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There is a need to better take into account forest soils in the planned soil monitoring law of the European Union

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Abstract

Key message A Soil Monitoring Law to improve soil health across all land uses has been proposed by the European Commission. As forests soils have different chemical and physical properties as well as biogeochemical dynamics compared to agricultural land, they also face different challenges in maintaining and restoring soil health. Examples are soil acidification, eutrophication by atmospheric deposition, responses to climate change, and loss of biodiversity. Therefore, we propose forest soil specific health descriptors and thresholds based on experience and knowledge from existing long-term monitoring programs.

Keywords Forest soil monitoring, ICP Forests, Soil health, Forest floor, Thresholds, Indicators

1 Introduction

Soil is one of the basic pillars of the environment, human society and the world economy. Currently, 33% of soils worldwide are already degraded and over 90% of soils could be degraded by the middle of the century (FAO and ITPS 2015; IPBES 2018). It is estimated that in the European Union (EU) alone, the costs associated with soil degradation amount to over 50 billion euros per year (Kraamwinkel et al. 2021). To protect soil resources and maintain and improve their quality, the EU Soil Strategy for 2030 sets the long-term vision that by 2050, all EU soil ecosystems are in healthy condition and are thus more resilient. The Soil Strategy for 2030 announced that the Commission would table a legislative proposal on soil health to enable reaching the objectives of the Soil Strategy. In its resolution of 28 April 2021 on soil protection, the European Parliament emphasised the importance of protecting soil and promoting healthy soils in the EU. The European Parliament called on the Commission to design a Union wide common legal framework, with full respect for the subsidiarity principle, for the protection and sustainable use of soil, addressing all major soil threats. We therefore welcome Soil Monitoring Law (SML) proposed by the European Commission (EU COM) as it will promote soil health, create a soil monitoring network for all soils across the EU, make sustainable soil management a standard in the EU, and enhance restoration of contaminated soils. However, to be successful, the specific

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characteristics of forest soils in terms of properties and management should be taken into account in the SML, as explained below. This would not only improve the implementation of the EU Soil Strategy, but also increase the acceptance of the SML by the Member States and stakeholders.

2 EU activities to improve soil health

In the EU, different strategic actions dealing with soils underlined the interest of an EU-wide assessment of indicators leading to soil health for all land uses. The SML (EU 2024) said that: "As part of the Green Deal, the Biodiversity Strategy for 2030 announced the update of the 2006 Soil Thematic Strategy (STS) to address soil degradation and fulfil EU and international commitments on land-degradation neutrality. The EU Soil Strategy for 2030 set the vision to have all soils in healthy condition by 2050, to make protection, sustainable use and restoration of soils the norm and proposes a combination of voluntary and legislative actions. Addressing soil degradation and ensuring the protection and sustainable use of soil, including by a Soil Monitoring Law (SML), is also included in the 8th Environment Action Programme." The second draft of the SML (Rev II) has been developed through expert and scientific workshops and a public consultation process. Furthermore: "The SML proposal puts in place a solid and coherent soil monitoring framework for all soils across the EU, which will address the current gap of knowledge on soils. It should be an integrated monitoring system based on EU level, Member State and private data. This data will be based on a common definition of what constitutes a healthy soil and will underpin the sustainable management of soils, to maintain or enhance soil health, and thus to achieve healthy and resilient soils everywhere across the EU by 2050. The soil monitoring framework is crucial to provide the data and information needed to define the right measures. It is therefore appropriate to lay down criteria for sampling points that are representative of the soil condition under different soil types, climatic conditions and land use." (EU 2024). That means the EU calls for Member States to prepare a system for the monitoring, descriptors and thresholds of soil for all land uses. At the same time, there is already a great deal of expert knowledge and harmonized monitoring systems.

3 Why are forest soils important and what makes them different?

Forests cover approximately 39% of the EU's total land area. Compared to arable soils, forest soils are often unsuitable for agriculture, as they tend to be stonier, less fertile, affected by waterlogging, and often located on steeper slopes. Forest soils are not disturbed by annual tillage and harvest, and their management usually takes place over decades to centuries. For this reason, soils under forests have different physical and chemical properties and biogeochemical dynamics compared to adjacent agricultural soils. Forests typically develop an organic surface layer (forest floor). Several properties of the forest floor are used as indicators as mentioned in the European indicator report (EEA 2022). According to EEA (2022), one possible indicator for the impact of nitrogen eutrophication in forests is the low C/N ratio for either the highly humified organic layer (H horizon, for moderate to nutrient-poor forest soils) or the top few centimetres of mineral soils (nutrient-rich forest soils without H horizons). The characteristics of forest soils (incl. well-developed organic layer) should be taken into account when developing EU-wide regulation of soil management and soil monitoring network. Forest soils store much more organic matter than agricultural soils, which is why forests play a crucial role in the European soil carbon balance and related climate change mitigation measures in the EU (Grüneberg et al. 2014; Jonard et al. 2017; Leitgeb et al. 2013). Organic soils like peatlands have the highest C content, but in case they get drained, those turn into a carbon source. Moreover, the forest floor organic layer is a biological hotspot, affecting the carbon, water and nutrient dynamics of forest soil and of the whole ecosystem (Dise et al. 1998).

4 Forest soil health is affected by various factors

Forest soil health is affected by various factors, both natural and human-induced, which are different from the threats to soil health under other land uses. Soil health is affected differently depending on the region and the pollution climate. Human-induced nitrogen deposition, heavy metals and acid rain also have long-lasting effects, e.g., extreme pollution from the second half of the twentieth century is still clearly visible in forest soil properties in some European regions (Ulrich 1991; Thimonier et al. 2019).

Furthermore, climate change become more evident in forests and their soils in recent years (Bytnerowicz et al. 2013; Hickler et al. 2012; Filho et al. 2023). In Europe, most forests are semi-natural ecosystems that are usually managed much less intensively compared to agricultural land. In forests, where tree roots grow in many cases much deeper than those of arable, annual crops, the parent material and soil type play a more important role in the nutrient supply than in agroecosystems because, unlike arable soils, forest soils are only fertilized in exceptional cases. Essential macronutrients like nitrogen and phosphorous both of which widely limit primary productivity across forest ecosystems are decreasing (Talkner et al. 2009; Elser et al. 2007; Vitousek et al. 2010). Thus,

Fig. 1 An example of forest soil profile: Norway spruce forest with an alumic stagnic Albeluvisol (cutanic, greyic, ruptic, siltic) and mor as typical clearly distinguishable organic layer. Copyright: Janis Kreiselmeier. This is according to WRB (IUSS 2022) and Zanella et al. (2009)

increased nitrogen deposition often stimulates tree growth and hence ecosystem Carbon sequestration in nitrogen-limited forests (Högberg 2007; De Vries et al. 2009; Thomas et al. 2010), considering that in forests SOC decomposition is often reduced in response to (high) nitrogen deposition (e.g., Janssens and Luyssaert 2009). The nitrogen-induced increase in the growth can be diminished, however, when the accompanying phosphorous supply is deficient (Braun et al. 2010; Lang et al. 2016). Soil phosphorous availability in terrestrial ecosystems is primarily driven by mineral weathering and atmospheric deposition (Vitousek et al. 2010). P input from atmospheric deposition is low, and this also holds for weathering, which is also generally low.

European forests grow on a wide variety of soil conditions. Moreover, due to long rotation periods, soil and forest management practices have long-term impact and require a longer period of monitoring and evaluation. Such a survey can be less frequent (10–15 years) than is proposed by the SML which expect that "Member States shall ensure that new soil measurements are performed at least every 6 years within one sampling campaign or as part of a continuous sampling scheme which expect sampling every 6 year".

Specific disturbances threaten forest soil health and are of a different nature and magnitude than on arable soils. For instance, forest fires, soil perturbation by windthrow, invasive species, pest infestation, improper forestry practices, overuse of timber resources, drainage of peatlands and resulting soil compaction have long-lasting impact on soil properties. In many cases, the deterioration in soil quality cannot be directly attributed to forest management, but is due to many different influencing factors (Fig. 1).

5 Harmonized European forest soil monitoring since the 1990s

Member states can build the proposed soil monitoring on existing forest soil monitoring system, which provides long-time data series, expertise and proven methods for soil surveys based on the ICP Forests Manual (Cools and de Vos 2020). For reasons of representativeness on a country scale, the countries should increase the number of plots accordingly. According to the SML, the number and location size of the national sample sampling points shall meet the requirement of representing the variability

of the chosen soil descriptors within the soil units with a maximum per cent error (or coefficient of variation) of 5% for the estimation of the area having unhealthy soils.

The International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (UN ECE ICP Forests) under the authority of the Air Convention of the United Nations Economic Commission for Europe is a network to assess forest health, including a soil monitoring programme on a European scale. Forest soil monitoring under the ICP Forests is internationally coordinated through a structured governance system, harmonized and standardized protocols, covers the majority of the member states, and is in line with existing reporting systems such as the LULUCF regulation, the EU Nature Restoration Law or the NEC Directive. The ICP Forests activities include optimization of sampling design considering spatio-temporal variation, methodological uncertainties, investigation of systematic errors to improve accuracy, intercalibrations between analytical procedures, and in-depth understanding of the chemical, physical and biological dynamics of forest soils. Since 1990, a systematic 16×16-km grid (Fig. 2) provides monitoring on around 5500 plots across Europe for forest health condition (ICP Forest Level I). Several harmonized soil surveys were realized within the network starting from the 1990s. Together with soil sampling, biodiversity data (forest type, tree species, ground vegetation, deadwood, etc.) was collected during the EU co-funded demonstration project (2006–2009) so that forest soil condition can be closely linked to biomass productivity and to forest condition. Some Member States have soil monitoring schemes in place like the French network ReNEcofor, which is linked to the ICP Forests network.

6 Suggested actions

a. SML — Monitoring should use existing forest monitoring and reporting systems that include forest inventory data. This allows to link tree stand structure, forest productivity, forest management and its impact soil health and is therefore in line with existing reporting systems like LULUCF, the proposed Nature Restoration Law or NEC Directive.
b. The design of the sample survey should be using the best available information on soil properties distribution, including, but not limited to information resulting from previous national or subnational surveys, relevant measurements from soil managers and measurements under the LUCAS Soil program and the ICP Forests Program. Data obtained from sampling points taken during soil investigations at contaminated sites may be used for the assessment of

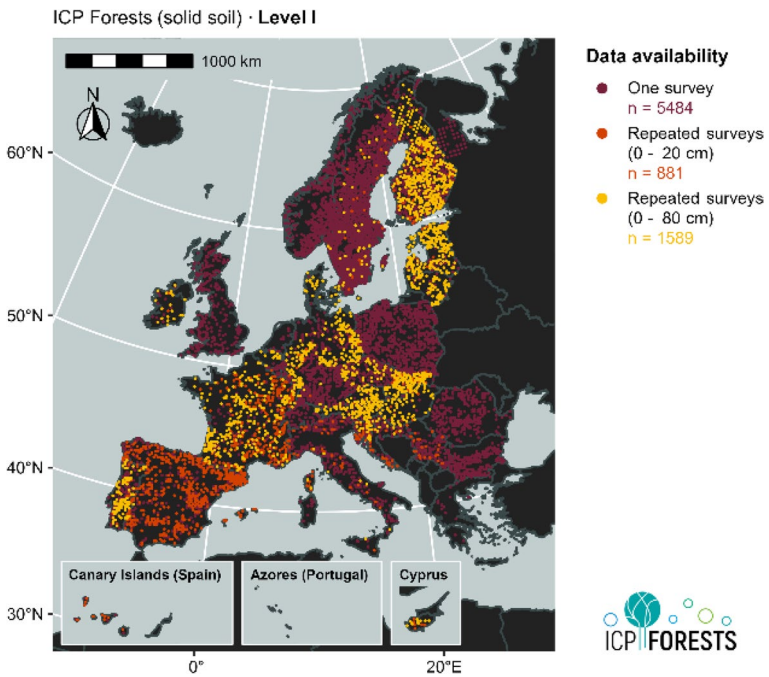

Fig. 2 Pan-European distribution of ICP Forests Level I plots with one or more soil surveys since 1990. On 93% of all plots, the forest floor was sampled by areal-mass. The majority of plots with repeated surveys underwent subsoil sampling to a depth of 80 cm, which is required for proper forest soil health assessments. Average time interval between surveys is 15 years

soil health criteria provided they are not linked to the contaminating activity. The existing pan-European forests monitoring program (ICP Forests) is particularly suitable because it is harmonized across Europe and offers long-term data to identify thresholds for healthy forest soils.

c. Specific indicators and thresholds applicable for the identification of degraded forest soils are needed. Furthermore, the sampling and inventory design should take into account the whole rooting zone of trees, the spatial heterogeneity of forest soils and the sampling of the forest floor.
d. If the number of plots will be expanded by LUCAS Soil or national soil monitoring programmes, the sampling scheme for SML should be improved for proper forest soil spatio-temporal monitoring, in line with existing monitoring programs. Careful sampling of the forest floor on all plots where it exists is particularly important for the evaluation of forest soil condition and its changes. In addition, the bulk density and coarse fraction should also be collected at each plot in order to calculate the stocks and stock changes correctly.
e. Building on and upgrading the existing EU soil observatory, the Commission should establish a digital soil health data portal that should be compatible with the EU Data Strategy24 and the EU data spaces and which should be a hub providing access to soil data coming from various sources, in the aggregated form. A data interface like those of the ICP Forests should be developed for the provision of data within the framework of the SML, via which (i) all national data can be checked in a standardized manner and (ii) made available in harmonized formats for further analyses and evaluations.

7 Conclusion

Successful implementation of the proposed Soil Monitoring Law will provide important data for evaluation to enhance soil health and bring the European soil monitoring to a new era. By using existing forest soil monitoring networks and national forest inventories as well as harmonized sampling design and developed expertise, the EU Soil Monitoring Law can build a soil monitoring system that supports the Soil Mission targets and serves stakeholders by providing relevant information about changes in the soil properties. A harmonized approach offers the opportunity to assess soil conditions across Europe with coordinated indicators and threshold values. We recommend to use the long-time series of the ICP Forests for this purpose.

Authors' contributions
Conceptualization: Raisa Mäkipää, Nicole Wellbrock; writing—original draft preparation: Nicole Wellbrock; writing—review and editing: Vit Sramek, Pavel Pavlenda, Bruno de Vos, Ernst Leitgeb, Robert Jandl, Natalie Cools, Kai Schwärtzel, Raisa Mäkipää, Aleski Lethonen; Figures: Bruno de Vos, Nicole Wellbrock. The authors read and approved the final manuscript.

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