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Recent results and updating of scientific and technical knowledge

Effects of air pollution on forests

Executive summary report by the Programme Coordinating Centre of the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests

Summary

The present report presents the results of the activities undertaken since the previous report by the Programme Coordinating Centre for the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests. The activities and the report on them are in accordance with the request of the Executive Body to the Convention on Long-range Transboundary Air Pollution in its 2012–2013 workplan for the implementation of the Convention (ECE/EB.AIR/109/Add.2, items 3.1 (c) and 3.4). The report details, in particular, work on monitoring and modelling in 2013.

Contents

I. Introduction

1. The present report presents the results of the activities undertaken since the previous report by the Programme Coordinating Centre for the International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). The activities and the report on them are in accordance with the request of the Executive Body to the Convention on Long-range Transboundary Air Pollution in its 2012–2013 workplan for the implementation of the Convention (ECE/EB.AIR/109/Add.2, items 3.1 (c) and 3.4).

II. 2012 results of monitoring/modelling

A. Forest soil carbon stocks

1. A new benchmark for European forest soil carbon stocks

2. Soil is the largest terrestrial pool of organic carbon. It contains more carbon (C) than the biosphere and atmosphere together (Batjes, 1996; Schlesinger, 1997; Grace, 2004). Since soils contain (at least) more than twice the C found in the atmosphere, loss of C from soils can have a significant effect on atmospheric carbon dioxide (CO_2) concentration, and thereby on climate (Smith, 2008). The response of soil carbon stock (SOC) to global warming is, therefore, of critical importance.

3. Forest soils are a major reserve of terrestrial C stock. Roughly about 30 per cent of the global land area consists of forest soils. In absolute terms, the extent of forest soils is greatest in “continental” Europe (~1,000 millions of hectares (Mha)), accounting for 27 per cent of the global forest soil extent (Ministerial Conference on the Protection of Forests in Europe (Forest Europe), United Nations Economic Commission for Europe (ECE) and Food and Agriculture Organization of the United Nations (FAO), 2011). In the present is study, however, the focus is only on a fraction of this European forest area (i.e. ~163 Mha), since the vast forest areas of the Russian Federation (> 800 Mha) are not included.

4. Prentice (2001) estimated the world’s forest soil carbon stocks at 704 gigatons (Gt) C out of ~1,500 Gt C for all soils(Jobbágy and Jackson, 2000), consisting of 213 Gt C (30 per cent) in tropical forests, 153 Gt C (22 per cent) in temperate forests and 338 Gt C (48 per cent) in boreal forests. Average soil carbon stocks (till 1 metre (m) depth) are 122 t C per hectare (ha^{-1}), 147 t C ha^{-1} and 296 t C ha^{-1} for tropical, temperate and boreal forests, respectively (Prentice, 2001; Lal, 2005). Thus, forest soils store roughly about half of the terrestrial SOC stock with the largest C densities in boreal forest soils. The latter is partly explained by the relatively high occurrence of peat soils in this region.

5. Despite the tremendous importance of accurate estimation of EU forest soil carbon stocks, only a few studies reported SOC estimates at the European level (Baritz and others, 2010). The areal extent and the methodology for these estimations vary greatly, and until now, did not allow for a reliable benchmark to be set.

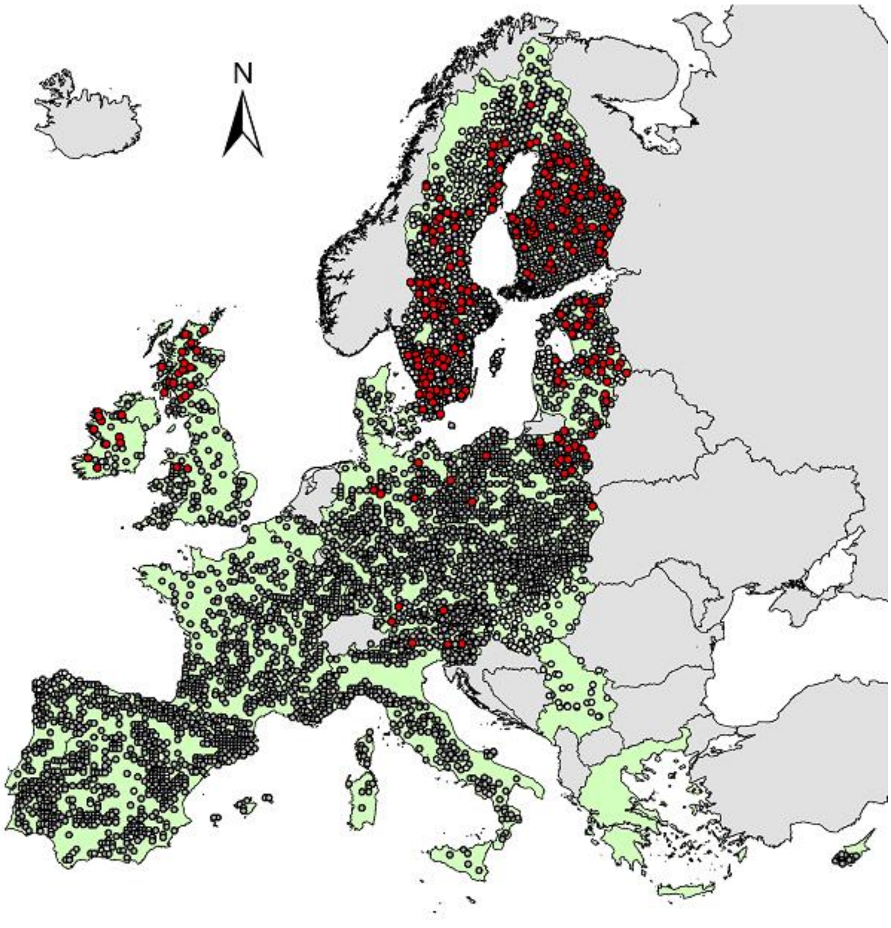
6. Based on the second forest soil condition survey, conducted between 2004 and 2009 during the European Union (EU) Forest Focus BioSoil demonstration programme (Hiederer, Michéli and Durrant, 2011), soil samples from 4,928 ICP Forests level I plots of 22 European countries (figure 1) were collected and analysed.

7. For the first time, variables essential for reliable carbon stock estimations were effectively quantified using harmonized methods: bulk density; coarse fragments; limiting soil depth; and carbon concentrations of all mineral and organic layers up to 80 centimetres (cm) of depth. Compared to the data set of the first European forest soil survey

(1985–1996) reported by Vanmechelen, Groenemans and Van Ranst (1997) and used for carbon quantifications by Baritz and others (2010), the current forest soil data set (FSCDB.LI.2.1) is much more complete and adequate. About half of the level I plots assessed during the BioSoil survey were also sampled during the first survey, albeit with variable sampling schemes and diverging analytical methods, complicating assessment of carbon stock changes over time. This will be the next challenge to address.

8. The carbon stocks in the forest floor could be estimated for 82 per cent of all level I plots (figure 1). Average organic carbon (OC) pools in terrestrial humus forms range from 8 tons (t) C ha^{-1} in Mull types to 22.5 t C ha^{-1} in Mor types, and from 19.6 to 74.4 t C ha^{-1} in semi-terrestrial (wet) humus forms. Histomoders and Histomors store over two to three times more OC than Moders and Mors, respectively. In all, the OC stock of European forest floors reveal an estimated median value of 13.8 t C ha^{-1} and a mean of 22.1 t C ha^{-1}. When upscaling the plot-based averages to the European level, forest floors store about 3 Gt carbon in all the surveyed countries (135 Mha of forest). Extrapolated to a European reference forest area of 163 Mha, this amounts to 3.66 Gt C.

Figure 1
Map of surveyed countries (green) and their systematic level I plots (O)



Note: Plots where 1-m SOC stocks could be quantified are filled in grey. Red dots show afforested peat soils as carbon "hotspots".

9. Excluding Histosols (peat soils), the average carbon stocks in mineral soils is 64.9 t C ha^{-1} till 30 cm of depth, ranging from 10.8 to 176 t C ha^{-1} (95 per cent range). To

100 cm or effective soil depth the average SOC stock is 108 t C ha^{-1}, with 95 per cent of all SOC stocks comprised within 15.5 and 349 t C ha^{-1}. For the Histosols, the average 0–30 cm stock is 186 t C ha^{-1} (95 per cent range: 25–383) and for 0–100 cm depth 578 t C ha^{-1}, with 95 per cent of these plots ranging from 63.1 to 1,159 t C ha^{-1}, depending on peat thickness.

10. Generally, 30-cm C stocks represent 44–66 per cent of total 1-m stocks in mineral soils, whereas they account for only 32 per cent in peat soils, indicating distinct and specific depth profiles between mineral and organic soils. In all, about 50 per cent of the 1-m stock is stored in the upper 20 cm, and ~22 per cent, ~12 per cent, ~10 per cent and ~7.5 per cent in the subsequent 20-cm intervals. Since carbon stored in the forest floor and topsoil (< 20 cm) is much less sequestered compared with deeper layers (Trumbore, Chadwick and Amundson, 1996), roughly half of the 1-m carbon stock might become a source of CO_2 to the atmosphere upon deforestation or due to severe climatic changes, causing in turn a positive feedback mechanism for global warming.

11. When upscaling the SOC stocks to the European level, the 1-m stock in the surveyed countries (135 Mha) is 18.03 Gt C and 21.8 Gt C for the EU (163 Mha). Confidence intervals for each of these estimates and a description of the calculation methods is given in De Vos, Bruno and Cools (2011). Relative to the estimates of Prentice (2001), the forest soils' carbon reservoir in the ICP Forests study area represents only ~3 per cent of the global forest SOC stock and ~14 per cent of the stock of temperate forests. The total European SOC reservoir is estimated at ~75 Gt C by the CLIMSOIL report (European Commission, 2008). If that estimate is correct, 34 per cent of that pool is stored in forest soils (including forest floor).

12. The present study clearly shows that the carbon stored in forest floors should not be neglected, as it is in most carbon-accounting efforts, since it represents ~17 per cent of the 1-m forest soil stock. The carbon stored in EU forest floors is 3.3 times the total C emitted each year from the combustion of fossil fuel in Europe (based on CLIMSOIL data).

13. Though the areal extent of afforested peat soils (Histosols) is limited (i.e., between 7.4 and 8.8 Mha), they store between 4.3 and 5.3 Gt C. Hence, on ~5 per cent of the forest area, 20–24 per cent of the total forest soil carbon stock is stored in these peat soils, underscoring their importance for preservation and wherever possible, for their extension.

14. At the European scale, the factors explaining the carbon stock in the forest floor are mainly humus type, soil type and tree species and, to a lesser extent, climatic variables. For the carbon stock in the soil, soil type is the dominant predictor, followed by mean annual precipitation. The future holds promise for a further exploration of this EU soil carbon data set, predominantly for calibration and validation of (forest) soil carbon models and comparison with legacy and future soil carbon data sets.

2. Carbon to nitrogen ratio

15. The carbon to nitrogen (C:N) ratio is considered as an indicator of nitrate leaching in coniferous forests in response to high atmospheric nitrogen (N) deposition (Dise, Matner and Forsius, 1998; Emmett and others, 1998; Gundersen, Callesen and de Vries, 1998; Macdonald and others, 2002).

16. In deciduous forests with thin forest floors, the C:N ratio of the mineral topsoil was shown to be a better indicator (Vesterdal and others, 2008; Gundersen and others, 2009). However, the C:N ratio is influenced by a multitude of other site-related factors.

17. During the second soil survey on the ICP Forests level I network (De Vos and Cools, 2011), very high C:N values in the forest floor have been recorded both in Northern (Finland and Sweden) and in Southern Europe, particularly in Portugal and Spain (figure 2). Ninety-five per cent of the C:N ratios were between 16 and 44 in the forest floor, between

13 and 44 in the peat topsoil and between 10 and 32 in the mineral topsoil. Within the terrestrial forest floor and mineral soil, the C:N ratios decreased with depth, while in the hydromorphic forest floor and the peat no clear trend with depth was observed.

18. A boosted regression tree analysis (Elith, Leathwick and Hastie, 2008) on 15 site and environmental variables (table 1), showed that tree species is the most important explanatory variable for the C:N ratios of the forest floor and the upper mineral soil (Cools and others, in press) at the European level.

19. Black locust and black alder, both nitrogen-fixing tree species, show mean forest floor C:N ratios below 20. While in Northern Europe Scots Pine shows very high C:N values (mean 30), tree species like maritime, lodgepole, Aleppo and Black Pine, but also broadleaved evergreen species like Eucalyptus and Cork Oak, show mean C:N ratios above 30 in Southern Europe. In the deeper mineral soil layers, up to 80 cm of depth, soil type was the most important explanatory variable. Deposition and climatic variables were of minor importance at the European scale. Following the N status classes as defined by Gundersen, Schmidt and Raulund-Rasmussen (2006), about one third of the coniferous sites had high N status, one third intermediate status and one third low N status (table 2).

Figure 2
C:N ratio of the forest floor on 3,837 plots of the ICP Forests level I network

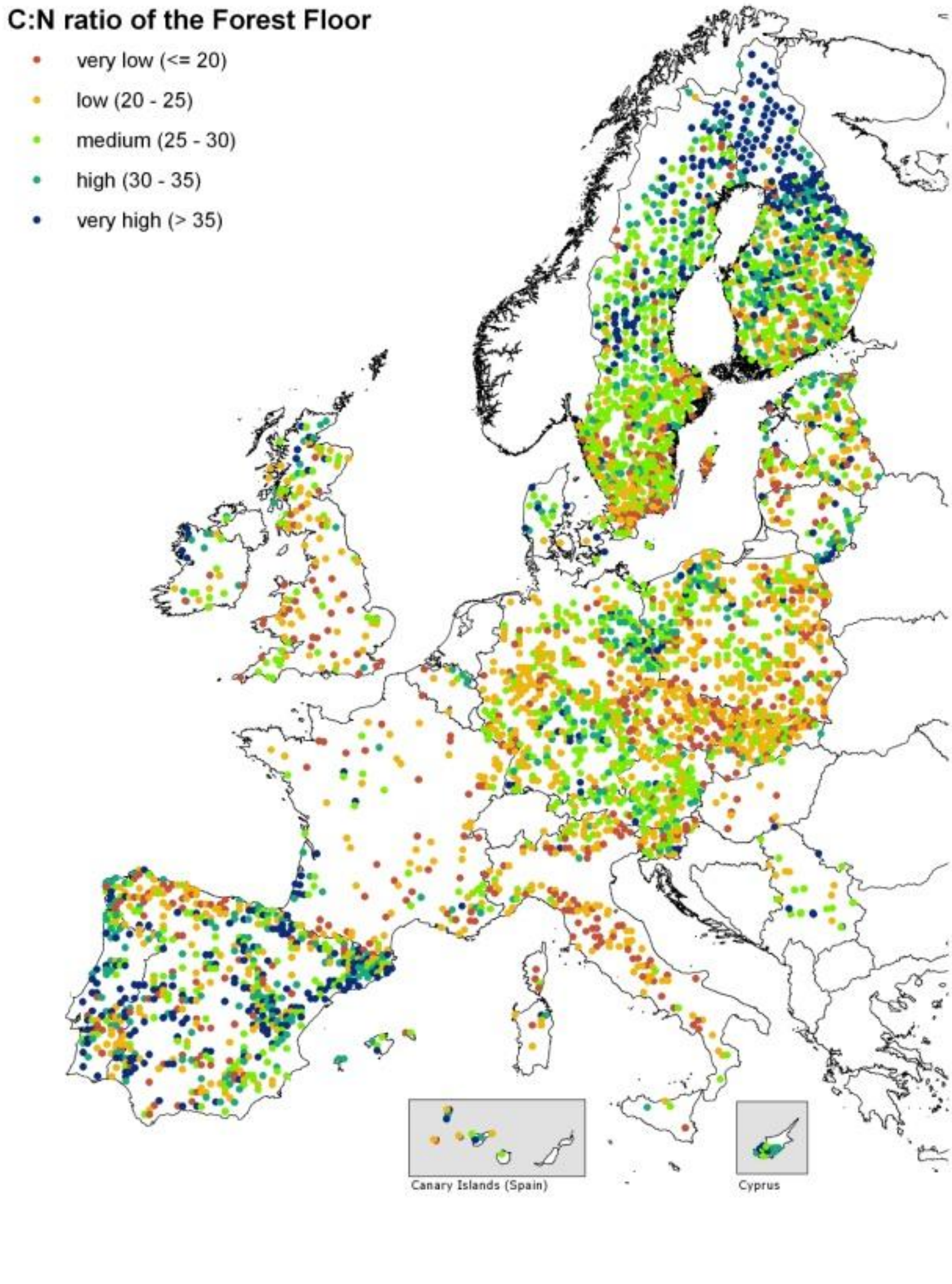


Table 1
Environmental variables used in the boosted regression tree analysis

Variable	*Type*	*Description*
Latitude, longitude	Numeric	X and Y coordinates of the site
Altitude	Numeric	Elevation above sea level
MAT	Numeric	Mean annual temperature
MAP	Numeric	Mean annual precipitation
Parent Material	factor (9)[a]	Parent material class
WRB RSG	factor (26)	World Reference Base for Soil Resources (WRB) reference soil group (International Union of Soil Sciences (IUSS) Working Group on the WRB (2007))
Soil depth	Numeric	Estimated depth of profile (till 100 cm)
Humus type	factor (9)	Amphi, Mull, Moder, Mor, Anmoor, Histoamphi, Histomull, Histomoder or Histomor
Forest type	factor (12)	Forest type (Forest Europe, ECE and FAO, 2011)
Tree species	factor (25)	Tree species code of main tree species
Ecoregion	factor (18)	Ecoregion (European Environment Agency, 2004)
NredTOT	Numeric	Total (dry+wet) depositions for reduced and oxidized N and oxidized sulphur (S) by the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP)/Meteorological Synthesizing Centre-West (MSC-W) model cumulative totals for the years 2002–2006
NoxTOT	Numeric	
SoxTOT	Numeric	

[a] Number of levels.

Table 2
Number of coniferous ICP Forests plots on level I by main coniferous tree species with high, intermediate and low N status according to the C:N ratio of the forest floor

	N plots	*High N status*	*Intermediate N status*	*Low N status*
		C:N < 25	**25 ≤ C:N ≤ 30**	**C:N > 30**
Scots pine	1 291	326 (25%)	431 (33%)	534 (41%)
Norway spruce	927	425 (46%)	368 (40%)	134 (15%)
Maritime pine	103	10 (9.7%)	20 (19%)	73 (71%)
Aleppo pine	90	20 (22%)	28 (31%)	42 (47%)
Total (all coniferous stands)	**2 745**	**924 (34%)**	**922 (34%)**	**899 (33%)**

Source: Gundersen, Schmidt and Raulund-Rasmussen, 2006.

20. Further analysis for the eight main forest tree species individually showed that the influence of environmental variables on C:N ratios was tree-species dependent. For Aleppo Pine and Holm Oak, both with a typical Mediterranean distribution, the relationship between N and S deposition and C:N ratio appeared to be positive. The present study suggests that applying C:N ratios as a general indicator of the N status in forests at the European level, without explicitly accounting for tree species, is probably too simplistic, the intensive monitoring offers a better insight into the potential relationship between tree species and risks for nitrate leaching. It should be analysed which other indicators are relevant for adequate evaluation of the nitrogen status.

B. Development of pH[1] and base saturation

1. pH

21. Figure 3 shows the evolution of pH on revisited observation plots across Europe. Of the 2,182 plots, 4 per cent are acidifying by more than 0.75 pH units, 21 per cent by between 0.25–0.75 units, 57 per cent remained stable, 15 per cent recovered between 0.25–0.75 units and 3 per cent recovered by more than 0.75 pH units. Considering all observations, soils are slightly acidifying by 0.03 pH units on average. Whereas, in the acid forest soils (with pH below 4.0), pH increased significantly, it decreased in forest soils with pH above 4.0. This finding confirms the modelled recovery of the pH in soil solution where the recovery was indeed more pronounced at low pH values (Lorenz and others, 2007).

2. Base saturation

22. Following the changes in pH, the base saturation increased in the acidified forest soils (with a base saturation below 20 per cent) and decreased in forest soils with initial (first survey) base saturation values above 20 per cent. The percentage of plots with low buffering capacity decreased from 48 per cent in the first observation period to 28 per cent in the second observation period. This again indicates a recovery from soil acidification at the European level on the most acid soils. Classified by the major reference soil groups according to the soil classification system of the World Reference Base for Soil Resources (IUSS Working Group on WRB, 2007), there is a statistically significant decrease in base saturation in the topsoil of Regosols, Arenosols and Stagnosols, whereas a statistically significant increase is found in Luvisols and Gleysols (figure 4.).

[1] A measure of the acidity or basicity of an aqueous solution.

Figure 3
Changes in soil pH in the top mineral soil layer (0–10 cm) between the two surveys

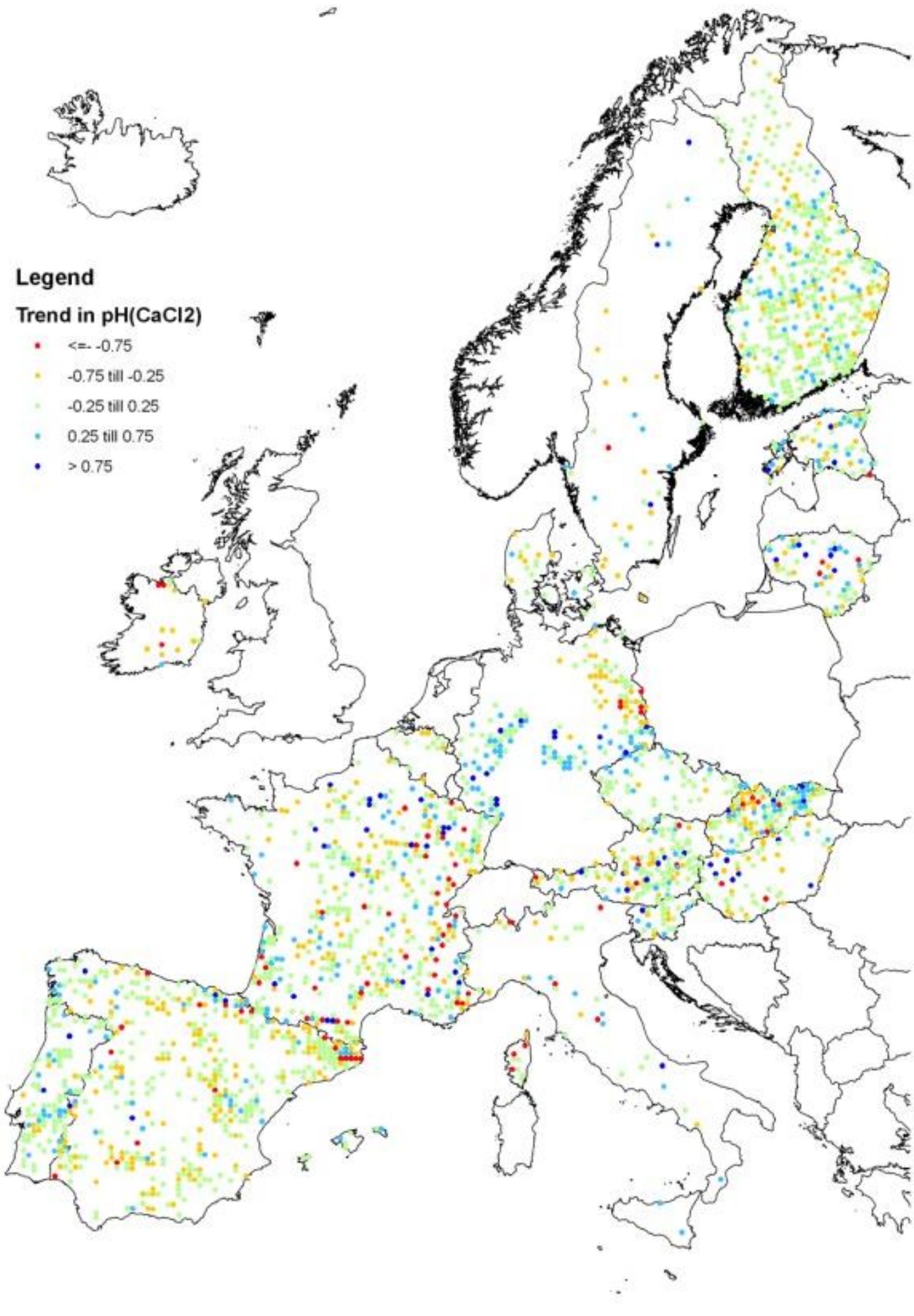
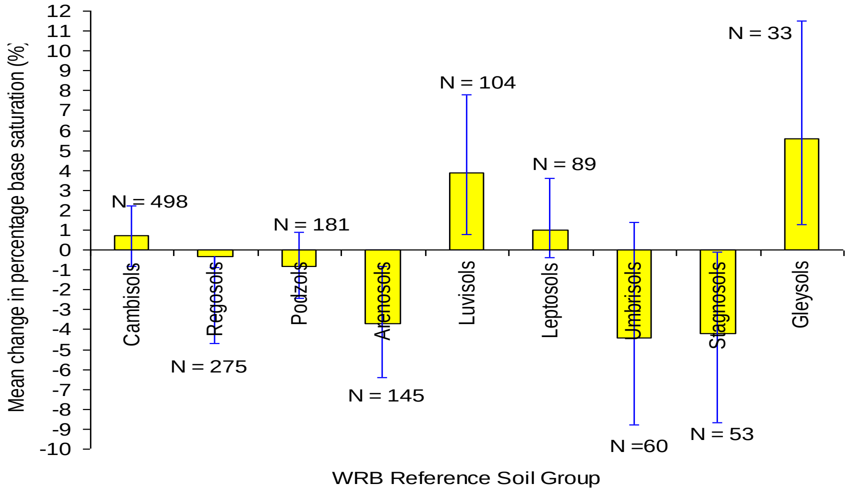


Figure 4

Mean change in percentage base saturation between the first and the second forest soil survey



Note: When the error bars do not cross the 0 line, the change is statistically significant.

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