Soil information for forest soils and carbon monitoring

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Soil organic carbon (SOC)

- Integral component of **soil functioning; SOC is key indicator for ecosystem services**: habitat, biological archive, water retention/supply, flood protection, reduction of wind and water erosion, reactive surface to store nutrients and filter pollutants
- **Reservoir** for soil C: the largest terrestrial reservoir of carbon (2 x the atmosphere, 3 x that in global vegetation)
- **Dynamic** pool: large proportion is exchanged annually (respiration, uptake): high C storage (positive feedback) accompanied with high CO2 production, but also consumption in biomass growth (especially forest soils!)
- Thus: Soil C plays key role in **climate forcing (**indicator for the capacity of the terrestrial environment to act as a climate regulator)

Forest soils:

- hold about one-third of the carbon stored in terrestrial ecosystems
- Predominant role in **Kyoto Protocol reporting** (besides managed organic soils)
- Understanding of **hot spots** seems crucial: e.g. forest soils in urban areas
  (unconcentional example: forest area reduced to half of the surrounding 26 % Frankfurt; 41 % avg in Hesse); Groundwater exploitation, etc.

Forest soils: Hydraulic properties

Flood protection
Water storage/buffer for draught periods

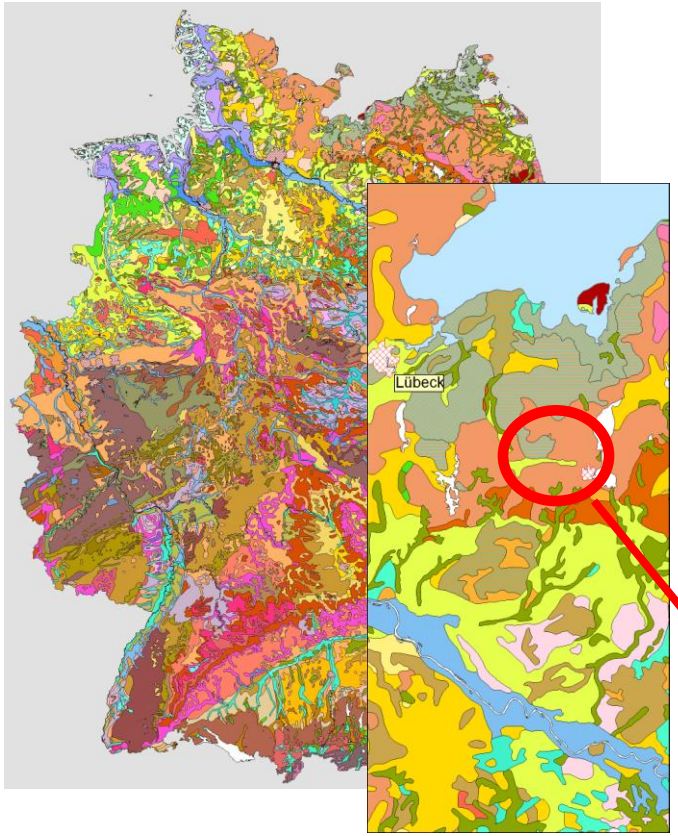
- Forested soils: higher **infiltration** of rain water, movement of surface water into slower channels, increase **water storage** in soils (higher middle pores in forest soils)
- **Soil structure** sensitive to machinery!! (up to 20 % to intensively managed forests (machine harvesting) covered with trail network (skidding trails; 4 m width, every 20 m); „site-adapted“ machinery
- **Sensitivity to climate change** – effect of tree species: soil water storage is refilled during winter: conifers use up this storage in milder winters (high evaporation during winter Spruce > Pine, no loss under deciduous forest)

Forest soils: Abundance

- Increasingly reduced to extreme sites (Plains: azonal/extrazonal, mountains, if not overgrazed and devastated): shallow soils, wet soils (periodically flooded, ground-/stagnic water, climate-dry or „parent material-dry“ soils)
- These soils fulfil specific functions: biological reservoir, ecosystem-connectivity (corridors); sites are extremely sensitive to degradation

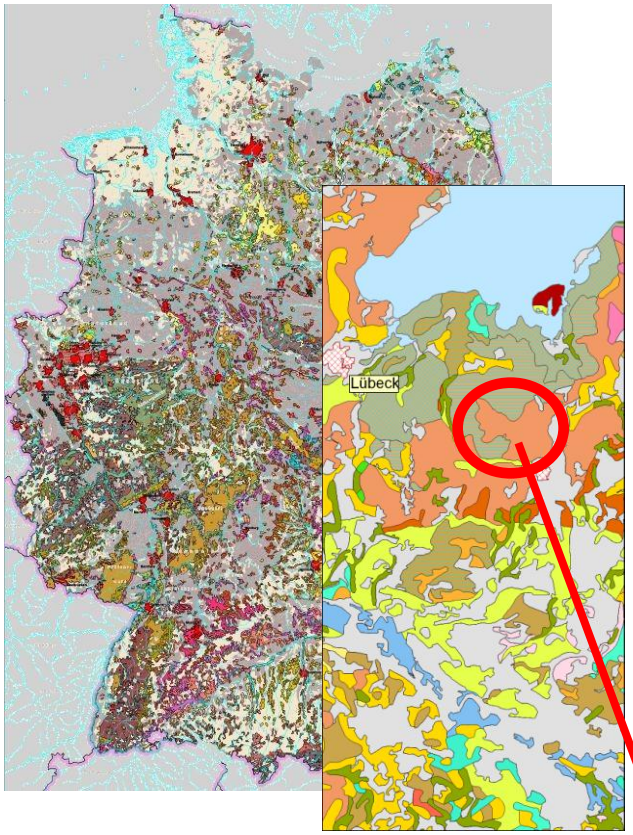
Forest soils: abundance

General soil map



Cambisol

Map legend under forest vegetation



Stagnosol

Forest soils: abundance

⇒ **Spatially-explicit modelling with the dominating soil type (and properties derived from it) from general soil maps leads to wrong results for forest-related conclusions**

(soil biophysical models, spatial property prediction)

Forest management

Forest management

natural site factors
(soil, meso-/macro climate, topography, ground water, etc.)

management history

tree species selection

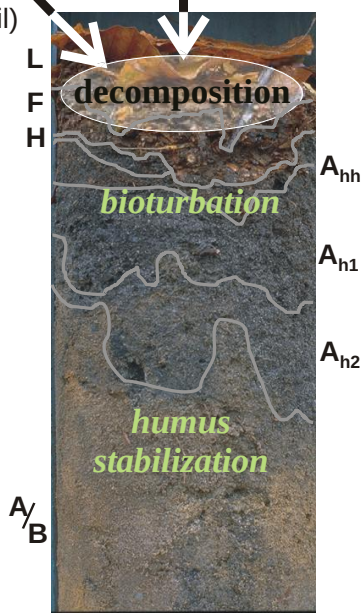
regeneration system

canopy density

throughfall

micro-climate
(below canopy, topsoil)

litter
(leaves, needles, roots, woddy debris)

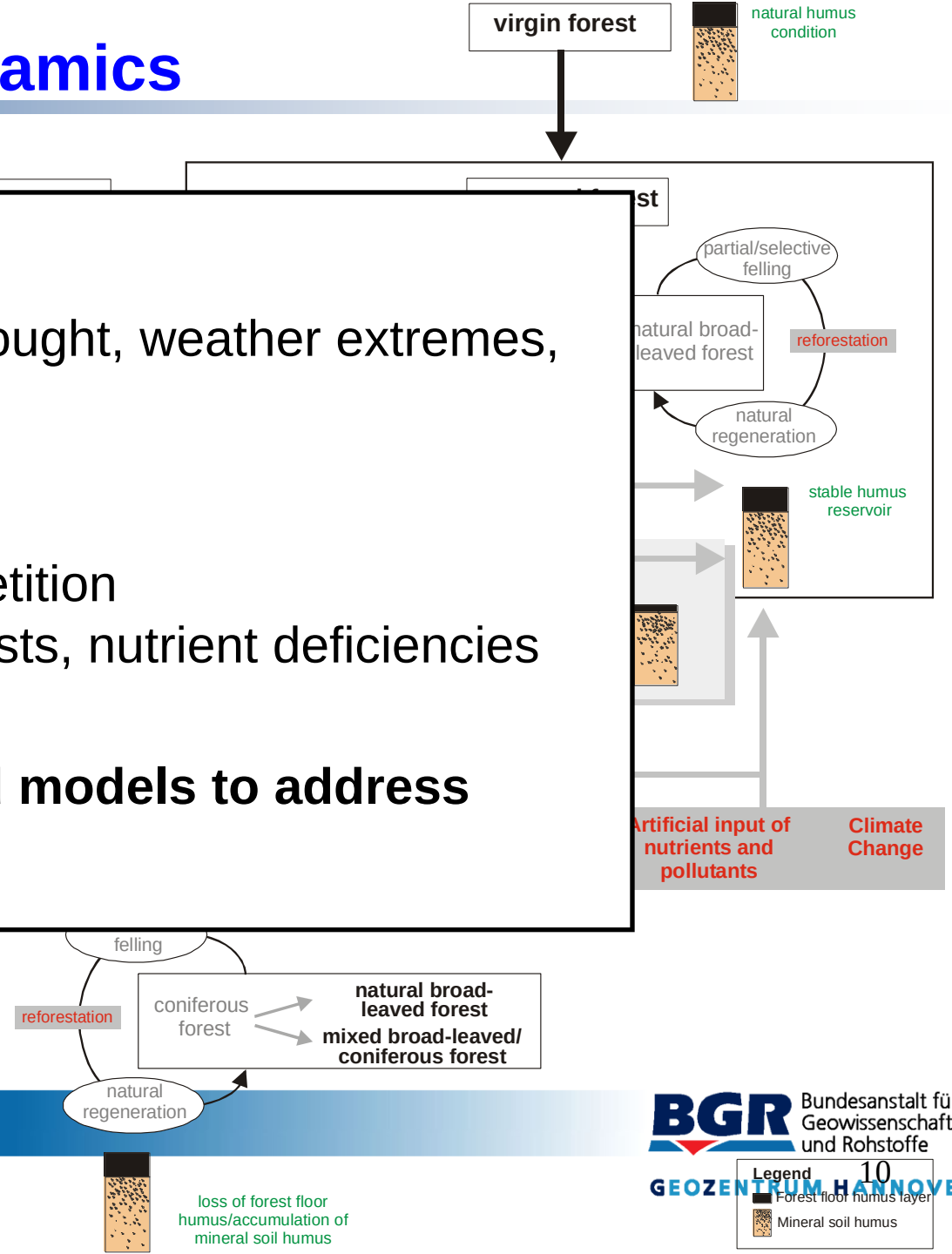


soil horizon	compartments
L, F, H	forest floor humus layer
A_{hh}, A_{h1}, A_{h2}	top mineral soil
A-B, B, C	subsoil

SOM

- rotation length
- site preparation/ planting system
- thinning intensity
- fertilization/liming
- fire control
- drainage

Forest Soils: C dynamics



Policy questions

- Climate change (drought, weather extremes, milder winters, etc.)
- Pollutant input (N)
- CO2 fertilization
- Tree species competition
- Susceptability to pests, nutrient deficiencies

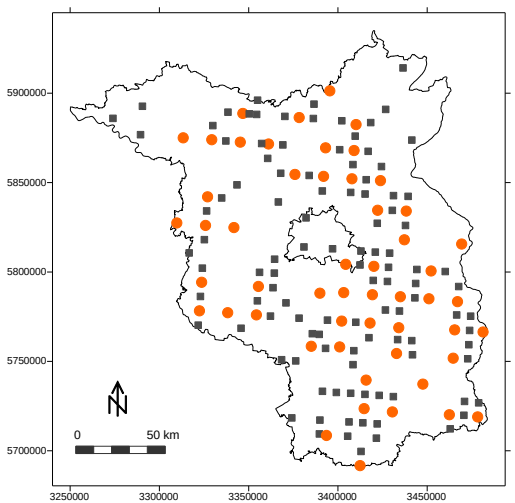
⇒ **Available data and models to address these questions**

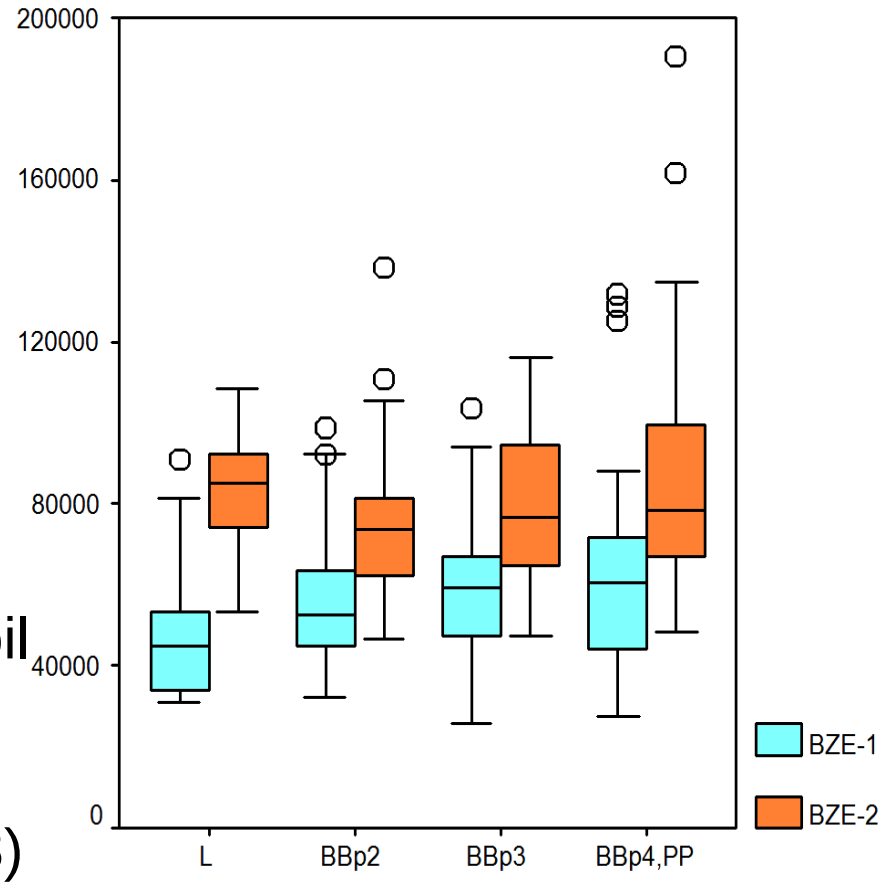
Examples: effects of forest management on SOC

- Optional reporting under the Kyoto Protocol (Art. 3.4; GHG reporting means SOC change, not just single inventory/baseline): but many questions about the sink/source directions of the effects of forest management
- Soil C is expected not to change over a forest generation, but C storage shifts between compartments (becomes more labile, at least on insufficiently buffered sandy dry soils)
- Management effects need several years to kick in

Examples: effects of forest management on SOC

- Riek (2010), Level I and BioSoil Inventory (O-layer + 0-90 cm)





- Best stratification: groups of soil types
- Mean annual change rate: 1.5 [t/ha] (1991/1992 to 2006/2008)

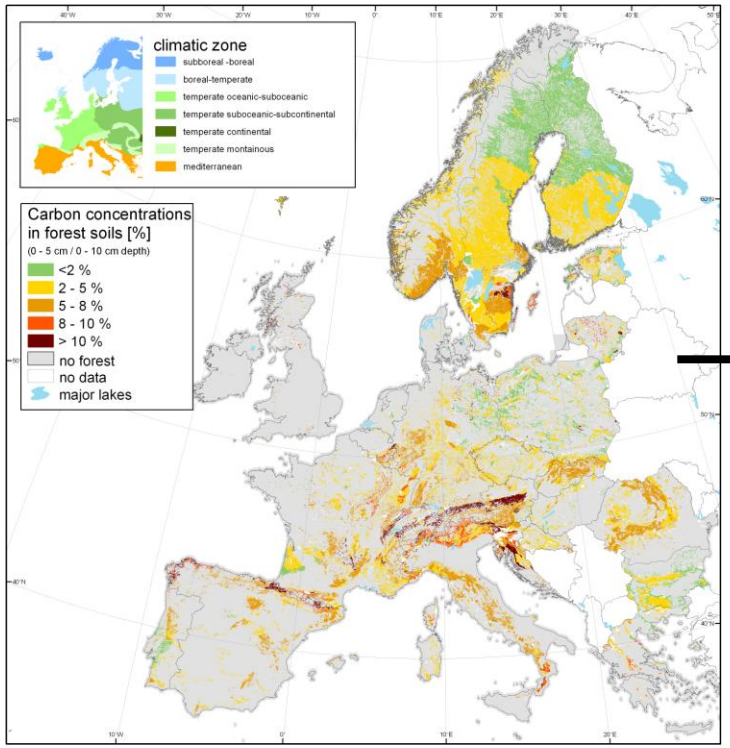
UNFCCC category: drained and cultivated peat

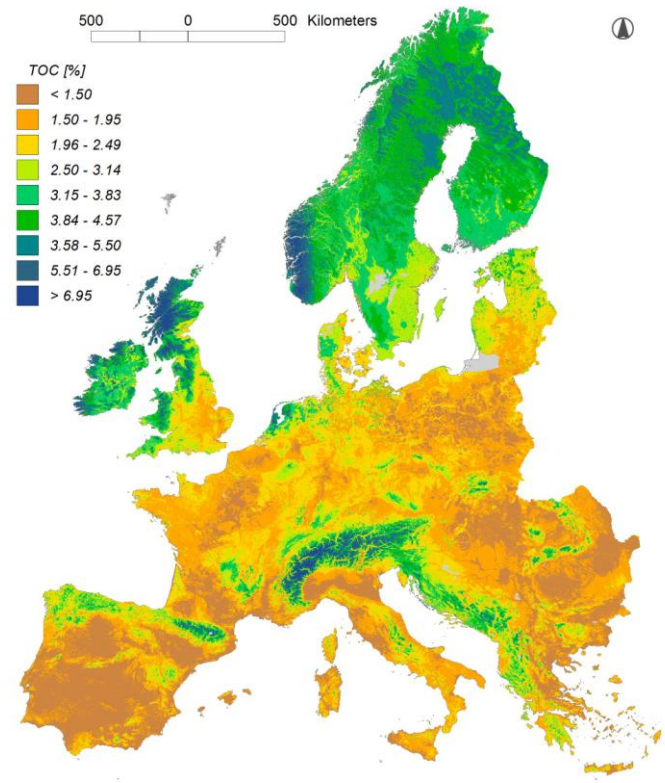
- **Peat is not necessarily forested; chronic data gap in inventories**
- **carbon source: 4 t C/ha/year for Finnish managed organic soils**
  (11(+/-4) t CO2/year under drained grassland; 20 and 70 for drained cereals and drained row crops, respectively (Kasimir-Klemedtsson et al. 1997)
- **GHG balance:**
  - CO2 release increases, emissions of CH4 decrease;
  - if mineral fertilizer is used; N2O increases

Deforestation (mandatory under Kyoto Protocol)

- between 40 and 60 % loss (first, the forest floor humus layer is lost, which can represent up to 36 % of the total SOM in German forest soils

Historic and future losses can be reliably quantified?





⇒ ***Baseline vs. change assessment***

Forest soils: C dynamics – feedback mechanisms

	SOM content	Bio-diversity	Farm economy	N_2O emission
Land use change				
arable – forest *incl. bioenergy crops*	+	+	–	–
forest – arable	–	–	+	+
set aside (*natural revegetation*)	+	+	*subsidized*	–
Forestry				
forest preservation	+	+ +	–	0
natural regeneration	+	+	+	0
plantation forestry	(–)	(+)	+ +	(–)

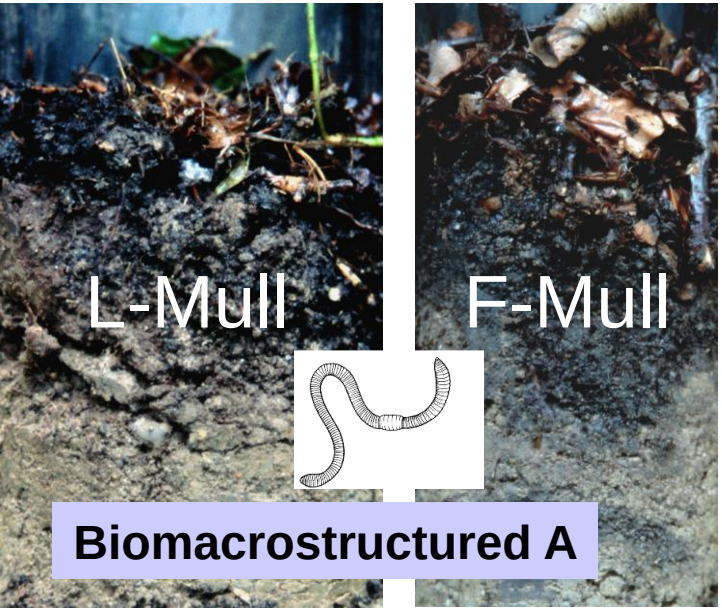
Forest soils, SOC, and soil classification

Forest soil morphology, SOC and classification

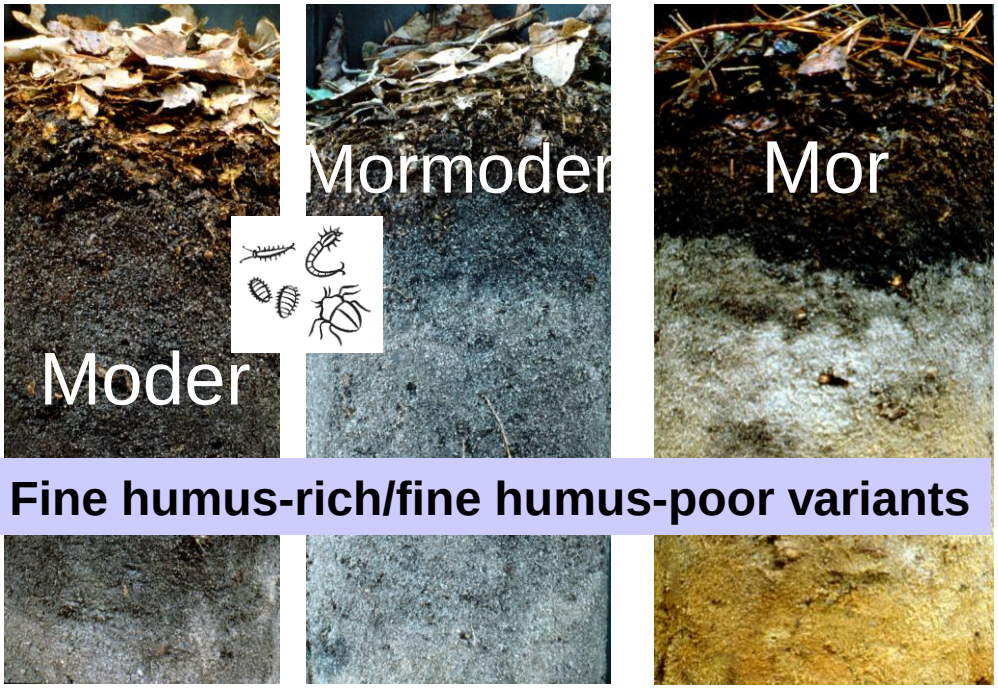
Forest productivity

Decompositional activity/soil biodiversity

C storage O-Layer



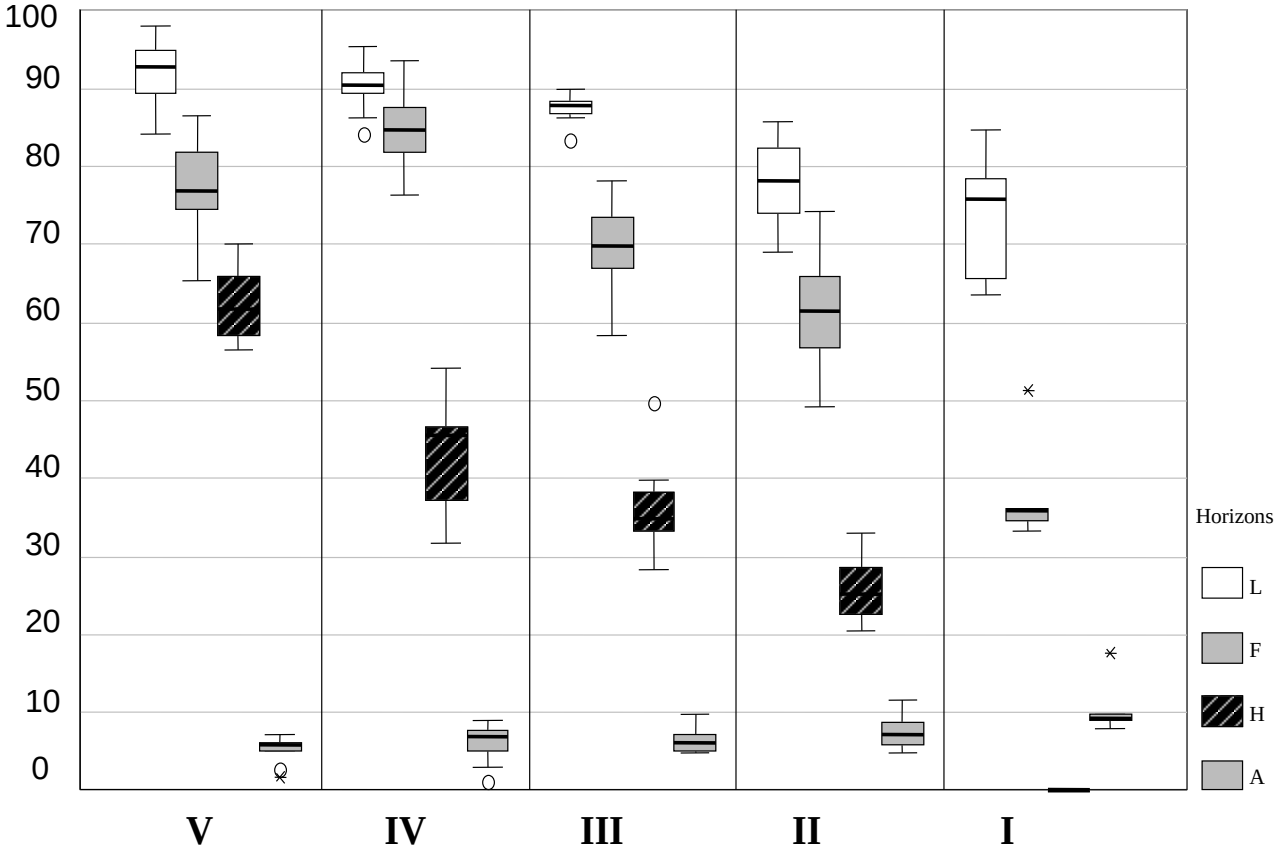
Biomacrostructured A



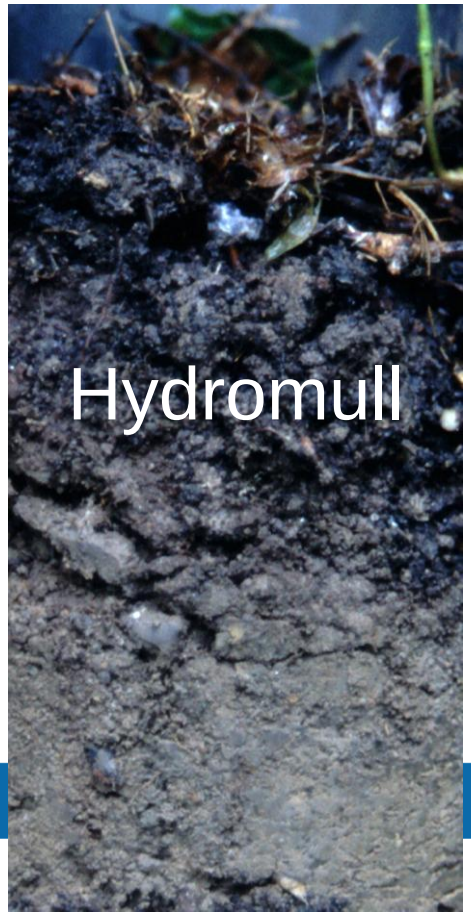
Fine humus-rich/fine humus-poor variants

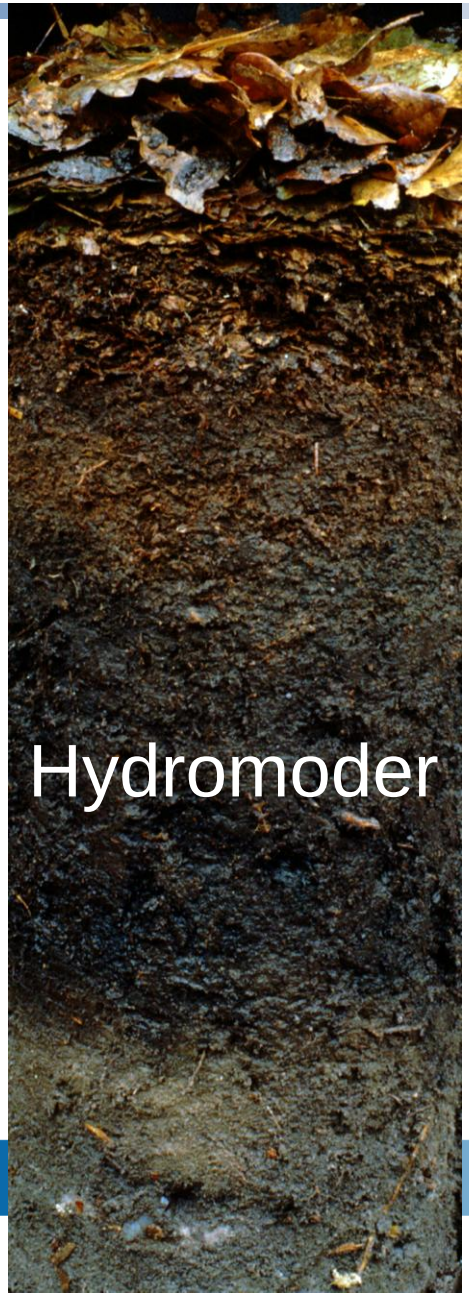
Soil carbon

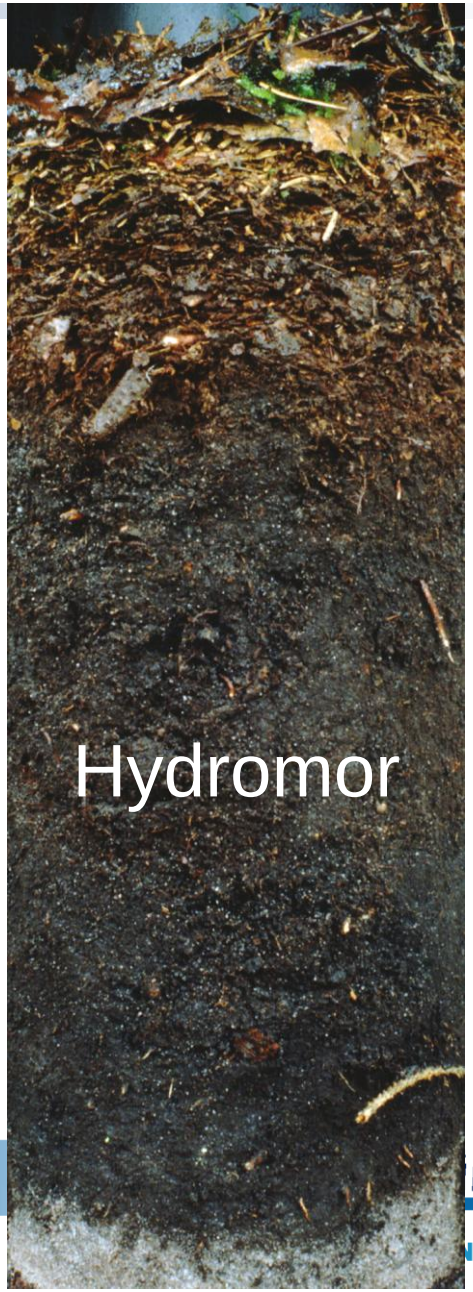
[%] organic matter



Soil carbon





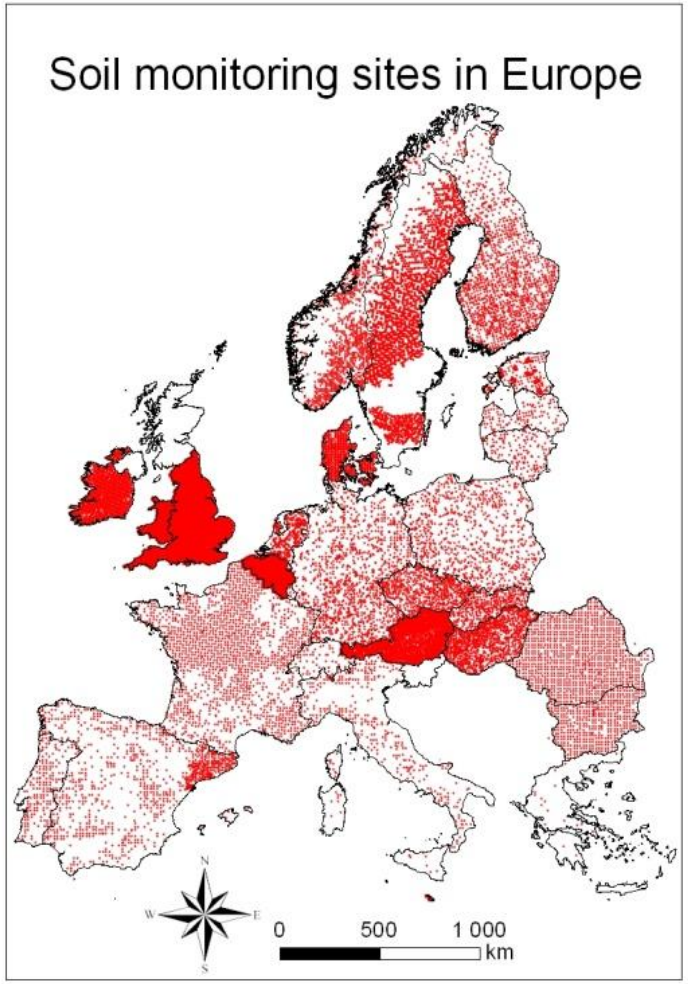


A few conclusions…

- **Top soil properties not sufficiently reflected in international soil classification** (thus are often not described and available in data bases, e.g. thickness of layers with amounts of plant residues, etc.)
- **Variability is extremely high** (especially subsoils: stones, topsoil: O-layer thickness and density; organic soils and intensively managed soils: microtopopgraphy)
- **Managed forest ecosystems: O-layer and mineral soil processes decoupled** (different drivers/predictors in spatial models)

What can we say with existing continental level data sets? (Europe)

Digital plot-level soil data in Europe:



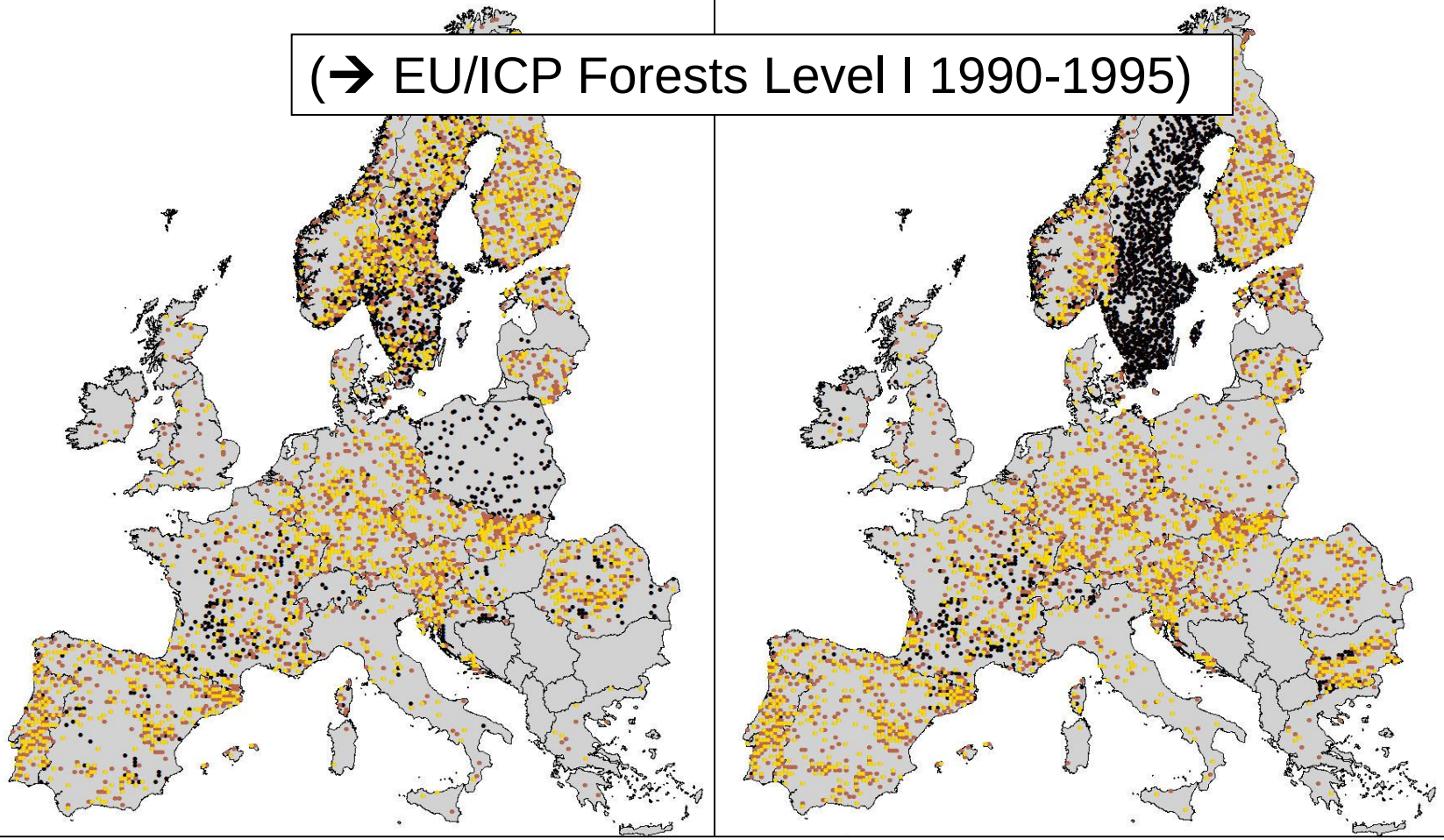
- 300,000 digital plots (questionnaire FP6 ENVASSO)
- Situation changes for C stock assessment
- Situation drastically changes for SOC change assessment (less dramatic for forest soils)
- Data available, very difficult to access

Arrouays et al. (2008)

Continent-wide forest soil condition inventories

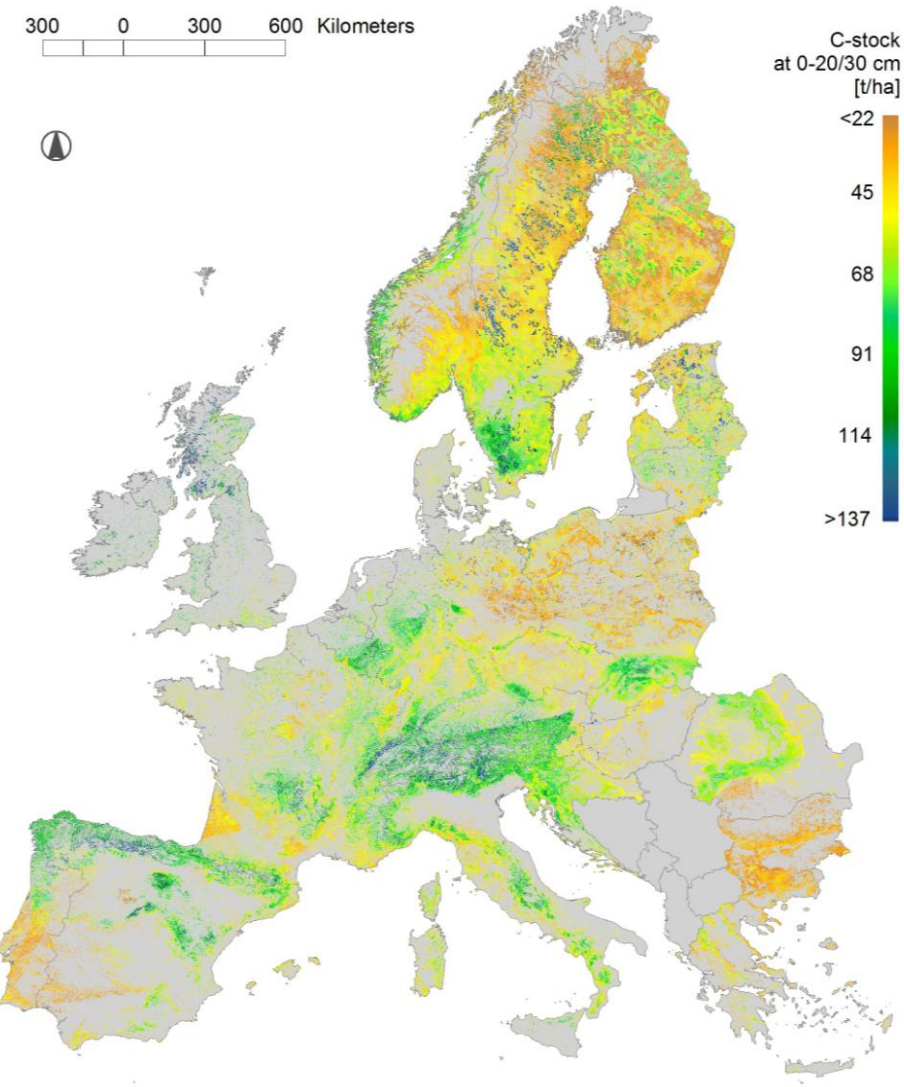
O-layer	mineral soil (0-20 cm)

(➔ EU/ICP Forests Level I 1990-1995)

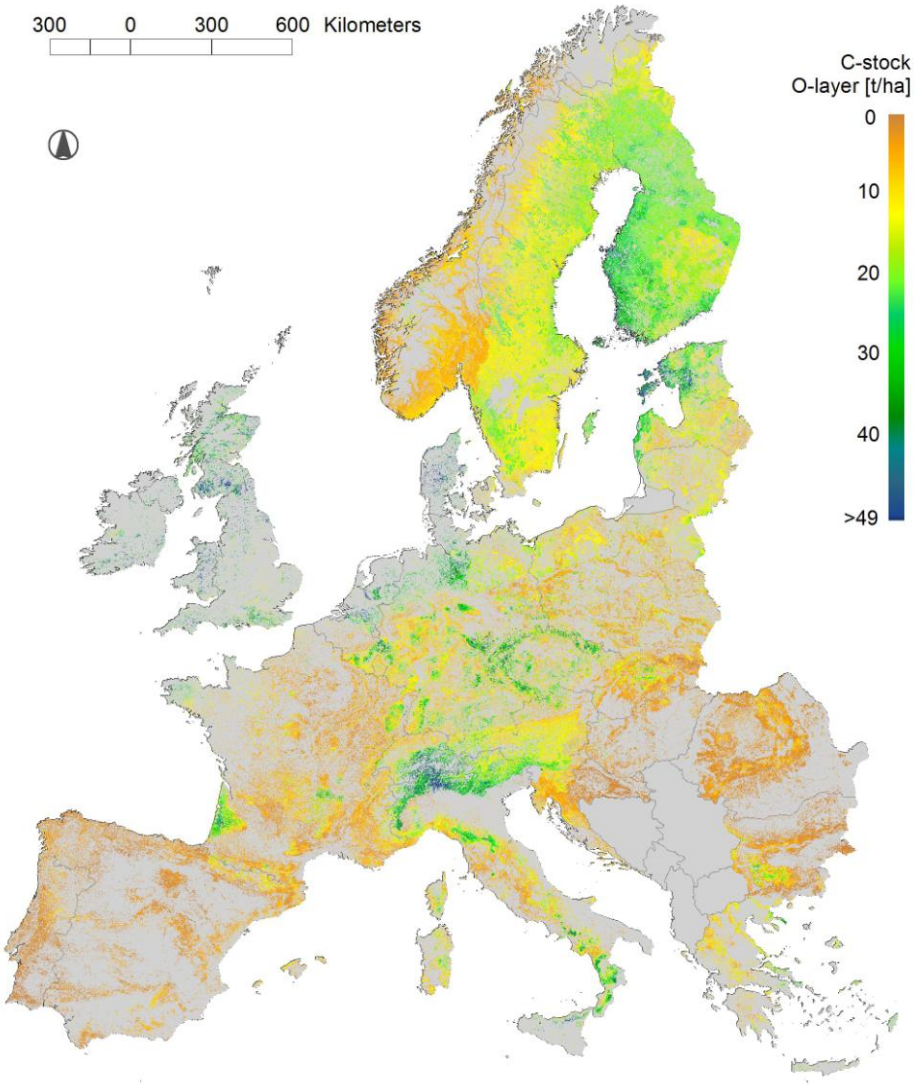


A large proportion of these plots was now re-visited: measurements of BD, particle size classes, improved estimation of coarse fragments, systematic link to WRB (➔ BioSoil Inventory 2006-2008)

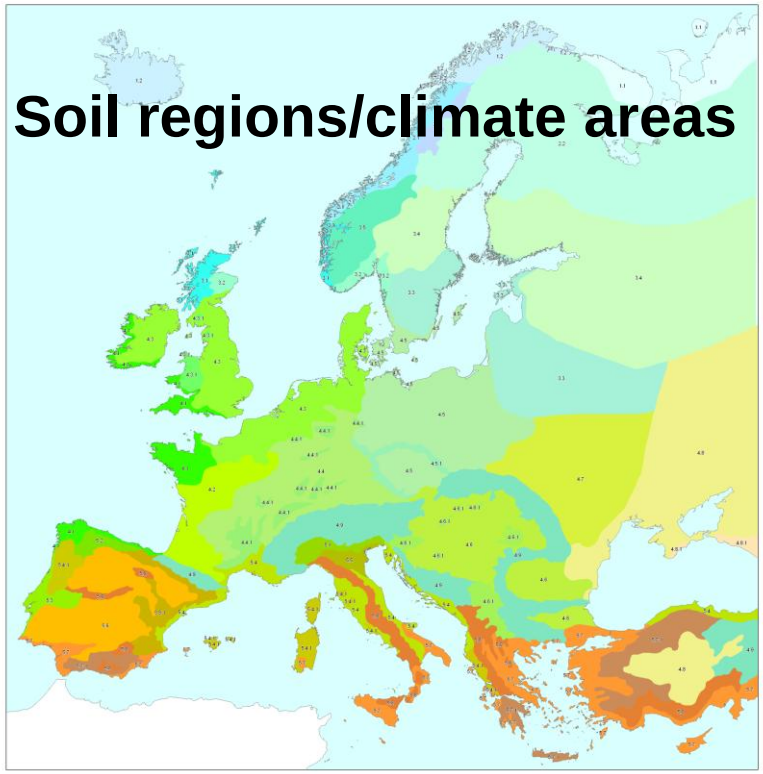
Mineral soil 0-20 cm

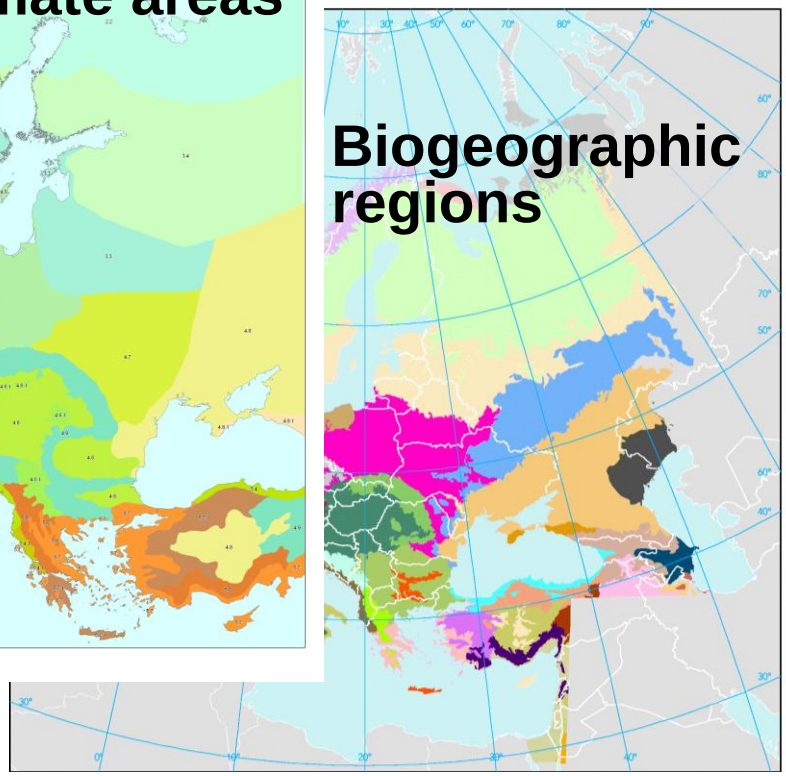


O-layer



Stratification





+ partly national borders (systematic errors)

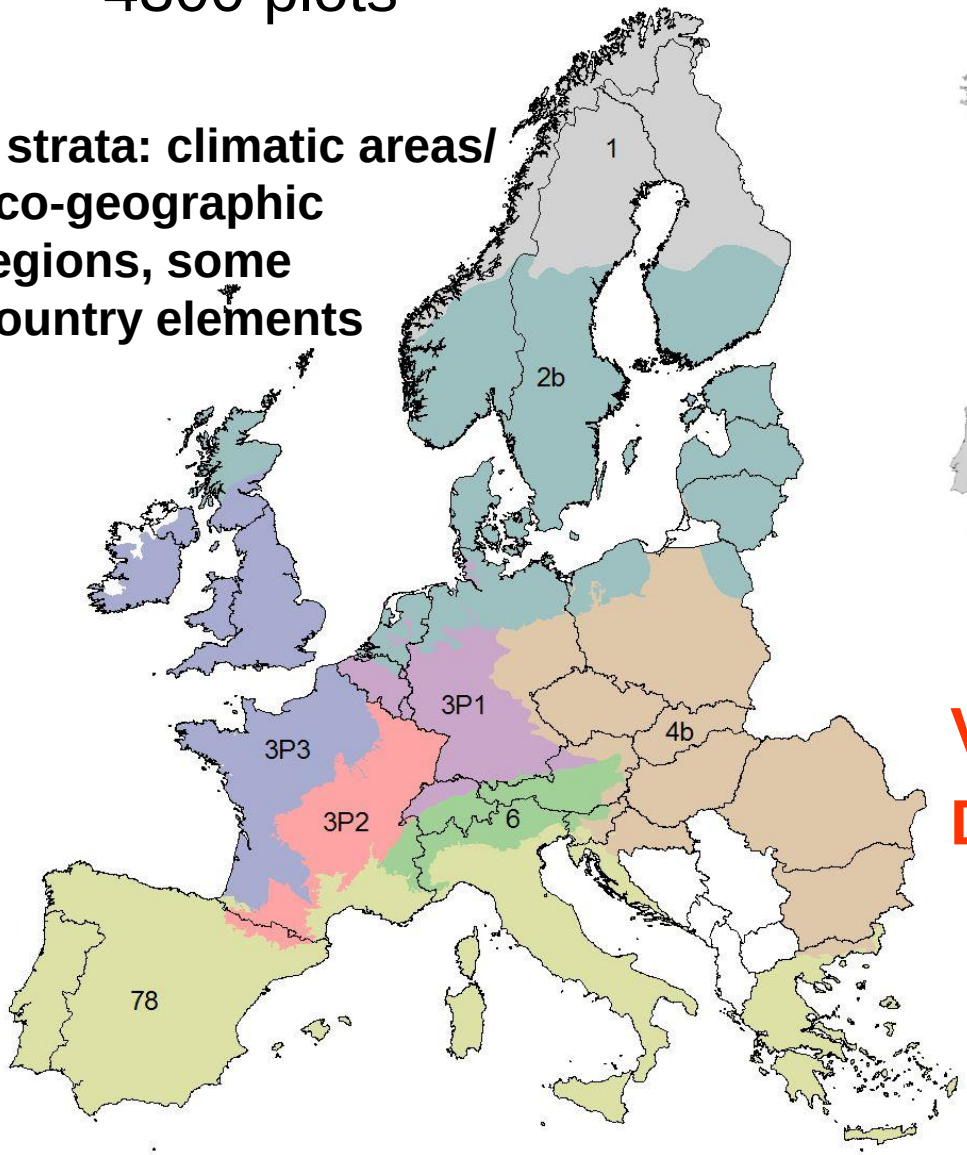
Stratification

Europe:

Forest SOC

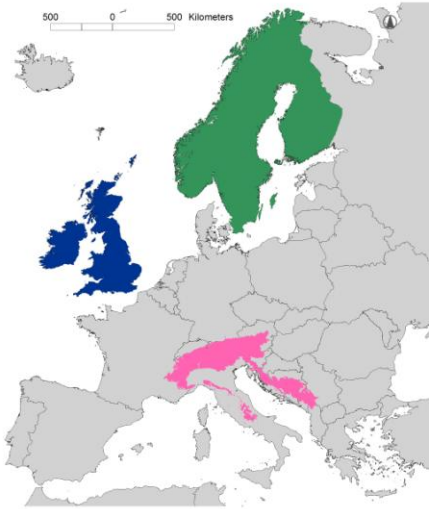
4300 plots

8 strata: climatic areas/ eco-geographic regions, some country elements



Agricultural land

2300 plots



SOC

pH

Variability?

Data density?

Europe (0-20 cm depth)

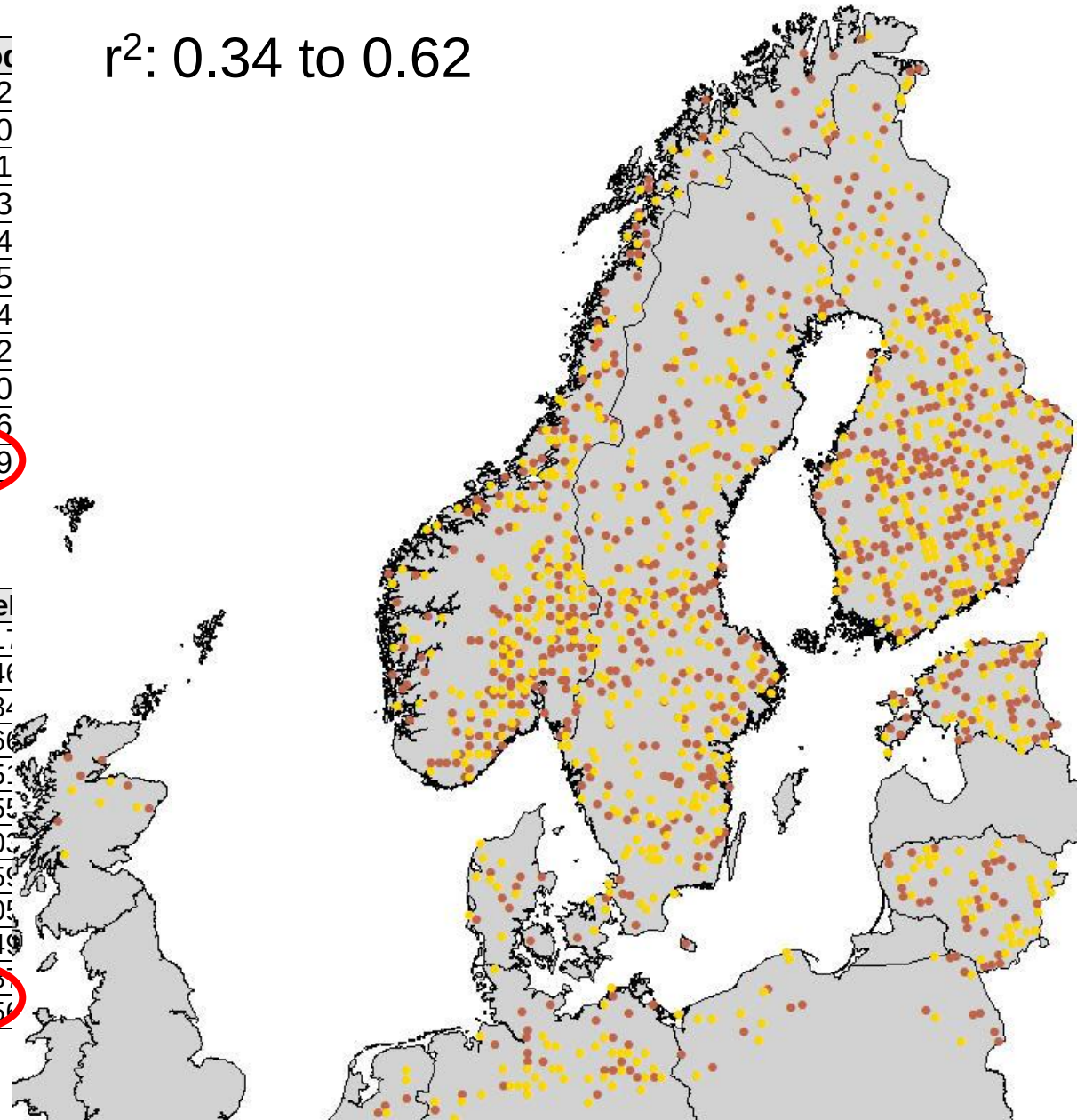
Boreal

Step	Variable	Partial R^2	Mod
1	p_Histosol	0.4027	0.402
2	BIOCLIM_3	0.0974	0.500
3	DEM	0.0211	0.521
4	TMIN8	0.0321	0.553
5	p_Cambisol	0.0115	0.564
6	WR3	0.0106	0.575
7	p_Regosol	0.0088	0.584
8	p_Podzol	0.0181	0.602
9	BIOCLIM_15	0.0079	0.610
10	PICEA	0.0060	0.616
11	PREC8	0.0036	0.619

Subboreal/Baltic

Step	Variable	Partial R^2	Model
1	p_Histosol	0.3617	0.3617
2	TMAX2	0.0729	0.4346
3	p_pinus	0.0538	0.4884
4	p_Regosol	0.0282	0.5166
5	SlopeDegr_kl5	0.0185	0.5351
6	Ecocode_46	0.0204	0.5555
7	Ecocode_86	0.0048	0.5603
8	PREC7	0.0056	0.5659
9	p_Luvisol	0.0046	0.5705
10	p_Cambisol	0.0044	0.5749
11	DICONVG	0.0038	0.578
12	TPI1000	0.0070	0.5856

r^2: 0.34 to 0.62



Conclusions

- **Drivers for SOC known, but for spatial assessment: dependent on the quality of the data base/resolution**
- **SOC stocks: BD increasingly covered on the basis of regionally calibrated PTF; coarse fragments (stones) is probably main uncertainty (especially forest soils!)**
- **C stock change assessment** (GHG effects): **Management effects, climate change, projections, sensitivity etc. only on the basis of soil biophysical models** (issue: hydrological homogenous response units: do not require soil type, but spatially explicit texture and SOC baseline, if possible hydraulic data (soil moisture module), and chemical data (CEC, pH) related to soil fertility (productivity module) – depending on the model)

- **Resolution of digitally available (transboundary) soil maps is poor, any area-related estimate inaccurate; specific soils under forest often not known, data about the O-layer is often missing, ability of models to reflect decompositional activities in forest soils (O-layers – mineral soil) becomes increasingly solved**
- **Density of plot measurements is actually <u>not</u> poor (for Europe), but access and quality restrictions**
- **Quality of spatially explicit data on land use and climate is still poor (despite 1 km World Clim)**

Thank you for your attention!

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