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Finnish forest soils

Pekka Tamminen and Erkki Tomppo

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Office
Post Box 18
FI-01301 Vantaa, Finland
tel. +358 10 2111
fax +358 10 211 2101
e-mail julkaisutoimitus@metla.fi

Publisher
Finnish Forest Research Institute
Post Box 18
FI-01301 Vantaa, Finland
tel. +358 10 2111
fax +358 10 211 2101
e-mail info@metla.fi
http://www.metla.fi/

Authors
Tamminen, Pekka & Tomppo, Erkki

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Abstract
It was possible to classify forest soils according to the World reference base soil classification system (WRB) on the basis of the site and soil variables measured or estimated in the Finnish 9th National Forest Inventory. A small sub-sample was selected from the NFI plots (n = 285) and the soils of these plots were inventoried by the soil survey teams. This second-phase sample was selected to cover the whole range of soil texture, organic layer thickness and site fertility throughout Finland.

The soil type on about 67 400 NFI sample plots was predicted and the frequencies of soil types were estimated over the whole country and in the areas of the forestry centres. The most frequent soil types were Podzols (50 %), Histosols (25 %), Arenosols (11 %) and Leptosols (9 %). Finer-textured soils, Cambisols (1.9 %), Gleysols (1.4 %) and Regosols (1.2 %), had only a small proportion.

International soil classifications seem to be relatively unsuitable for forest soils in Finland, because the important organic layer is not taken into account at all. Instead of many separate soil classes based on soil formation processes or associated properties, the use of continuous variables would be more useful for primary soil users.

Keywords
soil survey, soil classification, WRB classification, forest soils, national forest inventory

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Is replaced by

Contact information
Pekka Tamminen, Forest Research Institute, Box 18, FI-01301 Vantaa.
E-mail pekka.tamminen@metla.fi

Other information
Layout and image processing by Maija Heino

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Abbreviations

Tempsum	Sum of effective temperature, d.d. (>5 ^oC)
Elev	Elevation above the sea level, m
Stype	Forest site type: 1 = the most fertile, ..., 6 = the poorest site type (Cladina type) and 7= rocky land, accretion, dunes etc. and 8 = top of fjelds
Paludified	Wetness decreases tree growth (0/1)
NotDitched	Site has not been ditched
Swampmosses	Coverage of Sphagnum and other swamp mosses: 0 = 0; 1 = <1 %; 2 = 1–10; 3 = 11–25; 4 = 25–50 and 5 = >50 %
Orgtype	Type of the organic layer: 0 = missing, 1 = mor, 2 = moder, 3 = mull, 4 = peat, 5 = a mor layer on the top of peat, 6 = mull-like peat
Orgthickness	Thickness of the organic layer, cm
Fine	Field-estimated median particle size class is clay or silt (d_{50}<63 µm)
Medium	Field-estimated median particle size class is fine or medium sand
Coarse	Field-estimated median particle size class is coarse sand or gravel (d_{50}>630 µm)
Sorted	Soil is sorted, i.e. the opposite to till (morainic) soils
Finesorted	Fine sorted soils
Finetill	Fine till soils
Coarsesorted	Coarse sorted soils
ln	Natural logarithm
exp(x)	e^x

1 Introduction

Soils are not similar to living organisms, because they have no clear borders in all three dimensions and their development is not ruled by genes, but their parent material and outer circumstances. Soil units or "individuals" have to be separated according to technical rules or subjectively. The difficulties in soil classification appear in the variety of national soil classification systems (Finkl 1982). However, there are many systematic features in soils due to the fact that the development of soils is governed by quite few factors (Glinka 1914, Jenny 1941, Glazovskaya 1983). In spite of the difficulties to describe and classify soils, many national and international soil surveys have been complished successfully (see Rossiter 2005).

Soil classification dates back to 19th century (see e.g. Glinka 1914). Soil classification was at first a counterpart for taxonomy of living organisms, i.e. a tool to arrange the knowledge about soils and processes that affect on soils and that are going on in soils. Afterwards, soil classification became a necessary tool used in soil survey and mapping. Soil classification systems were developed mainly for agricultural purposes and from national standpoints. Therefore there are many different classification systems in the world. However, we have also genuine international soil classification systems, which can be used all over the world, namely the system of the FAO and the new WRB classification system (FAO-UNESCO 1988, World Reference Base for Soil Resources 1998, IUSS working group WRB 2006). But unfortunately, due to e.g. their stoniness, small-scale topography and variable organic layer Finnish forest soils seem to be suited poorly to any soil classification system.

Already (Glinka 1914, p. 244) stated that "Finnish soils comprise mainly podzols and peatlands". Finnish forest soils has been seriously studied first by Aaltonen (e.g. 1935, 1939, 1941, 1947, 1951), who constructed a map about soil formation (podzolization) zones in Finland. The best published map of genetic soil types over Finland (Rasmussen et al. 1991) is rather detailed, but not reliable. At that time there was very little information on forest soils.

Although, we have had no country-wide field-verified maps on soil types, we have had many studies on our main soil formation process, podzolization (Aaltonen 1935, 1939, 1941, 1947, Jauhiainen 1969, 1973a, 1973b, Ritari and Ojanperä 1984, Koutaniemi et al. 1988, Starr 1991, Petäjä-Ronkainen et al. 1992, Starr and Tamminen 1994, Starr and Lindroos 2006).

Finnish soil maps are based on soil texture and geomorphology, i.e. on quaternary deposits (1:20 000, 1:50 000, 1:100 000, 1:400 000 and 1:1 mill). First from the year 2002 Agrifood Research Finland, Geological Survey of Finland and Finnish Forest Research Institute started to compile a soil map in a scale of 1:250 000 (Talkkari and Nevalainen 2003, Yli-Halla 2004). This map will be based on the quaternary deposit map in scale 1:250 000, which will be made at the same time as the map for soil types.

The aim of this paper is to give a picture on forest soils based on the soil profiles described in the connection of the before mentioned project in the 9th national forest inventory plots. At the same time, we will try to develop methods to generalize studied profile information for whole country by using the forest inventory data.

2 Material and methods

Soils were described and classified on 285 sample plots of the 9th national forest inventory in the years 2002 to 2004 (Fig. 1). The field groups of the national forest inventory had measured during the years 1996–2003 several variables, of which some soil relevant variables have been presented in the Table 1 (Valtakunnan metsien 9. inventointi 1996).

Plots for the soil survey were sampled from the NFI sample plot population. In year 2002 the Kainuu area in eastern Finland was the target area for a so called Soil database 1:250 000 project (Talkkari and Nevalainen 2003, Yli-Halla 2004). In the years 2003 and 2004 fourteen sub-areas were selected all over Finland in order to get representatives for the main forest soils, except for Histosols. From these sub-areas (Fig. 1) 18 to 25 sample plots were picked systematically from the texture classes fine, medium coarse and coarse-grained soils having an organic layer thickness of 0 to 9, 10 to 19 or 20 to 39 cm and representing the whole site fertility range from the poorest sites to the most fertile sites. The idea was to get a small, but evenly distributed sample along the most important dimensions, i.e. hydrology, soil nutrient status and circumstances for the main soil formation process in Finland, podsolization (Table 2).

The profile description and sampling of soil horizons was made at the same site and soil compartment, where the center point of the NFI sample plot was situated. The profile pit, c. 60 cm deep, was dug in a spot representing best the NFI sample plot soil based on a quick survey of soil features (thickness of organic and mineral soil and texture of mineral soil). The field group leaders described the profile and classified it according to the FAO system (FAO-UNESCO 1988) and took samples from the first and second genetic mineral horizon. Samples were air-dried and

Table 1. Site and soil variables in the 9th national forest inventory.

Rectangular map coordinates by GPS, m (27° East = 3 500 000 m)	
Land class	Forest land, poorly productive land, waste land, other forestry land, agricultural land...
Forest site type	1 = the most fertile, herb-rich sites,...,6 = the poorest (Cladina type), 7 = rocky land, accretion, dunes etc., 8 = top of fjeld
Main site type	Upland, spruce-birch swamp, pine swamp, open swamp
Topography	Flat, hill top, slope, lower slope, depression
Coverage of swamp mosses (Sphagnum etc)	0, <1, 1–10, 11–25, 26–50, >50 %
Soil type at a depth of 30 cm	Organic, bedrock, stone-field, till, sorted mineral soil
Average particle size class	Fine = clay or silt (d50<63 µm), medium = fine or medium sand (63≤d50<630 µm), coarse = coarse sand or gravel (d50≥630 µm)
Thickness of the soil material (organic + mineral soil)	Under 10, 10–30, over 30 cm
Type of the organic layer	Missing, mor, moder, mull, peat, mor above peat, peaty mull
Ditching status	Not ditched, ditched mineral soil, ditched peatland without any changes, ditched peatland with clear changes, ditched peatland resembling upland site
Taxation class	0–4, productivity rating based on the site type and stoniness, paludification etc.
Stony site or very shallow soil	0/1, decreases productivity by one or two taxation classes
Paludified site	(0/1, decreases productivity by one taxation class

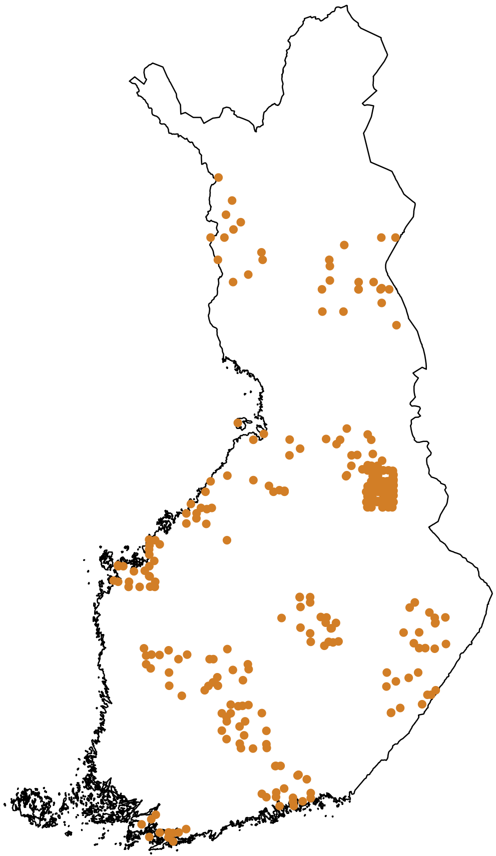

Figure 1. Sample plots (n=285) of the 9th national forest inventory (NFI 9), where a soil profile was described and classified in 2002–2004.

sieved to retain the fine earth fraction (<2 mm) and analysed in the laboratory. However, not all the samples were analysed. Particle size analyses and neutral ammonium acetate extractions (n=270) were mostly made on the second, i.e. enriched horizon of fine-grained soils representing more or less Cambisols, Gleysols and Regosols. Acid ammonium oxalate extractions (n=304) were mostly made on both bleached and enriched horizons of more or less podsolized soils. Organic matter content and colour measurements were made on all samples (n=350) in the years 2003 and 2004, but only on 27 samples out of 120 in the year 2002. Colour measurements were made with a Minolta colour meter on air-dry, moistened and burned samples. Colour readings were transformed into the Munsell scale (Munsell Soil Color Charts 1994).

The most important criteria in classifying the profiles were 1) mineral and organic soil thickness, 2) particle size class of a soil, 3) a Spodic horizon based on ammonium oxalate extraction concentrations of Al and Fe, $Al + 0.5 \cdot Fe \geq 0.5\%$ and the ratio of the Al and Fe concentrations between B and E horizons, $\frac{B_{Al+0.5Fe}}{E_{Al+0.5Fe}} \geq 2$ and features seen in the profile, i.e. 4) podzolization, 5) distance to ground water table and 6) to reduced layer and 7) type, distinctiveness and thickness of all the horizons.

The final classification of soils according to World Reference Base for Soil Resources (World Reference Base for Soil Resources 1998, IUSS working group WRB 2006) was made using data from field forms, photos taken from profiles and laboratory analysis. It became clear that classification will be rough and partly subjective, because there was quite little information on profiles and group leaders had a short training for the FAO's soil classification.

Used soil units were as follows. Histosols are soils having at least 40 cm thick peat layer on the top of mineral soil. Leptosols are shallow soils having either bedrock within 30 cm (FAO-UNESCO

Table 2. Distribution of the NFI sample plots by organic layer thickness and average particle size class. Characteristics have been estimated by the NFI field groups.

Particle size class	Organic layer thickness, cm				
	0–9	10–19	20–29	30–39	Total
Missing	0	0	0	19	19
Fine	49	25	18	1	93
Medium	94	32	18	3	147
Coarse	26	0	0	0	26
Total	169	57	36	23	285

1988) from the soil surface or a very coarse texture. Lithic Leptosols have a bedrock contact within 10 cm, Haplic Leptosols within 10–30 cm and Hyperskeletic Leptosols have over 90 % of gravel and stones in the layer of 0–75 cm. Arenosols are medium or coarse textured, weakly developed and often podzolized or groundwater affected soils. Brunic Arenosols are the most fertile in this group having an organic-matter-rich Ah horizon and often a moder or mull layer. Endogleyic Arenosols have a peat layer on the top of mineral soil and groundwater or a reduced horizon within 50–100 cm from the soil surface. Albic Arenosols are soils with an eluviated, whitish-light grey E horizon and weakly developed illuvial B horizon. Haplic Arenosols form the rest of weakly developed sandy soils. Podzols have a so called Spodic B horizon enriched with aluminium, iron and organic matter, and this horizon has to meet some colour and chemical criteria (described above). Ortsteinic Podzols have a very hard subhorizon, called ortstein. Carbic Podzols, typical for moist or wet sites, have a B horizon which does not turn to redder during ignition. Entic Podzols are the most fertile in this group having often a moder or mull instead of a mor layer, i.e. organic-matter-rich Ah horizon and no E horizon. Gleyic Podzols have groundwater or a reduced horizon within 100 cm from the soil surface, and Haplic Podzols are ordinary and most frequent, so called humus-iron Podzols. Cambisols are fine-textured (median particle diameter<63 µm) and fertile soils with a Cambic B horizon which has a secondary structure and more colour than underlying horizon. Gleysols are also mostly fine-textured soils which have a reduced horizon within 50 cm from the soil surface, i.e. they are situated on wet sites and have usually a peat layer on the top of mineral soil. Histic Gleysols have a rather thick peat layer, 11 to 39 cm and Haplic Gleysols are soils having an organic layer under 10 cm thick. Regosols are weakly developed, finer-textured soils than Arenosols or soils with more than 40 % of gravel and stones. Endogleyig Regosols have a reduced horizon within 50-100 cm from the soil surface and Haplic Regosols form the rest of Regosols.

Separation of soil types and statistical treatment

In the studied material the soil classification was based on the information gathered by the soil survey field group. On the basis of this small collection of the NFI sample plots we tried to predict the soil type for all the NFI sample plots using the information collected by the NFI field groups.

Histosols, organic layer over 40 cm thick and Leptosols, soil thickness under 10 or 30 cm, were separated mechanically according to these criteria. Soil thickness in the NFI was 0–10 cm for Lithic and 10–30 cm for Haplic Leptosols. Hyperskeletic Leptosols were defined to have a NFI soil type “stone-field”, but were united to Lithic variant because of their rarity, only 21 when shallow soils were excluded.

The soil types Cambisols, Gleysols and Regosols, i.e. fine-textured soil groups, were separated by using a logistic regression. A binary variable, i.e. is the observation a fine-textured soil or not, had values 1 and 0. After that the fine-textured group was divided into these three groups by using a discriminant analysis.

Then for those cases, which were not Histosols, Leptosols, Cambisols, Gleysols or Regosols, a logistic regression equation was calculated to separate Podzols and other coarse-textured soils, i.e. Arenosols. After that, separately for Podzols and Arenosols, discriminant analyses were calculated to classify profiles into the subgroups of these soil groups.

After creating an analytical soil naming system according to the WRB soil classification, soils on all the 9th NFI sample plots were named using this analytical system. Because the NFI plots represent land areas of different sizes, i.e. there were in the NFI a different cluster and plot density in different regions, plots were weighted when calculating values for the whole country. Maps representing the proportions of the first level WRB soil units were based on the cluster-wise relative frequencies of soil types. Each cluster of sample plots contained 1 to 18 sample plots and on average 10 plots/cluster. In the national forest inventory sample plots form clusters to make field work more efficient.

3 Results

3.1 Predicting a soil type based on the NFI field variables

Distribution of soil types in the calculation material did not correspond to the actual distribution in the whole NFI material, because of favoring rare instead of common cases, resulting in a more or less even soil type distribution, i.e. roughly the same number of all soil types (cf. Tables 3 and 8).

A direct discriminant analysis for classifying soil groups Cambisols, Gleysols, Regosols, Arenosols and Podzols had a poor success, because only 62 % of observations could be correctly classified. Therefore the separation task was divided into several phases. At the first stage a logistic regression equation was calculated to identify all fine-textured soils, Cambisols, Gleysols and Regosols (Equation 1)(see for abbreviations on the first page of this article).

Table 3. Frequency distribution of the studied profiles by soil type.

Soil type	Abbrev.	Frequency	Percent
Albic Arenosol	ARab	5	1.8
Brunic Arenosol	ARbr	8	2.8
Haplic Arenosol	ARha	23	8.1
Endogleyic Arensol	ARng	41	14.4
Haplic Cambisol	CMha	15	5.3
Haplic Gleysol	GLha	16	5.6
Histic Gleysol	GLhi	8	2.8
Fibric Histosol	HSfi	3	1.1
Sapric Histosol	HSsa	5	1.8
Haplic Leptosol	LPha	5	1.8
Lithic Leptosol	LPli	2	0.7
Carbic Podzol	PZcb	23	8.1
Entic Podzol	PZet	10	3.5
Gleyic Podzol	PZgl	2	0.7
Haplic Podzol	PZha	91	31.9
Ortsteinic Podzol	PZos	4	1.4
Haplic Regosol	RGha	17	6.0
Endogleyic Regosol	RGng	7	2.5
Total		285	100.0

(1) Probability for a soil of being fine-textured (CM, GL, RG) = f/(1+f), where

$$f = \exp(-2.749 + 0.004992 \cdot Tempsum - 1.677 \cdot Orgtype1 - 2.092 \cdot Stype456 - 0.6755 \cdot \ln(Elev + 1) + 4.043 \cdot Finesorted + 1.755 \cdot Finetill)$$

Equation (1) was quite successful in classifying observations into fine-textured (1) and other soils (0), because 90 % of observations were correctly classified.

	Predicted		
Observed	0	1	Total
0	**181**	12	193
1	14	**45**	59
Total	195	57	252

According to equation (1) fine-textured soils situated in the southern part of the country, on coastal areas and these sites were very or medium fertile and had other than a mor-type organic layer.

The fine-textured soils were further divided into three groups, Cambisols, Gleysols and Regosols, with the help of discriminant equations (2a–2c). These equations were based on a material containing only these fine-textured soils (n=60).

(2a)

$$Cambisols = -173.16 + 10.784 \cdot \ln(Elev + 1) + 0.2047 \cdot Tempsum + 6.437 \cdot \sqrt{Swampmosses} + 11.644 \cdot Sorted$$

(2b)

$$Gleysols = -156.324 + 9.748 \cdot \ln(Elev + 1) + 0.1942 \cdot Tempsum + 8.249 \cdot \sqrt{Swampmosses} + 12.437 \cdot Sorted$$

(2c)

$$Regosols = -138.322 + 9.814 \cdot \ln(Elev + 1) + 0.1818 \cdot Tempsum + 6.796 \cdot \sqrt{Swampmosses} + 9.34 \cdot Sorted$$

An observation belonged to that group, whose equation gave the highest value. For instance, if the equations gave the values Cambisols=263.6, Gleysols=265.8 and Regosols=265.6 for an observation (=a sample plot), the soil type was a Gleysol.

The equations (2a–2c) separated quite successfully these fine-textured soil groups (Table 4). In the calculation material 82 % of observations were correctly classified.

According to the discriminant equations (2a–2c) Cambisols had, on average, a more southern location and a little bit higher elevation and Gleysols had a lower elevation than other fine-textured soils. Gleysols were best separated from other fine-textured soils by higher coverage of swamp mosses.

Table 4. Classification of fine-textured soils, Cambisols (1), Gleysols (2) and Regosols (3) by a discriminant analysis.

		Predicted		
Observed	1	2	3	Total
1	13	2	0	15
2	2	17	2	21
3	0	5	19	24
Total	17	17	26	60

When Histosols, Leptosols, Cambisols, Gleysols and Regosols had been classified, the coarser-textured soils, Podzols and Arenosols were separated from each others by using a logistic regression (Equation 3).

(3) Probability for a soil of being a Podzol = f/(1+f), where

$$f = \exp(-6.449 + 1.491 \cdot \ln(Elev + 1) - 1.11 \cdot Stype12 - 2.006 \cdot Coarsesorted - 1.1126 \cdot \sqrt{Orgthickness})$$

The overall success of the equation (3) in separating these groups was 80 % and 88 % of Podzols could be identified.

	Predicted		
Observed	0	1	Total
0	**50**	26	76
1	16	**114**	130
Total	66	140	206

According to equation (3) Podzols were situated on higher areas than Arenosols. The mean measured elevations for these soil groups were 156 and 75 m. Podzols had a thinner organic layer than Arenosols, i.e. 5 vs. 12 cm.

Podzols were classified into the subgoups of Carbic (Carbic+Ortsteinic+Gleyic) (1), Entic (2) and Haplic (3) using a discriminant equations (4a–4c) calculated in a discriminant analysis.

(4a)

$$Carbic = -123.52 + 0.5013 \cdot Tempsum - 0.0934 \cdot Stype12 + 128.28 \cdot Fine + 119.28 \cdot Medium\&Coarse$$
$$-16.376 \cdot ModerMullPeatmull + 30.067 \cdot \ln(Orgthickness + 1) + 9.334 \cdot NotDitched - 2.402 \cdot Paludified$$

(4b)

$$Entic = -121.04 + 0.6147 \cdot Tempsum + 8.26 \cdot Stype12 + 117.07 \cdot Fine + 107.54 \cdot Medium\&Coarse$$
$$+3.949 \cdot ModerMullPeatmull + 24.526 \cdot \ln(Orgthickness + 1) + 11.684 \cdot NotDitched - 7.574 \cdot Paludified$$

(4c)

$$Haplic = -109.04 + 0.5377 \cdot Tempsum - 0.4214 \cdot Stype12 + 114.55 \cdot Fine + 108.25 \cdot Medium\&Coarse$$
$$-13.977 \cdot ModerMullPeatmull + 25.683 \cdot \ln(Orgthickness + 1) + 13.022 \cdot NotDitched - 8.973 \cdot Paludified$$

About 84 % of the Podzols were correctly classified (Table 5). Compared to other Podzols, Carbic Podzols had the thickest organic layer, their sites had most often been ditched and showed most often signs of paludification, i.e. peat formation. Entic Podzols were situated on the most fertile sites and had a moder- or mull-type organic layer instead of mor or peat layer.

Table 5. Classification of Carbic (1), Entic (2) and Haplic (3) Podzols by a discriminant analysis.

	Predicted			
Observed	1	2	3	Total
1	**22**	1	6	29
2	0	**8**	2	10
3	6	6	**79**	91
Total	28	15	87	130

The last group, Arenosols, were classified into three groups, Brunic, Gleyic and Haplic (Albic+Haplic) by calculating discriminant equations (5a–5c).

$$\text{(5a)}\quad \mathit{Brunic} = -9.148 + 8.098 \cdot \mathit{Stype12} + 5.989 \cdot \mathit{ModerMullPeatmull} \\ + 5.099 \cdot \mathit{NotDitched} \quad 4.533 \cdot \ln(\mathit{Swampmosses} + 1)$$

$$\text{(5b)}\quad \mathit{Gleyic} = -5.437 + 3.361 \cdot \mathit{Stype12} \quad 3.23 \cdot \mathit{ModerMullPeatmull} \\ + 1.817 \cdot \mathit{NotDitched} + 5.512 \cdot \ln(\mathit{Swampmosses} + 1)$$

$$\text{(5c)}\quad \mathit{Haplic} = -4.558 + 2.545 \cdot \mathit{Stype12} - 0.235 \cdot \mathit{ModerMullPeatmull} \\ + 6.096 \cdot \mathit{NotDitched} + 1.948 \cdot \ln(\mathit{Swampmosses} + 1)$$

Equations (5a–5c) separated Arenosols quite well, about 83 % of the observations were correctly classified (Table 6) in the calculation material.

Brunic Arenosols were met, on average, on the most fertile sites having a moder- or mull-like organic layer, and Gleyic Arenosols represented paludified and peaty, i.e. moist or wet sites.

For all the NFI plots situated on forest land, on poorly productive land and on forest wasteland a soil type was predicted using these logistic regression and discriminant equations.

Table 6. Classification of Dystric (1), Gleyic (2) and Haplic (3) Arenosols by a discriminant analysis.

	Predicted			
Observed	1	2	3	Total
1	**7**	1	0	8
2	4	**33**	4	41
3	0	4	**24**	28
Total	11	38	28	77

3.2 Distribution of soil types in Finland

Naming the soils for all the NFI plots was started by separating first Histosols on the basis of organic layer thickness, which had to be at least 40 cm. Then were separated Leptosols according to soil thickness or soil type (bedrock or stone-field). Soil classification was reduced to include only 12 units due to the difficulties to identify soil types analytically. Therefore fine-textured soils were named only at main group level, Albic Arenosols were united with Haplic variant, Hyperskeletic Leptosols were united with Lithic variant and Ortsteinic and Gleyic Podzols were united with Carbic Podzols.

In the NFI material there were 67 400 sample plots whose soil was classified according to the WRB classification system (IUSS working group WRB 2006).

According to this material, Podzols, Histosols, Arenosols and Leptosols are the most frequent soil types in Finland (Table 7). Their proportion is 95.5 %. Podzolized soil types, i.e. Podzols and Arenosols, cover about 61 % of forestry land. Proportion of Podzols alone is 67 %, if organic Histosols are not taken into consideration. Proportion of Histosols is only 25 %, although peatlands, i.e. forestry land having a peat layer of varying thickness or being dominated by peatland vegetation, cover even 34 % of forestry land area (Sevola 2002). The reason for this is the criteria of 40 cm for the organic layer thickness in Histosols. Soil types on fine-textured soils are relatively rare, their proportion is only 4.5 %. But the total area of the fine-textured soil types is, in every case, about 12 000 km^2, which is a larger area than for instance the total forest area of Belgium and the Netherlands together. Total area of forestry land in Finland is 261 000 km^2 (Sevola 2002).

When the soil groups are presented by forestry center (Table 8, Fig. 2), some regional features can be seen, like high frequency of shallow soils due to bedrock in Åland, high frequency of peatlands in Pohjois-Karjala, Etelä- and Pohjois-Pohjanmaa, Kainuu and Lappi, high frequency of weakly developed soils in Kusten, i.e. along seaside and high frequency of fertile soil types, ARbr, CM and PZet, in Häme-Uusimaa (Table 8).

Table 7. Distribution of the WRB soil types on forestry land in Finland.

Soil group	%	Subgroup	%
Arenosols	10.7	Brunic	1.8
		Gleyic	5.7
		Haplic	3.2
Cambisols	1.9		1.9
Gleysols	1.4		1.4
Histosols	25.4		25.4
Leptosols	9.3	Lithic	3.5
		Haplic	5.8
Podzols	50.1	Carbic	8.3
		Entic	1.1
		Haplic	40.7
Regosols	1.2		1.2
Total	100.0		100.0

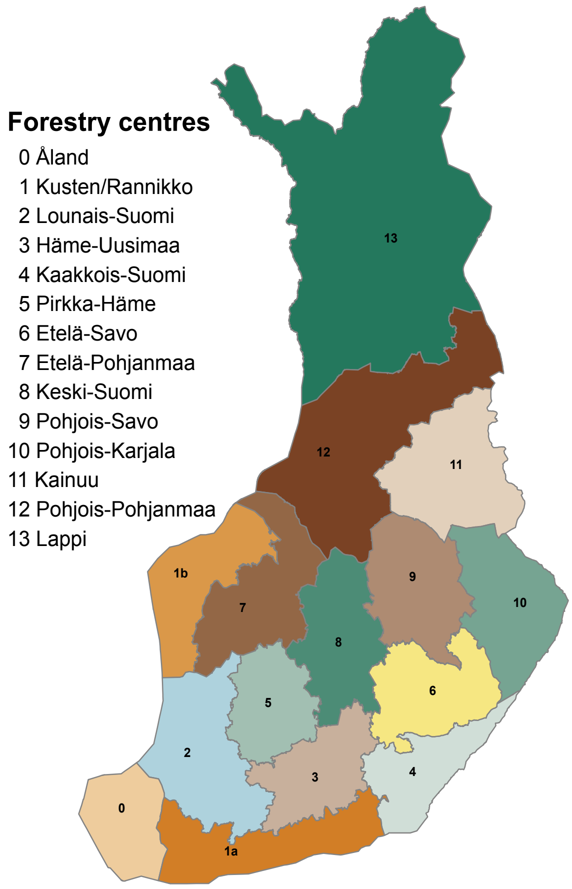

Figure 2. Forestry centres.

Table 8. Distribution of soil types by forestry center as weighted relative frequencies.

Forestry center	ARbr	ARgl	ARha	CM	GL	HS	LPli	LPha	PZcb	PZet	PZha	RG	Total
0 Åland	4.4	1.2	9.3	1.8	4.2	3.9	53.6	14.4	0.0	0.7	0.5	6.0	100.0
1 Kusten /Rannikko	3.2	7.6	26.8	5.4	5.0	13.6	13.5	13.5	0.1	0.2	7.2	3.9	100.0
2 Lounais-Suomi	2.8	7.7	14.7	5.4	5.8	17.7	8.1	12.6	2.6	0.2	20.9	1.5	100.0
3 Häme-Uusimaa	4.6	2.1	3.3	14.8	3.0	12.2	4.0	10.4	1.6	3.6	40.1	0.3	100.0
4 Kaakkois-Suomi	1.9	3.0	0.7	7.4	2.8	15.7	4.4	11.6	5.6	2.4	43.8	0.7	100.0
5 Pirkka-Häme	3.2	2.3	8.8	8.5	2.6	13.9	4.4	12.2	1.4	2.1	39.6	1.0	100.0
6 Etelä-Savo	4.9	3.7	1.7	2.5	1.1	15.7	3.7	8.6	3.5	2.8	50.6	1.2	100.0
7 Etelä-Pohjanmaa	1.0	11.3	5.6	0.0	1.6	33.7	2.5	5.2	7.1	0.5	30.3	1.2	100.0
8 Keski-Suomi	1.1	4.2	0.3	1.5	1.7	19.1	3.4	7.7	7.7	2.4	49.3	1.6	100.0
9 Pohjois-Savo	2.5	5.3	0.8	2.2	2.3	19.2	2.1	8.6	7.5	4.0	43.2	2.3	100.0
10 Pohjois-Karjala	2.0	3.6	1.0	1.3	1.8	28.0	0.9	4.2	6.0	2.4	46.4	2.4	100.0
11 Kainuu	0.4	6.2	0.4	0.0	0.3	33.9	0.5	2.5	11.2	0.3	43.4	0.9	100.0
12 Pohjois-Pohjanmaa	1.5	12.0	3.6	0.0	1.1	38.2	0.9	1.9	10.1	0.3	28.7	1.7	100.0
13 Lappi	1.3	4.0	0.6	0.0	0.1	26.1	3.8	3.9	11.5	0.3	47.8	0.6	100.0
Total	1.8	5.7	3.2	1.9	1.4	25.4	3.5	5.8	8.3	1.1	40.7	1.2	100.0

ARbr=Brunic Arenosol, ARgl=Gleyic Arenosol, ARha=Haplic Arenosol, CM=Cambisol, GL=Gleysol, HS=Histosol, LPli=Lithic Leptosol, LPha=Haplic Leptosol, PZcb=Carbic Podzol, PZet=Entic Podzol, PZha=Haplic Podzol, RG=Regosol.

3.3 Geographical distribution of soil types in Finland

The regional distribution of main soil groups were presented on maps (Figs. 3–9) based on cluster-wise relative frequencies. Each cluster contained 1 to 18 plots, on average 10 plot/cluster, and there were 5400 sample plot clusters in total.

Geographical distribution of soil groups corresponded to the picture given by Table 8. Histosols concentrated on Ostrobothnia and eastern and northern Finland (Fig. 6), Leptosols (Fig. 7) on the south-west coastal area, Cambisols on southern and eastern Finland (Fig. 3) and Arenosols on the coastal areas (Fig. 3). The pattern of Podzols resembled more or less the average site elevation or the age of soils (Fig. 8). The distribution of Regosols seemed to be more or less random, except for a small coastal tendency (Fig. 9).

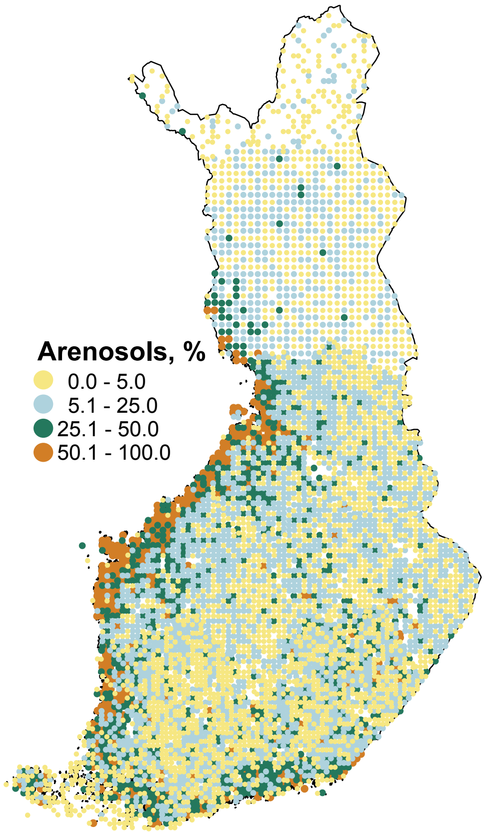

Figure 3. Proportion of Arenosols.

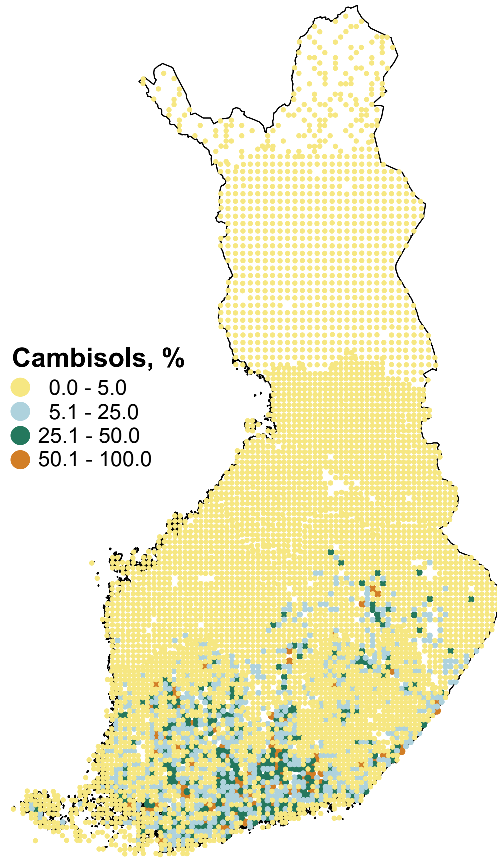

Figure 4. Proportion of of Cambisols.

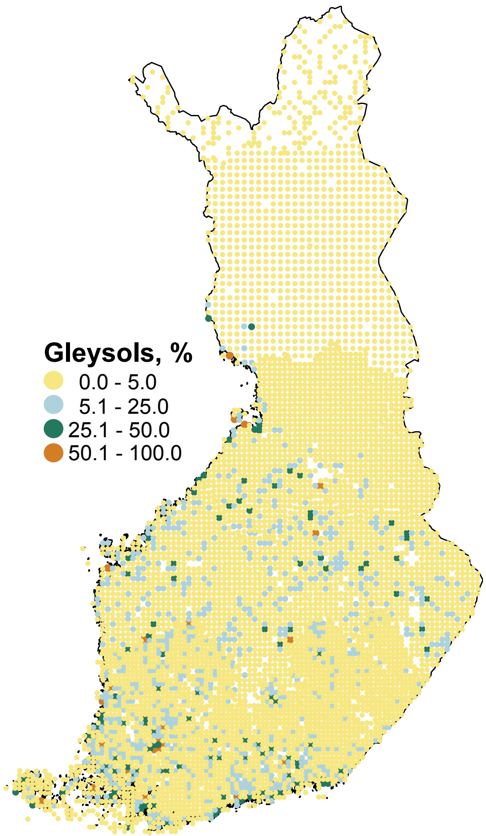

Figure 5. Proportion of Gleysols.

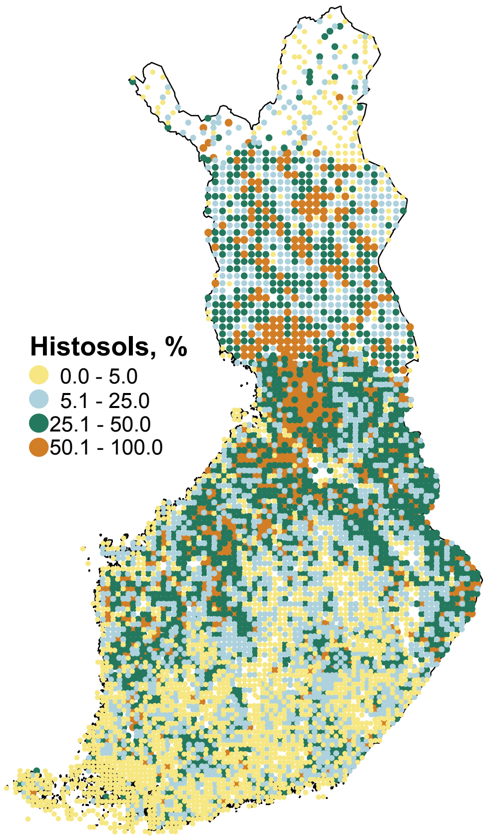

Figure 6. Proportion of Histosols.

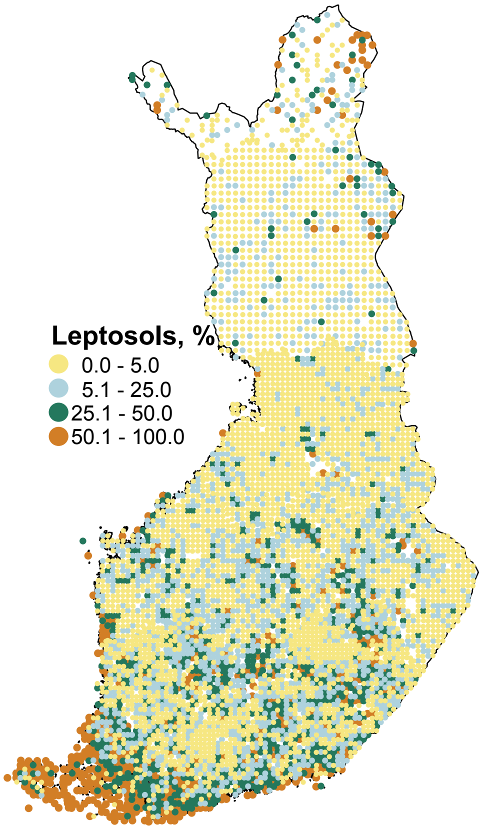

Figure 7. Proportion of Leptosols.

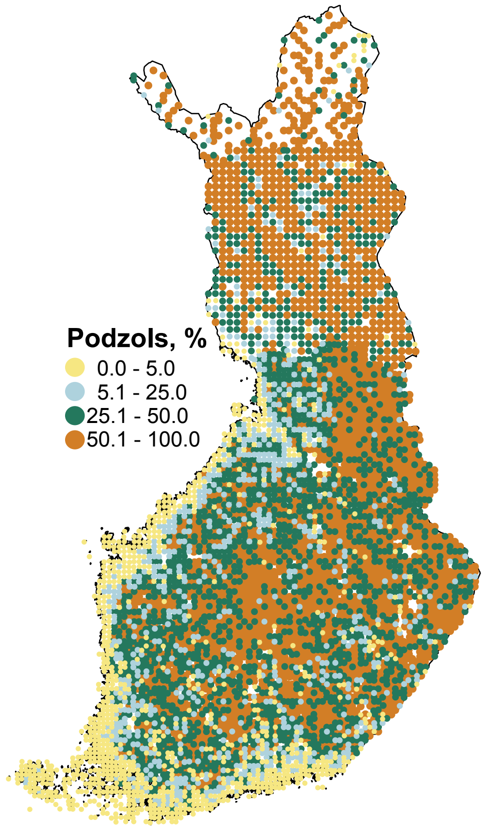

Figure 8. Proportion of Podzols.

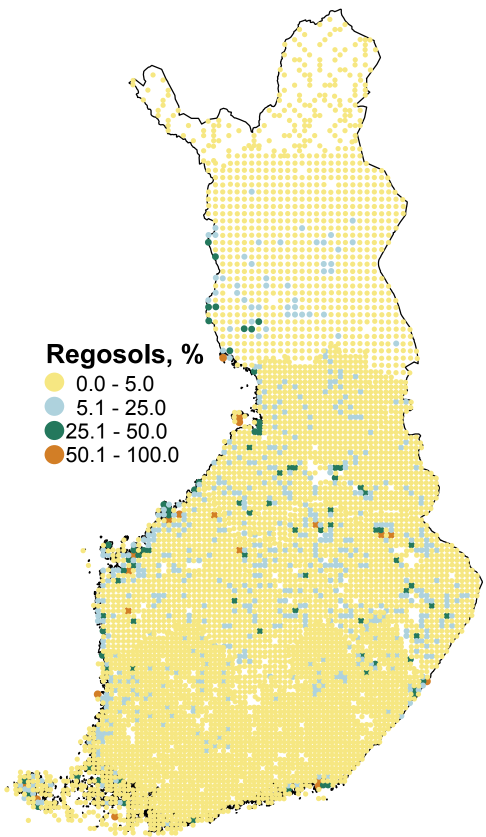

Figure 9. Proportion of Regosols.

4 Discussion

We have had scarcely information about genetic soil types in Finland, except for peatlands and Podzols. However, soil texture and quaternary deposit maps with explanations have been published in different scales (see: http://www.gsf.fi/palvelut/info/kartat/index.htm). Podzols, the most common soil group, have been studied by several authors (Aaltonen 1935, 1939, 1941, 1947, Jauhiainen 1969, 1970, 1973a, 1973b, 1976, Petäjä-Ronkainen et al. 1992, Starr and Tamminen 1994). Also information on soil chemical status has been published both on mineral soils (Urvas and Erviö 1974, Urvas et al. 1979, Urvas 1980, Tamminen and Starr 1990, Starr and Tamminen 1992, Urvas 1995, Tamminen 2000) and on peatlands (Urvas et al. 1979, Urvas 1980, Urvas et al. 1980, Westman 1981, Kaunisto and Paavilainen 1988, Hytönen and Wall 1997).

In this article the most common soil types on forestry land were surveyed. Although, it was obvious already before this study that podzolized soils and peatlands dominate in Finland. But the relative frequency of podzols and, especially rarer soil types was unclear. The survey method seemed to work well, although the field sample of soils was very small compared to about 260 000 km^2 of total area of forestry land in Finland. The data of the 9^{th} national forest inventory covered rather well the needs of soil classification, even though the NFI field groups had a short time to learn and estimate in practice soil characteristics. The soil survey field groups were experienced in forest soil inventory, but rather inexperienced in the FAO or WRB soil classification. Digital photos and analysed horizon samples helped to harmonize the soil classification. But unfortunately, the field soil classification was done according to the FAO system (FAO-UNESCO 1988). At the office, the classification was transformed to correspond to the WRB 1998 system and finally soils were tried to classify according to the WRB 2006 classification (World Reference Base for Soil Resources 1998, IUSS working group WRB 2006). Therefore the final classification is not totally equivalent with the WRB 2006 system.

Although, the results of this study have a high level of uncertainty, they are based on field observations. The two phase sampling made it possible to generalize information of the tiny soil survey material with the help of the huge NFI sample plot data for whole Finland. The level of uncertainty is impossible to estimate. On the basis of experience, the biggest errors are linked to the determination of each soil type, i.e. to the soil naming, to the insufficient models in analytical soil classification and to the estimation of site and soil characteristics in the NFI, perhaps in this order.

This soil survey is maybe not very important for forestry or forest research, but it is needed in order to be able to estimate the frequencies of the Finnish forest soils in the frame of a global soil classification system. Results, i.e. soil type distributions and maps, seemed to describe quite plausibly the overall situation in Finland as to the soil development processes.

Critics against the international soil classification systems

The international classification systems (FAO-UNESCO 1988, World Reference Base for Soil Resources 1998, IUSS working group WRB 2006) have been aimed to cover whole world and act as an independent global-scale soil classification system and as a link or an interpretation method between different national classification systems. However, all soil classification systems have been created to deal primarily with agricultural soils because of their greater importance compared to forest soils. Therefore the soils covered by forests, e.g. the soils in the boreal zone or mountainous areas, are forced into the classification systems. For instance, very important mor, moder or peat layers, cannot in most cases be taken into account at all in soil classification, or only after they have been thought to be ploughed and mixed with surface mineral soil. Another difficult feature in most soil classification systems is the preference for nominal scale variables, i.e. names of classes and subclasses, instead of continuous variables. The usage of soil information would be easier, if the variables describing a soil were continuous or even ordinal scale values. For instance, in the U.S.A. the soil survey has produced over 15 000 soil series with a detailed description and the WRB 2006 system has about 492 second level units. In a European forest soil survey project (Biosoil) field instructions contained 92 variables describing each soil profile, and only 12 were continuous variables, 48 ordinal and 35 nominal scale variables.

The use of nominal scale variables instead of continuous variables may lead to rather inconvenient situations. If the thickness of a peat layer is 40 cm, the soil is a Histosol, but if the peat layer is 39 cm thick, the soil is some other, mineral soil type. Or if a podzolized soil does not meet criteria for Podzols, e.g. aluminium+½iron percentage is 0.49 %, then the soil is classified as other, eg. as an Albic Arenosol. It is quite clear that in these cases the soil pairs correspond almost totally to each others. In the first case, the relevant variable, peat thickness, should be measured and used in classification or mapping. In the second example, the degree of podzolization could be measured using analytical data, but from the soil users point (eg. bearing capacity, sensitivity to soil frost heaving, fertility etc.), the degree of podzolization is hardly relevant at all.

Nowadays, the same kind of soil mapping as in the national forest inventories could be effective. Field observations of profiles can be generalized using satellite or other air-borne information and digitalized topographic maps with many details also on soils and elevation models. Maybe the soil classification systems based on the variables describing the soil forming processes and features mostly constructed for arable soils could be transformed to simpler systems to meet better the needs of primary soil users in forestry, i.e. farmers, foresters or forest entrepreneurs.

5 Conclusions

It was possible to classify forest soils according to the World reference base soil classification system on the basis of the site and soil variables measured or estimated in the Finnish 9th national forest inventory. A small subsample was taken from the NFI plots (n=285) and these plots were studied by the soil survey groups. This second phase sample was allocated to cover the whole range of soil texture, organic layer thickness and site fertility in whole Finland.

Soil type on about 66 000 NFI sample plots was predicted and frequencies of soil types were estimated in whole country and in administrative forestry centers. The most frequent soil types were Podzols (50 %), Histosols (25 %), Arenosols (11 %) and Leptosols (9 %). Finer-textured soils, Cambisols (1.9 %), Gleysols (1.4 %) and Regosols (1.2 %) had only a small proportion.

International soil classifications seem to suit poorly to forest soils in Finland, because the important organic layer in not taken into consideration at all. Instead of many separate soil classes based on soil formation processes or properties linked to these, the use of continuous variables would be more useful for primary soil users.

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