
Clay	Clay	g/100g
Ocstk	Soil organic carbon stocks	kg/m2
Icstk	Soil inorganic carbon stocks	kg/m2
Nistk	Soil nitrogen stocks	kg/m2

2.2 Environmental layers as covariates

The following covariates were used:

- Sentinel1 composites band Synthetic Aperture Radar (SAR) instrument. The data were pre-processed, prepared, mosaicked and downloaded from Google Earth Engine (Gorelick et al. 2017). VH is a vertically transmitted and horizontally received SAR (Synthetic Aperture Radar) backscatter signal from S1. VV is a vertically transmitted and received SAR backscatter signal. The polarization ratio was calculated: (VH-VV)/(VV+VV). The overall median (2018 to 2020) was calculated and used as covariates.
- Sentinel 2 composites. The overall median for 2021 was calculated and used to derive the vegetation indices. In this project the following basic indices were used: NDVI: Normalized Difference Vegetation Index, NDWI: Normalized Difference Water Index, NDSI: Normalized Difference Snow Index.

- Geomorphological and terrain parameters derived from Copernicus Digital Elevation Model (ESA, 2024), including:
    - Elevation from sea level (m),
    - Slope as the steepest slope angle, calculated using the 'D8 method' (O'Callaghan & Mark, 1984),
    - Topographic wetness index (Sørensen et al., 2006) defined as the ln(a/tan(b))
    - Multi-resolution Valley Bottom Flatness (MRVBF) index (Gallant & Dowling, 2003).
- Climate data derived from ERA5. ERA5 is the fifth generation ECMWF atmospheric reanalysis of the global climate. Reanalysis combines model data with observations from across the world into a globally complete and consistent dataset. ERA5 provides aggregated values for each month for the following ERA5 climate reanalysis parameters: temperature_2m, total precipitation, runoff, total evaporation, surface net solar radiation. Monthly total precipitation values are given as monthly sums. All other parameters are provided as monthly averages.
- Land cover: The Copernicus Global Land Service (CGLS). The 2019 products (Buchhorn et al. 2020) with the proportional estimates for vegetation/ground cover for the land cover types were used in this project.
- Parent material: Information on parent material was derived from the European Soil Database v2.0 (Panagos et al. 2022). Both primary (Code for dominant parent material of the STU) and secondary (Code for secondary parent material of the STU) units where rasterized in binary (presence/absence) format.

3. Mapping approach

To generate soil properties maps for European forests, soil observations from multiple locations in Europe were analysed in relation to a set of environmental covariates. Random Forests (Breiman 2001), were used as the modelling technique, using the *ranger* package (Wright and Ziegler 2017), with the option *quantreg* to build Quantile Random Forests (QRF) (Meinshausen 2006) for spatial uncertainty assessment. With QRF, predictions generate a cumulative probability distribution of the soil property at each location, rather than a single average value from the ensemble of decision trees. These observations were split in 10 equal folds for cross-validation. Model tuning was conducted using a 10-fold cross-validation procedure applied to multiple combinations of hyper-parameters.

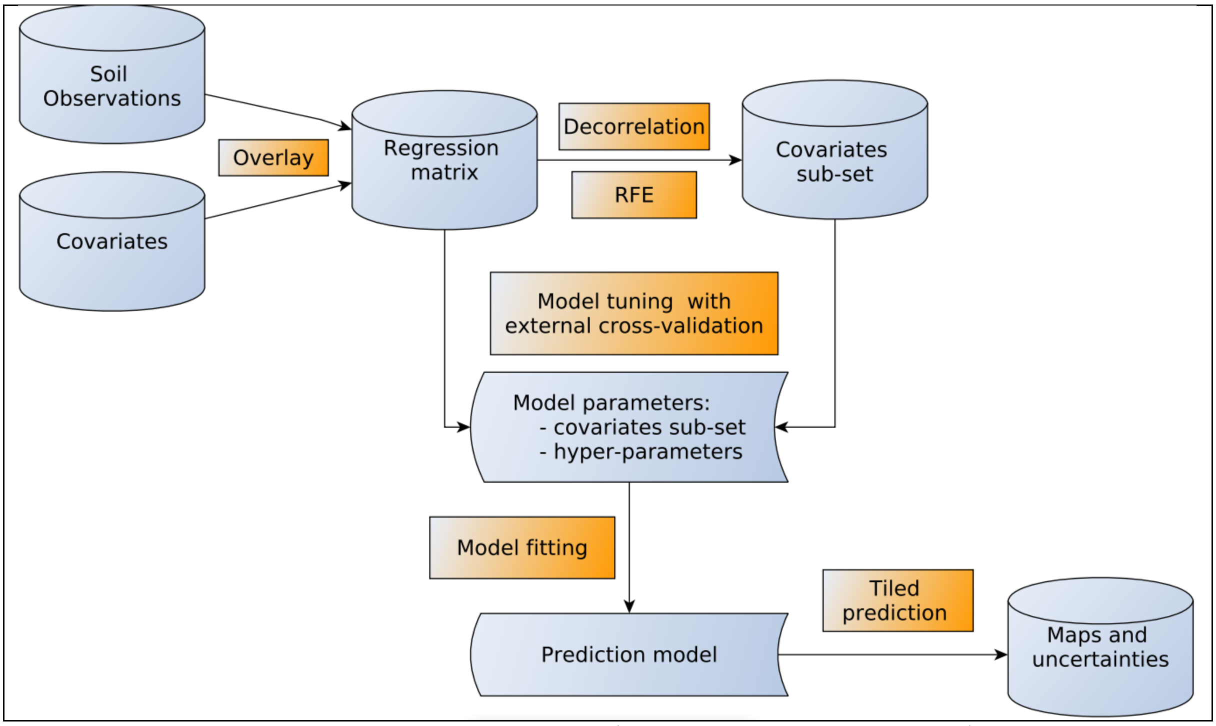


Figure 2. Workflow for the digital soil mapping (Source: Poggio et al., 2021).

Models were trained with different combinations of the number of decision trees (*ntree* parameter) and numbers of covariates (*mtry* parameter). Each of the resulting combinations of *ntree* and *mtry* parameters was used to train a different model with observations from nine folds. Predictions were then assessed on the remaining fold using root mean squared error (RMSE) and model efficiency coefficient (MEC)(Janssen and Heuberger, 1995). The model evaluation was based on the performance metrics of the selected hyper-parameters combination. The final model was fitted with all available observations, the covariates and the hyperparameters selected in the previous steps.

This approach provides the mean predictions, but also the quantiles. We chose the 5th and 95th quantiles according to the *globalsoilmap* specifications (Arrouays et al. 2014). The uncertainty was defined as:

$$uncertainty = \frac{|Q0.95 - Q0.05|}{Q0.50} * 10$$

This approach builds on the methods described in Poggio et al. (2021).

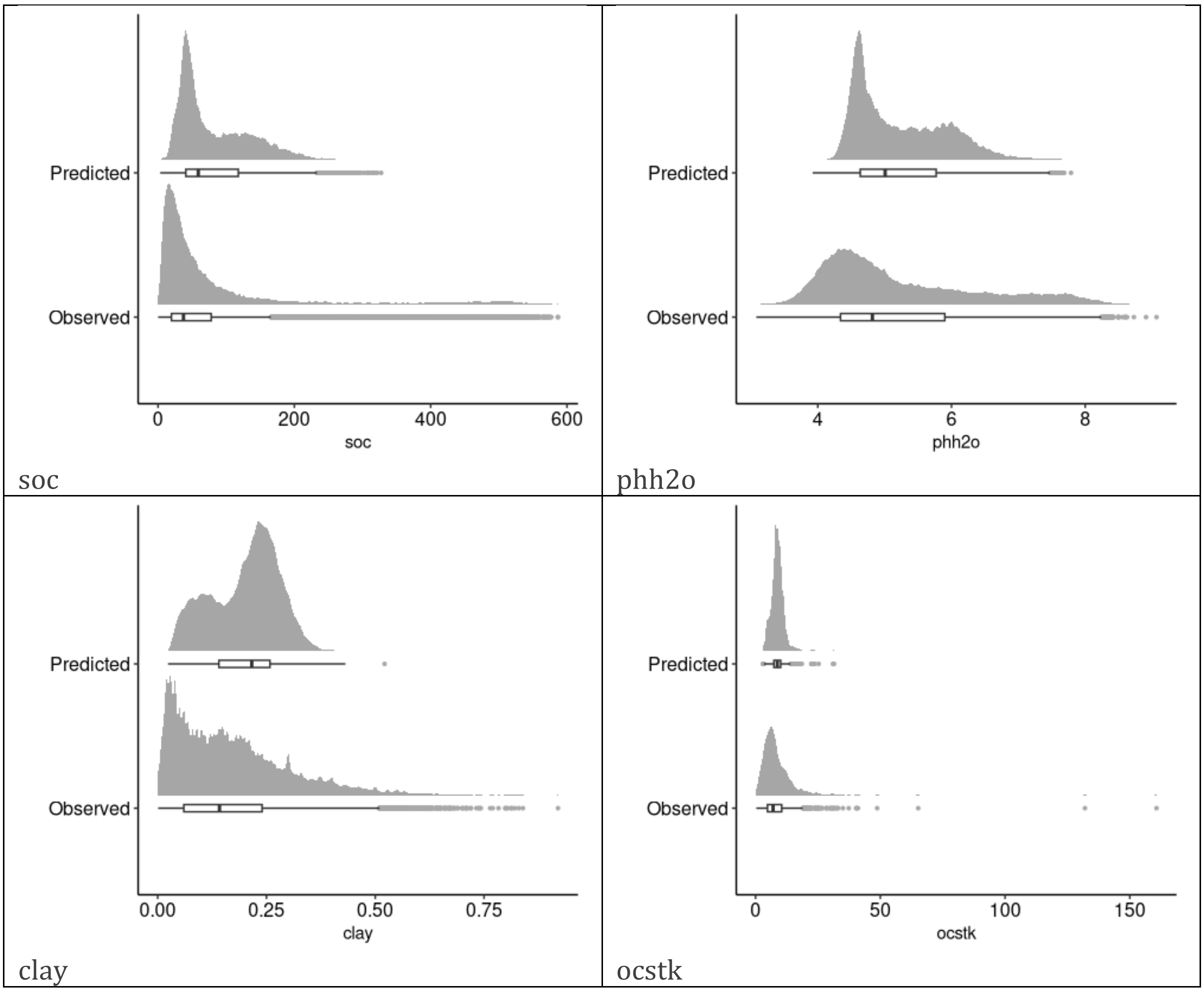
4. Summary of modelling results

4.1 Topsoil only

This section describes the results of the topsoil only modelling. Topsoil was defined here as 0-30 cm, in accordance with IPCC (2016) standards, and values were averaged using a weighted average by the thickness of the layer (Poggio et al. 2021).

	bdod	Cfvo	Clay	icstk	nistk	nitrogen	ocstk	pH	sand	sic	silt	soc
MEC	0.21	0.23	0.16	0.34	0.16	0.07	0.05	0.43	0.25	0.26	0.19	0.17
RMSE	0.35	15.02	0.12	3.93	0.38	4.73	7.78	0.88	0.21	9.73	0.16	12.88

MEC : model efficiency coefficient; RMSE : root mean squared error



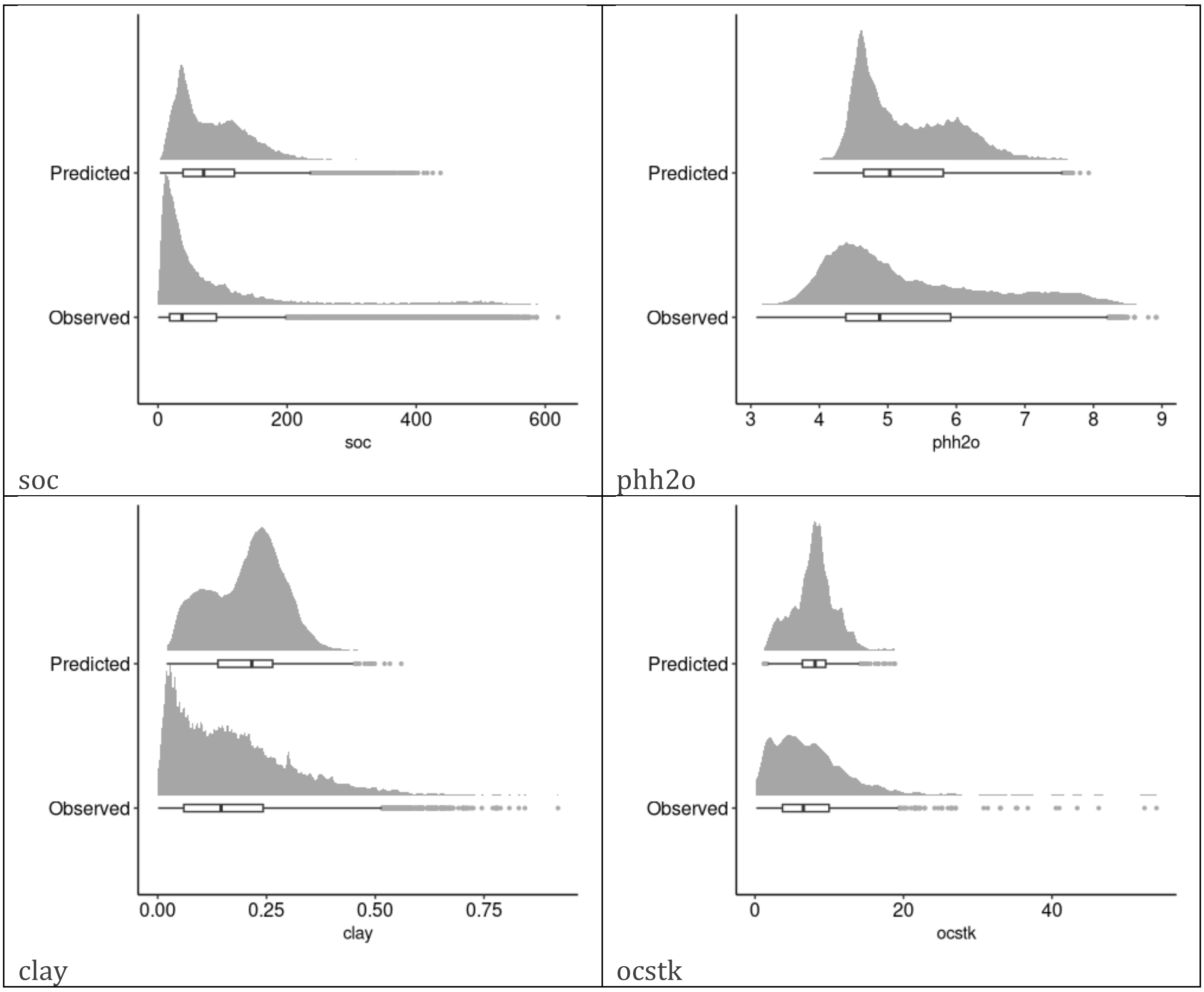
4.2 Soil to 60 cm thick

This section describes the results of the 3D modelling for three layers (0-20, 20-40 and 40 to 60 cm). Values were averaged using a weighted average by the thickness of the layer

(Poggio et al. 2021). For the purpose of this report, the cross-validation statistics are for the whole profile and not per layer.

	Bdod	cfvo	clay	icstk	nistk	nitrogen	ocstk	pH	sand	sic	silt	soc
MEC	0.49	0.35	0.08	-0.06	0.18	0.35	0.15	0.41	0.27	0.26	0.24	0.43
RMSE	0.30	17.71	0.14	11.74	0.36	4.66	5.49	0.92	0.23	11.46	0.16	10.72

MEC : model efficiency coefficient; RMSE : root mean squared error



5. Discussion and conclusion

As indicated earlier, relatively few forest soil data were shared in the context of the HoliSoils project, and many of these only considered the upper soil layers (<60 cm). This had direct implications on the possible accuracy of the predictions.

Comparisons with soil organic carbon (SOC) maps generated in the framework of several other EU-scale projects, such as EJP, CUP4SOIL and ESA World Soils, indicated that there are still quite some differences in the estimated properties as well as in their spatial distribution.

The work showed the importance of having sufficient quality-assessed, harmonised profile data when mapping and modelling across countries at continental scale to support decision making towards climate and sustainability goals. Possibly, data fusion of the different SOC maps could lead to better and more reliable estimates in the future.

6. Data availability

Ultimately, all maps produced by HoliSoils will be made available via the Thünen Institute Scientific Data Repository (TISDAR), which will provide improved visualisation and querying options. Meanwhile, the soil property maps can be accessed via web-services in WMS format from the ISRIC website.

The following webpage provides details on links, services and citation of the soil property maps:

https://data.isric.org/geonetwork/srv/eng/catalog.search#/metadata/b3d7c844-cbee-4b0f-8431-3a9373f5a59a

7. Acknowledgements

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