Chapter 13
Spatial Estimation of Estonian Forest Landscapes' Soil Cover Humus Status: Methods, Model Samples and Assessments

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Abstract Humus status of soil cover is of greatest importance in the formation and functioning of landscape. On the humus status of landscape soils (soilscape) depends in a great extent the floristic composition and diversity of forest ecosystems and its functioning peculiarities (level of annual productivity and litterfall, and as well the character of soil organic matter decomposition and the fabric of formed humus profile). The substantial part of this work is devoted to the evaluation of soil organic carbon (SOC) superficial densities (in Mg per ha) and its total stocks by the dominated Estonian forest soils and their different layers, as the most important quantitative indices of soil cover. The essential findings of this work are also the estimations of total SOC stocks (pools) in whole Estonian forested soil cover and in its main sublayers (humus cover and subsoil). Much attention is paid to the ecological aspects of humus cover type (*pro* humus form) formation and its profile fabric's matching with soil properties. The humus cover type may be taken as the main qualitative index of forest soils' humus status. Relevant are also the pedo-ecological

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analyses on the role of humus status indexes in the characterizing of SOC cycling and annual balance, and also in the formation of ecosystems biodiversity. Totally in the soil cover of Estonian forest land, 367 Tg of SOC is sequestrated. From the total SOC amount, 66.2% is located in the humus cover and 33.8% in subsoil layers. The mineral and peat soils role in sequestration of total SOC amount are accordingly 55.0% and 45.0%. For a better understanding to international audience, the used key terms of the study are elucidated and the soil names of the local classification are juxtaposed by the names of international classifications.

Keywords Humus status · Soil cover · Humus cover · Soil organic carbon · Forest soils · Pedocentric approach · Landscape · Digital soil map

13.1 Introduction

Soil cover (SC) forms the material basis for landscape (Kõlli and Ellermäe 2001; Arold 2005). The distribution pattern, appearance and functioning of the landscape depends besides of soils' properties and diversity (pedodiversity) on the extra-soil natural agents such as climatic conditions, geology and hydrography of the area. Moreover, it depends as well on different aspects of the anthropogenic activities such as the policy of application local natural resources, kind of land use and the intensity of the land management.

In characterizing landscape type and its functioning capability (i.e. in studying ecological aspects of landscape), it is essential to follow not only SC properties. The complexity of characterization is inconceivable without studying of soil type-specific plant cover, organisms' assemblages adapted to soil condition and hydrological regimes of the ambient territory. By these above-named components, their mutual relationships are determined in general lines the landscapes functioning activity and stability, and therefore the sustainable use of available local resources (as the plant available nutrition elements and water of the SC, photosynthetically active radiation and seasonal meteorological features). With other words, the characterization of landscapes structure and functioning requires an ecosystem approach as only in such case all essential components influencing landscape functioning will be taken into account.

The fabric, diversity and functioning capacity of forest ecosystems formed in natural landscape depend much on the physical–chemical properties and hydrological conditions of soils. For the best indicators in characterizing of forest landscape's functioning intensity is the potential fertility or annual productivity of SC, which is reflected via its nutritional and humus status (HS). In this work, the main attention was paid to the HS of soils, taking it as a driving force, which determines the character of processes and evolution direction of forest landscapes. It is important to mention that HS determines partly as well the nutritional status of ecosystems as most of the nutrition elements are cycling in the composition of organic matter.

The main quantitative indexes of organic matter flux via the ecosystem (landscape) are the annual increment of phytomass, annual litterfall intensity and annual accumulation rate of new organic matter on or into the SC. In the case of deliberation (decomposition) of soil organic matter (SOM), the captured nutrition elements are switched into the new cycle of elements' turnover or into the production process of forest ecosystems. For understanding these processes, it is utmost important to know the soil organic carbon (SOC) sequestration capacities of different soil types in diverse land-use conditions and distribution of SOC by separate SC layers.

In the past decades, the databases on SOC stocks in soils and its estimation methods have been continuously increased and perfected, enfolding the generalizations of data on European and global levels (Dixon et al. 1994; Bazilevich and Titljanova 2008; Baritz et al. 2010; De Vos et al. 2015). In Estonia, the problems connected with SOC sequestration into forest SC and with its role in functioning forest ecosystems were studied versatilely and long-lastingly (Kõlli 2002; Kõlli et al. 2004, 2009a; Lutter et al. 2018). Some of our previous researches may be taken as the prerequisite or basis for the current study (Kõlli 1992; Kõlli et al. 2009b, 2010; Lang et al. 2017; Lutter et al. 2018).

The main novelty of actual study consists (1) in the generalization of SOC superficial densities (Mg ha^{-1}) distribution data on normally developed (or post-lithogenic) mineral and organic soils' united matrix table, and (2) in using of different forest land maps for extraction of forest soils data. Therefore, the main aims of the study are the following:

- to characterize Estonian forest soils' HS and pedo-ecological properties by soil groups on different levels of generalization;
- to explain the role of soils' HS in the forming and functioning of landscapes by different soil groups;
- to introduce methodological principles used for determination of SOC's superficial densities and total stocks in the SC of forest landscapes;
- to estimate the total SOC stock sequestrated in the Estonian forest landscape's SC and in its sublayers, i.e. in the top and subsoil and
- to explain some regularities of matching soil mapping units (SMU) with forest management units (compartments) in relation to dominant forest soils.

13.2 Terminology and Methodology

13.2.1 Terminology

The humus status (HS) of a soil reflects in principle the character of its SOM management or the throughout flux of SOC via the SC. This flux begins with litterfall on or into the soil and follows by variegated processes in mutual relationships with soil living, liquid, gaseous and solid phases, until to its stabilization or/and total mineralization and elimination from the SC. The main parameters for the characterization of soils' HS are the thickness and morphology of soil horizons, SOC (or SOM) concentration (g kg^{-1}) and stock densities per area (Mg ha^{-1}) in different horizons, and SOC annual turnover (Mg ha^{-1} yr^{-1}).

In the quantitative characterization of HS in relation to soil mantle the notion of soil cover (SC) or solum is used. SC embraces the superficial landscape layer influenced by soil-forming process and consists of HC and subsoil (SS). As characteristic to boreal bioclimatic belt, the thicknesses of Estonian SCs are remarkably thinner as compared with southern regions SC's thicknesses. By our previous researches (Kõlli 2002; Kõlli et al. 2004) the SC thicknesses (depth from soil surface to unchanged parent material) depend in great extent on SC moisture conditions, calcareousness and texture, reaching in automorphic pseudopodzolic and podzolic soils to 100–110 cm, but the thickness of permanently wet gley-soils is in most cases in the limits 40–65 cm. Depending on this, for the benchmark thicknesses of peat soils or histosols in the current study is taken 50 cm.

Humus cover (HC), which is known as well as epipedon and humipedon (Zanella et al. 2011), encompasses the most active superficial (topsoil) part of SC via which the dominant share of SOC (SOM) cycling takes place. The HC consists of forest floor, humus or raw humus and peat horizons and is closely coupled with plant cover. For the benchmark thicknesses of peat soils' or histosols' HCs is taken in our work 30 cm.

Subsoil (SS), which underlies the biologically active topsoil, consists in the case of mineral soils from the *eluvial* and/or *illuvial* horizons, but in the case of peat soils, the SS embraces a peat layer located in the depth from 30 to 50 cm with thickness 20 cm.

Treating of SC on the basis of large-scale soil maps (1:10,000) needs quantitative assessments using of detailed level classification taxa as (1) <u>soil species</u>, which is the taxon of Estonian soil classification (ESC) identified by soil-forming processes and (2) <u>soil variety</u>—taxon of ESC identified by soil species' texture. Soil species contours recur and they are separated on soil maps in different patterns across the landscape.

For the qualitative characterization in Estonia, the <u>humus cover type</u> (*pro* humus form) is in use. Humus cover type, which characterizes SOC/SOM formation ecology, is a good index as well for using in landscape level. Totally in Estonian forest humus classification, 27 HC types have been separated (Kõlli 1992).

13.2.2 Methodological Principles

For explaining SC role in the development and functioning of forest landscapes in this study, the pedocentric approach is used (Kõlli et al. 2018). For the basis of this approach are the soil species or/and soil varieties of ESC or the SMU of the large-scale (1:10,000) soil map (Estonian Land Board 2012). The main pedological information about each soil contour (as SMU) is expressed by the code of soil species. In addition to this, with each contour is connected some additional information on soil properties, such as soil texture, calcareousness/acidity and fabric of humipedon.

At the same time for the most detail mapping unit in forest management is the compartment, which, besides information on forest stands, gives some information on site forest growth conditions. Therefore, the site properties of each compartment are described indirectly by forest site type (FST), which expresses site condition mostly by forest understory plant associations and indicator species presented in plant cover (Lõhmus 2004). In connection with this, for the one of our research task was to study the matching of mapping units of soil and forest management maps (Kõlli and Köster 2018).

By our understanding, the pedodiversity depends directly on soil-forming conditions of the area, among them on soil parent material and its deposition character (relief), i.e. pedodiversity depends on areal geodiversity (Kõlli et al. 2018). For the native zonal ecosystems in Estonia are the forests formed in equilibration processes with soil conditions. We are in the opinion that the best ecological conditions are formed in the case of optimal site-specific vegetation diversity. Therefore, biodiversity should be optimal and inherent to the site (or soil). It means that the vegetation should be adequate to site conditions or should be site specific, but not to be with maximal as possible biodiversity.

Four independent data sources were used in our study to identify forest land, (1) wooded land area of 1:10,000 Estonian basic map, (2) stand map of forest management inventory database, (3) forest mask constructed using satellite images (Peterson et al. 2004, 2008), and (4) satellite images-based tree species map (Fig. 13.1; Lang et al. 2018). Spatial overlay module in GRASS GIS 7.4 was used to cut soil map objects according to forest land maps (Fig. 13.2). The tested forest land maps' acreage used to clip 1:10,000 soil map for extraction of forest soil cover's SMU data are presented in Table 13.1.

In dominating cases for SMU were soil species, only in the case of fen soils the soil species were divided into soil varieties. The results of the current study are based on the data extracted from the large-scale soil map by the compartments' map of the State Forest Register (Table 13.1). The soil map database information is in connection with normally developed mineral and organic soils' united matrix table's litho-genetic and moisture scalars, which may be taken as the coordinates for each soil patch (Fig. 13.3). For assessing SC and HC SOC stock values for each soil patch in the soil map database the lookup tables (LUTs) were used. LUTs were constructed for the SOC stock values by interpolating the data by 0.1 step resolution of soil litho-genetic and moisture coordinates (Fig. 13.5). These coordinates were used to seek SOC data from LUT that are described further in the text in more detail.

The particle size distribution was determined by Kachinsky (1965). The volume of coarse soil fractions ($\varnothing > 1.0$ mm) was determined during the field research (Astover et al. 2013). In laboratory the content of fine-earth ($\varnothing < 1.0$ mm) and of fraction 1–10 mm in soil samples was determined by sieving, but the particle size distribution of fine-earth by using the sedimentation method. SOC concentration was determined by wet digestion of SOM with acid dichromate (Tjurin 1935). The

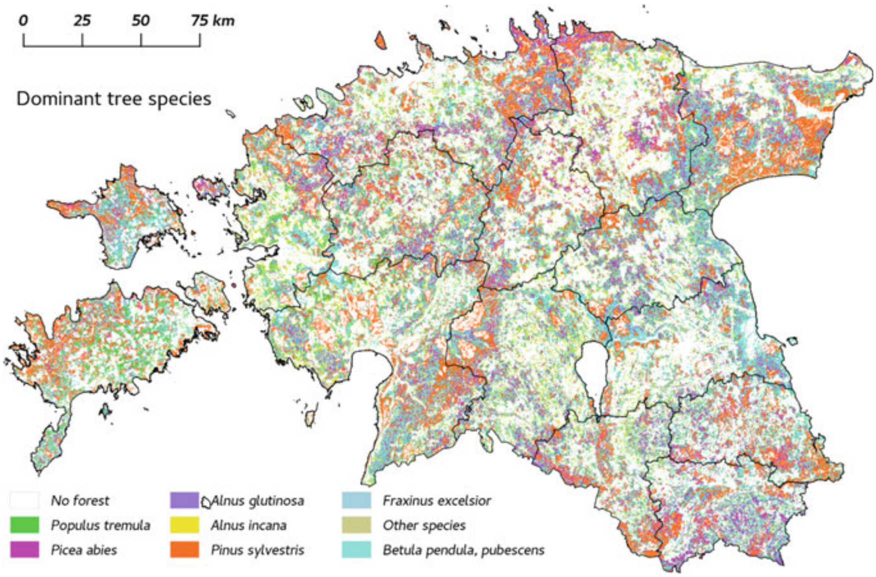

Fig. 13.1 Dominant tree species in Estonian forest landscapes. Adopted from Lang et al. (2018) with permission

SOC stocks in SC of different soil types are calculated on the basis of the SOC concentrations and bulk densities of corresponding soil horizons. In the calculation of SOM in mineral soils, the coefficient of value 1.72 was used but of peaty soils and forest floors the coefficient 2.00 was used (Astover et al. 2013).

The soil names given in the national databases by ESC were converted into World Reference Base (WRB) soil classification system (Estonian Land Board 2012; IUSS WG WRB 2015). The juxtaposition of ESC and WRB is seen also in Fig. 13.3.

13.3 Pedo-Ecological Conditions and Used Data

To the natural area of Estonia, which is located in mild and wet pedo-climatic conditions, mainly the coniferous and coniferous–deciduous mixed forests are characteristic (Laasimer 1965; Valk and Eilart 1974; Yearbook Forest 2017 2018). The list of dominant tree species found in Estonian forest landscapes contains less than 10 tree species (Fig. 13.1). As a result of intensified agricultural activity during last two centuries, the most productive areas of Estonia (soils suitable for crop cultivation and grasslands) have been turned into arable, pastured or hay-lands (Mander et al. 1995; Raukas 1995; Arold 2005).

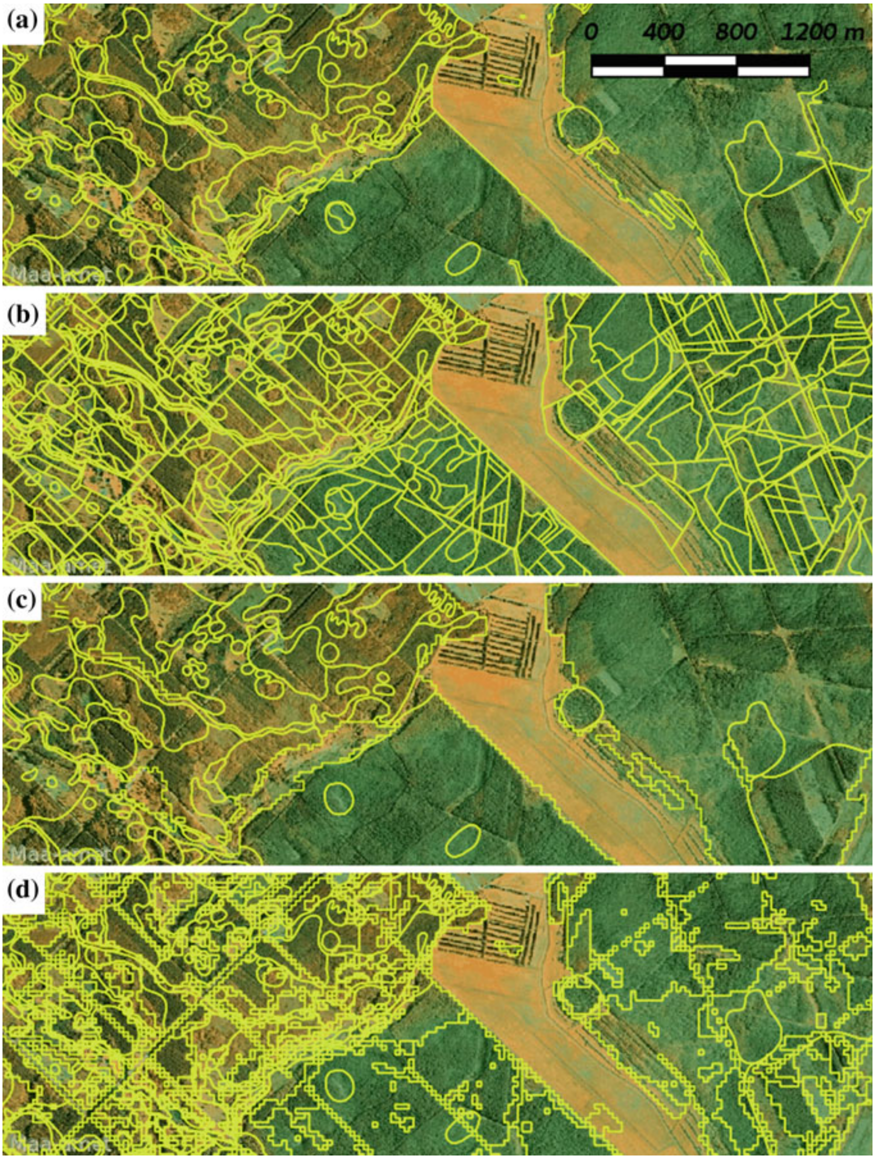

Fig. 13.2 Examples of cutting 1:10,000 digital soil map with **a** wooded land area of 1:10,000 Estonian basic map, **b** stand map of forest management inventory database, **c** forest mask constructed using satellite images (Peterson et al. 2004, 2008), and **d** tree species map based on satellite images (Lang et al. 2018)

Table 13.1 List of forest land maps used to clip 1:10,000 soil map for the extraction of forest soil cover's soil mapping units (for which is Estonian soil classification taxon 'soil species') data

No	Source of forest land data	Tested SC area, in km^2	Remarks
1	Compartments' map of the State Forest Register based on the distribution of forest site types	20,114	Forest land area by National Forest Inventory was 23,306 km^2 by the Yearbook Forest 2017 (2018)
2	Area of the basic map covered by woody plants	23,557	Exceeds National Forest Inventory (NFI) area by 251 km^2
3	Wintertime satellite images (Peterson et al. 2004, 2008)	24,002	Exceeds NFI area by 696 km^2
4	Map of forest stands' tree species composition (Fig. 13.1; Lang et al. 2018)	27,173	Exceeds NFI area by 3,867 km^2; enfolds also the bushy areas outside of forest land

The main part of parent materials of Estonian soils is derived from the glacial and aqua glacial Quaternary deposits. The parent material of half mineral soils are Pleistocene tills. The reworked tills glaciofluvial, glaciolacustrine, alluvial and aeolian sediments are distributed alternatively with tills (Raukas and Teedumäe 1997).

The integrating of soils' data into the forest landscapes management is possible thanks to the availability (1) of large-scale soil maps for forested lands and (2) of quantitative data on HS for all dominated forest soil species (Estonian Agri-Project 1983, 1985). A 1:10,000 digital soil map is provided by the Estonian Land Board (2012).

The quantitative data of soils' HS of the present study originate mainly from the soil profile horizons database (DB) *Pedon* (Kõlli et al. 2009a, b) created by us. The bulk density samples were taken from approximately one-tenth of profiles. In addition to our experimental data, the materials published on HS and productivity of mineral and peat soils of Estonia were used (Reintam et al. 2003). Overall, generalized volume weights from our own and other data sources (mainly data of Estsurvey pertaining to soil species and texture) were used.

13.4 Estimations of SOC Stocks

13.4.1 Distribution of Forest Soils by ESC Taxa and Some Essential Soil Cover Characteristics on the Level of Soil Species

For the basis of detail characterization which ever territory's HS (from one soil mapping contour to whole Estonian forest land) are the individual HS data of all

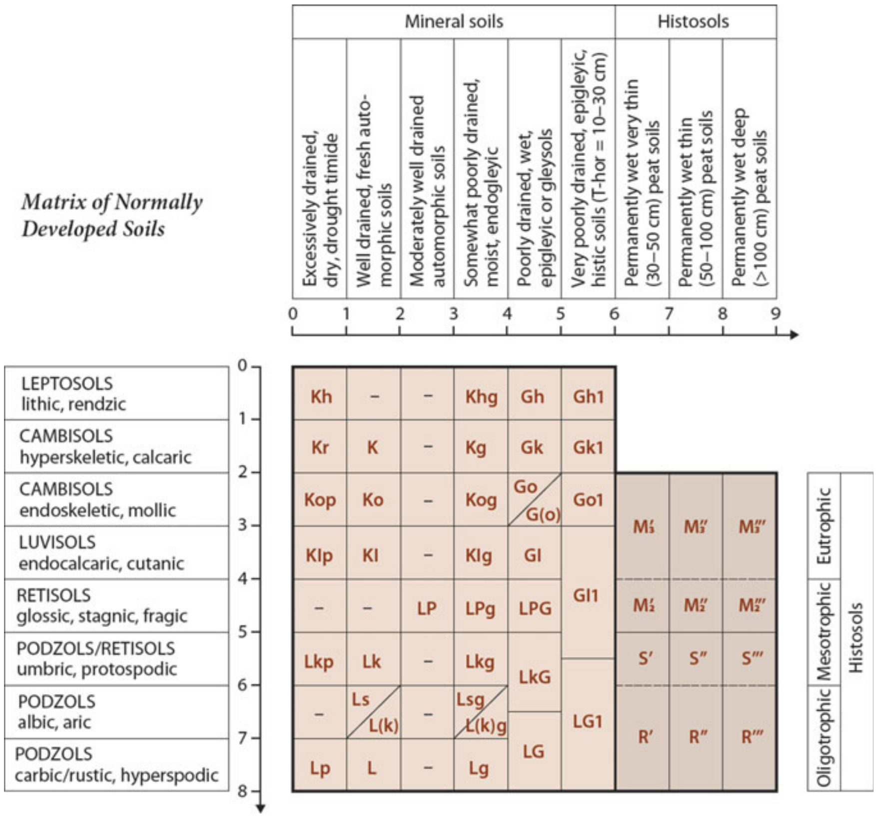

Fig. 13.3 Matrix of normally developed soils as a pedo-ecological background of SOC stocks lookup table (LUT) models with soil codes of Estonian Soil Classification (ESC). On the horizontal scalar the soils moisture conditions, but on vertical, i.e. litho-genetical scalar, the correlation with WRB reference soils are given. Additional explanation on right side characterizes the feeding water, which is drawing force of soil cover paludification processes. For soil names after their codes see Table 13.2

presented soils species and/or soil varieties and their distribution area. Totally on forested land of Estonia may be found more than 120 soil species, which enfold >300 different soil varieties. In the interest of generalization, the data on soil distribution are presented in this work in the level of small soil groups (SSG) in Table 13.2. The list of SSG is not only summarized similar by their properties soil species but also very similar to them abnormal soils. As the share of abnormal soils is relatively modest among others (Fig. 13.4), their nomenclature is not presented in actual work. In relation to tested territory, the abnormal mineral forest soils formed 2.5% from whole mineral soils and abnormal organic soils 1.0% from whole organic soils. The distribution of soil species was tested on the basis of the compartments' map of the State Forest Register (Table 13.1) in relation to territory 20,114 km^2, which forms 86.3% of total forest land (Table 13.2).

Table 13.2 Small soil groups' (SSG) codes and names by Estonian soil classification (ESC), and their areal distribution

SSG	Codes	Names by ESC[a]	Area[b]	
			ha	%
1	Kh	Limestone rendzinas	10,371	0.5
2	Khg	Gleyed limestone rendzinas	2,772	0.1
3	K Kr	Pebble and pebble-rich rendzinas	52,469	2.6
4	Kg Krg	Gleyed pebble and pebble-rich rendzinas	20,396	1.0
5	Ko Kor	Typical and pebble-rich leached soils	46,432	2.3
6	Kog Korg	Gleyed typical and pebble-rich leached soils	49,233	2.4
7	KI	Eluviated soils	29,329	1.5
8	KIg	Gleyed eluviated soils	57,968	2.9
9	LP	Pseudopodzolic soils	53,954	2.7
10	LPg	Gleyed pseudopodzolic soils	62,564	3.1
11	Lk	Sod-podzolic soils	66,457	3.3
12	Lkg	Gleyed sod-podzolic soils	41,768	2.1
13	L(k) Ls	Humuous and secondary podzols	28,409	1.4
14	L(k)g Lsg	Gleyed humuous and secondary podzols	12,748	0.6
15	L	Typical podzols	65,772	3.3
16	Lg	Gleyed typical podzols	22,881	1.1
17	Gh Gh1	Limestone gley- and peaty gley-rendzinas	2,830	0.1
18	Gk Go G(o)	Pebble gley-rendzinas; leached and saturated gley-soils	343,122	17.1
19	GI LPG	Eluviated and pseudopodzolic gley-soils	229,599	11.4
20	LkG	Sod-podzolic gley-soils	62,318	3.1
21	LG	Gley-podzols	59,767	3.0
22	Gk1 Go1	Pebble and saturated peaty gley-soils	69,456	3.5
23	GI1	Unsaturated peaty gley-soils	48,912	2.4
24	LG1	Peaty podzols	55,362	2.8
25	AM	Alluvial fen soils	5,224	0.3
25a	M3	Well decomposed lowland fen soils	252,346	12.5
25b	M2	Moderately decomposed lowland fen soils	102,923	501
26	S	Transitional bog soils	101,921	5.1
27	R	Raised bog soils	40,892	2.0
28	Tx	Technogenic eliminated soils	3,742	0.2
29	Ty	Technogenic mixed soils	5	<0.05
30	Tz	Technogenic buried soils	62	<0.05
31	Tu	Technogenic sediment soils	5,296	0.3
32	Pu	Ground sediment heaps	2,633	0.1

(continued)

Table 13.2 (continued)

SSG	Codes	Names by ESC[a]	Area[b]	
			ha	%
33	Pp	Bare ground	1,446	0.1
34	C	Artificial grounds	18	<0.05

[a]In list the codes and names of abnormal soils are absent (an exception are those of SSG 25 and 28–34), whereas for their share see Fig. 13.2

[b]Including area of similar to normal soils by their humus status different species of abnormal soils

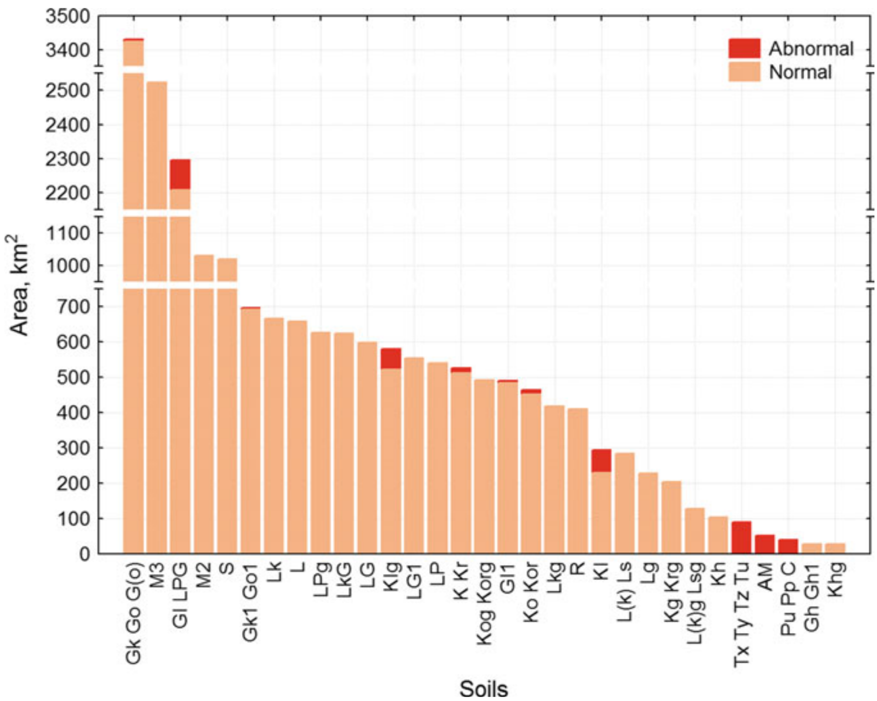

Fig. 13.4 Areas of normally developed soil species in Estonian forest lands' soil cover with these abnormal soils, which are by their properties similar to normal soils. For soil names by their codes see Table 13.2

Supporting to the data of more detail level analyses than it is presented in Table 13.2 and Fig. 13.4 was possible besides of soils HS to follow as well different other soil properties and pedo-genetic features, which are with essential importance in characterization of forest landscapes SC.

(1) By the podzolization formula—weakly (I): moderately (II): strongly (III): podzolized soils percentage, the soils with moist (gleyed) conditions are podzolized in greatest extent as compared with soils with fresh moisture conditions. If the

relationships (I:II:III) for Lk and L are accordingly 94:6:0 and 70:28:2, then the same for Lkg and Lg are accordingly 75:23:2 and 30:65:5.

(2) The ratio (in %) of pebble and pebble-rich rendzinas is an average of 73:27, but the ratio of typical and pebble-rich leached fresh and moist soils 93:7.

(3) The ratio (in %) M:S:R (fen: transitional bog: high bog) soils is an average 71:21:8.

(4) From the whole tested area, the moderately (E2) and strongly (E3) eroded soils (with slope accordingly 5°–10° and >10°) form 0.27%, whereas they are in ratio with deluvial (D) soils (E:D) as 36%:64%.

(5) If in the case of SSG 1–4 and 11–16 by the area are dominating fresh automorphic soils, then in the case of SSG 5–10 (more fertile soils) vice versa the dominating are moist or gleyed soils.

Estonian-forested landscapes SC is typical to north-eastern Europe with dominating of *Gleysols* and with a high share of *Histosols*. The share of automorphic mineral soils is approximately one-third of the forest area.

13.4.2 SOC Stocks Density Models for Estonian Normally Developed Forest Soils

The SOC superficial densities (Mg ha^{-1}) models are composed by the LUT principles on normally developed soil matrix (Fig. 13.3). The forest soils SC and HC SOC stock models are formed in the level of soils species.

The isolines of empirical SC and HC SOC stock values (Figs. 13.5 and 13.6) are too complex for the construction of mathematical equation that could represent all the variabilities with sufficient precision for all soils in the matrix. The LUT for SOC stock values were constructed by interpolating the isolines' data given in relation to soil litho-genetic and moisture scalars as coordinates (Figs. 13.5 and 13.6). The SOC stock densities, which are characterized by isolines, may be taken as decision support models (DSM). Totally two DSM are presented. One of them is elaborated in relation to whole SC (Fig. 13.5) and second in relation to HC (Fig. 13.6). By these models, it is possible to estimate whichever Estonian normally developed mineral and peat soils SC SOC stocks densities (Mg ha^{-1}). The total SOC stocks are calculated on the basis of soils' SOC densities and distribution areas.

In Fig. 13.7, it is presented total amounts of SOC, which have been sequestrated in the SC of the State Forest Register forests (20,114 km^2). In this figure, the whole SC SOC is divided into HC and SS. The SS SOC's total stocks and stocks density may be found by the formula $SOC_{SS} = SOC_{SC} – SOC_{HC}$. In connection with a modest share of abnormal soils among normal soils (see Fig. 13.3), on the basis of these two DSM were estimated also the SCs and HCs SOC total stocks of abnormal soils.

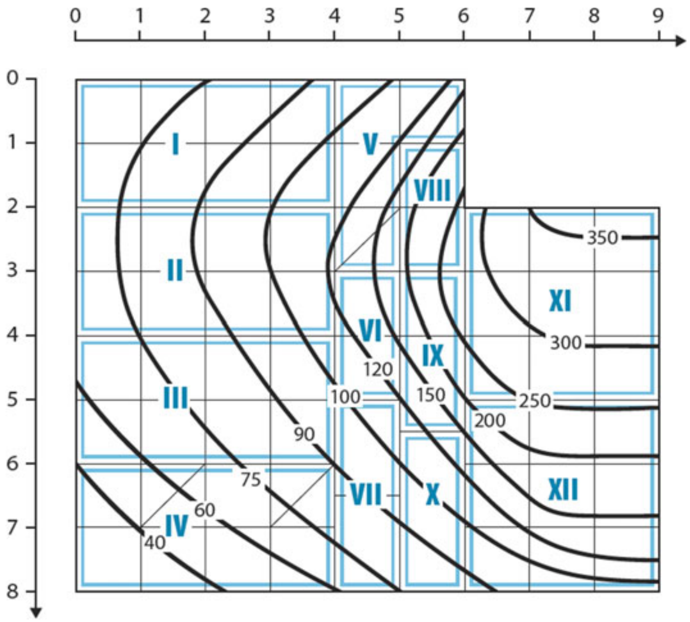

Fig. 13.5 LUT model about SOC stocks (Mg ha^{-1}) in soil cover of Estonian forest soils (given by isolines) on the background of large soil groups (LSG, I–XII). For pedo-ecological conditions of the background matrix see Fig. 13.3. The pedo-ecological characterization of LSG is given in Tables 13.4, 13.5 and 13.6

13.4.3 Estimation of SOC Stocks by Large Soil Groups (LSG)

For both tasks, generalization of the data and harmonization of calculated results by ESC with WRB, the LSG have been formed (Table 13.3). The information given by LSG was based on the same tested territory which was used in the case of SSG. For to being from the pedological aspect universally understandable to international audience, the LSG are characterized by reference soils and qualifiers of WRB (Table 13.3).

From the total amount of SC SOC (316.4 Tg) of tested area, the biggest share forms lowland fen soils (Table 13.4). Remarkable share (29.0%) belongs as well to different kinds of gley-soils (LSG V–VII). In sequestration of SOC into HC besides fen soils have formed in eutrophic conditions rich in calcium gley-soils. The subsoils of peat soils or histosols are also rich in SOC, but it should mention that this part of SOC does not participate in active cycling of SOC. At the same time, different mineral soil groups are sequestrated into their SS from 2.0 to 7.8 Tg of SOC. The highest share of SOC among mineral soils SS have different kind of podzols (as LSG II, IV, VII and X). For characterization of correlation between LSG soils and FST approximately 70% of dominated FST have been accounted in Table 13.4.

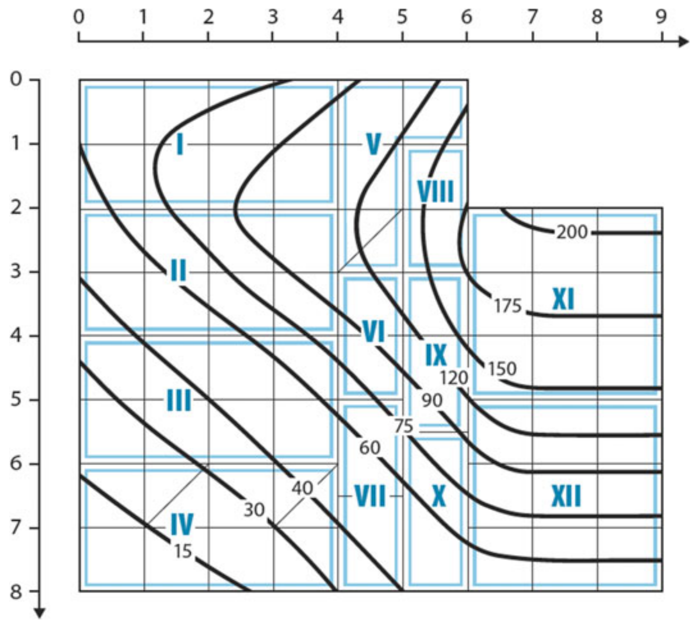

Fig. 13.6 LUT model about SOC stocks (Mg ha^{-1}) in humus cover of Estonian forest soils (given by isolines) on the background of large soil groups (LSG, I–XII). For pedo-ecological conditions of the background matrix see Fig. 13.3. The pedo-ecological characterization of LSG is given in Tables 13.4, 13.5 and 13.6

13.5 Estimations of Total SOC Stocks in the SC of Estonian Forest Land

As the tested area of Estonian forest land (20,114 km^2) enfolds 86.3%, we estimated the total SOC stocks for the whole forest area (23,306 km^2) according to three different scenarios (Table 13.5). These scenarios are based on prognoses of non-tested area's (3,192 km^2 or 13.7%) different soil cover compositions. It seems that more realistic from these three should be the first of them, where the non-tested part SC composition has been taken similar to tested one.

On the basis of forest lands, SC total SOC amounts the SOC stock densities (Mg ha^{-1}) for the different SSG were calculated (Fig. 13.8). It is important also to mention that these mean SOC sequestration capacities were calculated as mean weighted by the area in relation to whole SC and separately to mineral and peat soils. By the scenario I (Table 13.5) in the Estonian forest land SC totally 367 Tg of SOC is sequestrated, whereas 66.2% of it is located in the HC and 33.8% in SS. From the total SOC amounts, 55.0% is located in SC of mineral soils and 45.0% in peat soils.

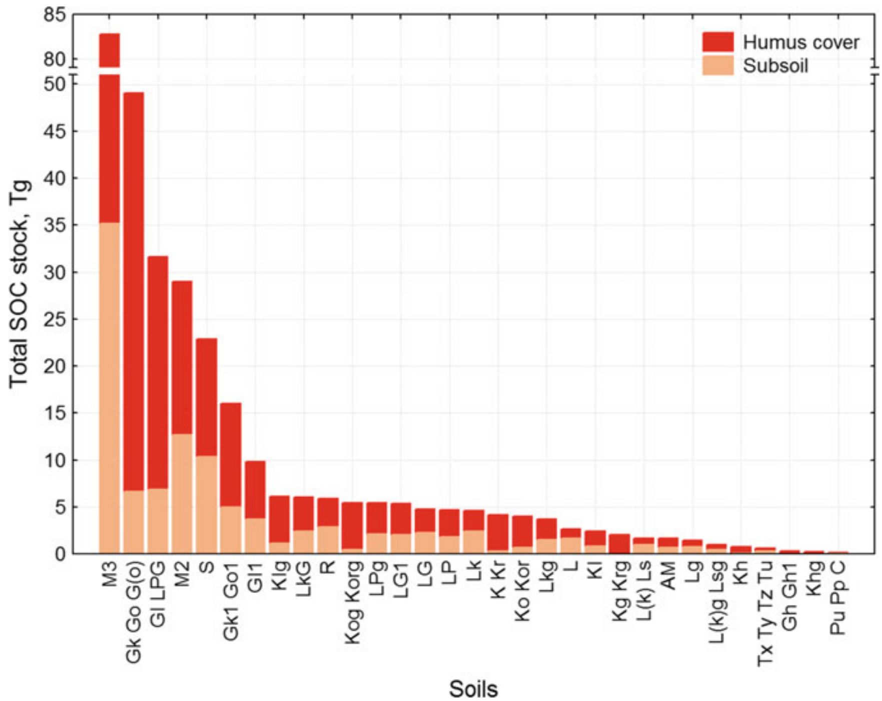

Fig. 13.7 Share of different soil species in sequestration of SOC in whole Estonian forest lands' soil cover or in solum. For soil names by their codes see Table 13.2

13.6 Essential Remarks Upon Determination Forest Soils' HS

The SC is a determining factor in the development of plant cover and its diversity. The pedodiversity of the landscape may be caused by soil texture variations (from sand to clay), mineralogical and chemical composition, calcareousness and acidity. The pattern of SC and its diversity are induced by the geodiversity and hydrological conditions. For a better understanding of mutual influences of SC and plant cover, the feedback influences of their main components (soil, plant) functioning should be studied at the ecosystem level, on typical-to-region soil types and management conditions (Photo 13.1).

In Table 13.6, besides SOC sequestration capacity into SC as well the dominant soil texture and HC types have been presented by LSG. With these characteristics are tightly connected the thicknesses of SC and HC, as well the fabric and acidity of the forest floor. The named characteristics' complex is reflected in forest ecosystems productivity (quality class) and in the composition of dominant tree species.

Table 13.3 Large groups of forest soils (LSG): composition, characterization with WRB qualifiers and distribution

LSG No	SSG	Codes by ESC	RSG of WRB	Characterization of LSG properties with WRB qualifiers	Area	
					km^2	%
I	1–4	Kh Kr K Khg Krg Kg	*Leptosols/Cambisols*	*leptic lithic skeletic rendzic calcaric hyperhumic gleyic*	860.1	4.3
II	5–8	Ko Kor KI Kog Korg KIg	*Cambisols/Luvisol*	*cambic endocalcaric luvic humic endogleyic loamic*	1,829.6	9.1
III	9–12	LP Lk LPg Lkg	*Retisols/Podzols*	*glossic stagnic fragic albic umbric epidystric endogleyic*	2,247.4	11.2
IV	13–16	L(k) Ls L L(k)g Lsg Lg	*Podzols*	*spodic albic rustic/carbic aric endogleyic arenic*	1,298.1	6.4
V	17–18	Gh Gk Gor Go G(o) Gh1	*Gleysols*	*epioxygleyic calcaric mollic eutric endoskeletic saprihistic*	3,459.5	17.2
VI	19	GI LPG	*Gleysols/Retisols*	*reductigleyic dystric glossic luvic umbric uterquic*	2,296.0	11.4
VII	20–21	LG LkG	*Podzols*	*epigleyic spodic albic dystric rustic arenic*	1,220.8	6.1
VIII	22	Gk1 Go1	*Gleysols*	*saprihistic epioxygleyic calcaric/calcic*	694.6	3.4
IX	23	GI1	*Gleysols*	*epigleyic histic reductic umbric*	489.1	2.4
X	24	LG1	*Podzols*	*epigleyic fibrihistic spodic ortsteinic arenic*	553.6	2.8
XI	25	M3 M2 AM	*Histosols*	*saprihistic/hemihistic rheic eutric fluvic*	3,604.9	17.9
XII	26–27	S R	*Histosols*	*fibrihistic ombric endohemihistic dystric*	1,428.1	7.1
XIII	28–31	T	*Technosols*	*nudic relocatic transportic cumulatic spolic*	91.0	0.5
XIV	32–34	P C	Non-soils/grounds	quarries pits dumps outcrops: ground, regolith, artifacts	41.0	0.2

Table 13.4 SOC stocks in soil cover (SC) and its distribution in SC sublayers presented by large soil groups (LSG) in relation to the tested area (20,114 km^2)

LSG No	SOC pools of SC, in Tg	Share of LSG, in %	Distribution of SOC pools by SC sublayers[a]			Dominant (>70%) forest site types
			HC, in Tg	SS, in Tg	HC:SS, in %	
I	7.3	2.3	6.8	0.5	93:7	*Calamagrotis*-alvar, *Hepatica*
II	18.0	5.7	14.9	3.1	83:17	*Hepatica*, *Aegopodium*
III	18.5	5.9	10.7	7.8	58:42	*Oxalis*, *Oxalis-Myrtillus*
IV	6.7	2.1	2.8	3.9	42:58	*Rhodococcum*, *Oxalis-Rhodococcum*, *Myrtillus*
V	49.4	15.6	42.8	6.6	87:13	*Filipendula*, *Aegopodium*, *Carex-Filipendula*
VI	31.6	10.0	24.7	6.9	78:22	*Filipendula*, *Oxalis-Myrtillus*, *Aegopodium*, *Myrtillus*
VII	10.8	3.4	6.2	4.6	57:43	*Myrtillus*, *Polytrichum-Myrtillus*
VIII	16.0	5.1	11.0	5.0	69:31	*Filipendula*, *Carex-Filipendula*, *Carex*
IX	9.8	3.1	6.1	3.7	62:38	*Filipendula*, *Oxalis-Myrtillus*, *Myrtillus*, *Carex-Filipendula*, *Carex*
X	5.3	1.7	3.3	2.0	62:38	*Myrtillus*, *Vaccinium*, *Polytrichum-Myrtillus*
XI	113.4	35.8	64.8	48.6	57:43	*Oxalis* drn[b] fen, *Alder-birch* fen, *Myrtillus* drn bog, *Filipendula*
XII	28.8	9.1	15.6	13.2	54:46	Transitional bog, Oligotrophic bog, *Myrtillus* drn bog, *Vaccinium*
XIII	0.6	0.2	0.3	0.3	50:50	Reclamationed pits, *Myrtillus* drn bog
XIV	0.2	0.1	0.1	0.1	50:50	Reclamationed pits

(continued)

Table 13.4 (continued)

LSG No	SOC pools of SC, in Tg	Share of LSG, in %	Distribution of SOC pools by SC sublayers[a]			Dominant (>70%) forest site types
			HC, in Tg	SS, in Tg	HC:SS, in %	
Total	316.4	100.0	209.9	106.5	66:34	Totally 27 forest site types may be found
Organic soils	142.2	44.9	80.4	61.8	56:44	*Oxalis* drn fen, *Alder-birch* fen, *Myrtillus* drn bog, Transitional bog
Mineral soils	174.2	55.1	129.6	44.6	74:26	Totally 21 forest site types may be found

[a]SC—sublayers: HC—humus cover, SS—subsoil; [b]drn—drained

Table 13.5 Estimation of total stocks of SOC in the soil cover of Estonian forest land, which area is by the national forest inventory data 23,306 km^2 (Forestry Yearbook 2017 2018)

No of scenario	Characterization of the scenario	Total SOC stocks of forest land,[a] in Tg		
		SC	HC	SS
I	Non-tested territory's (3,192 km^2) SC composition is taken similar to that of the whole tested area	367	243	124
II	Non-tested territory's SC composition is taken similar to the tested area's mineral soils composition	353	237	116
III	It is supposed, that from non-tested territory's SC formed 50% mineral and other 50% peat soils	380	249	131
I	Total SOC stock in mineral soils	202	150	52
I	Total SOC stock in organic soils	165	93	72

[a]SC—soil cover, HC—humus cover, and SS—subsoil

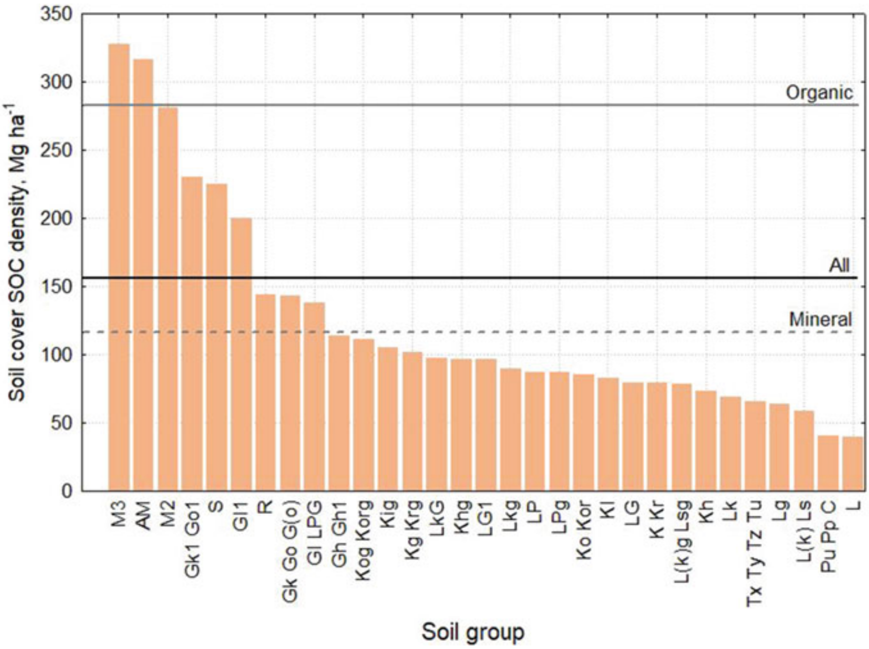

Fig. 13.8 Different soil species' SOC superficial densities (Mg ha^{-1}) per soil cover or solum. The mean density level for all soils, and separately for organic and mineral soils is given on the figure by horizontal lines. For soil names by their codes see Table 13.2

Photo 13.1 Variegated forest landscape with pine, birch, spruce and mixed-forest stands on the transitional area of Kõrvemaa and Pandivere Upland (Photo T. Kõlli). The prerequisite of the high pedodiversity of this area is its high geodiversity: lightly undulating calcareous loamy till plains are variegated here by chains of stony-rich eskers, gravelly sandy kame fields and paludified floodplain fens

The annual productivity of natural ecosystems on well-drained soils depends mainly on clay and SOM content and stocks in the soil profile but on wet soils from the moisture conditions. The matching of soil–plant systems by LSG may be followed on the basis of the data given in Tables 13.3, 13.4 and 13.6. The SC properties are characterized by WRB qualifiers (Table 13.3), by SOC sequestration capacity (Table 13.6) and its distribution in SC (Table 13.4), and as well by HC and SC thicknesses, HC types, dominating textures of SC and acidity of forest floors (Table 13.6). The plant cover of the ecosystems is characterized by the FST, dominating tree species and site quality classes (Tables 13.4 and 13.6). The maximum functioning activity of an ecosystem is observed in the presence of plant cover, which is suitable for soil properties (Kõlli 2002; Lõhmus 2004; Lutter et al. 2018).

HC type (Table 13.6) may be used as a complex landscape's indicator, which reflects the functioning of soil–plant system, among them it characterizes the intensity of biological turnover and the activity of detritus food chain organisms. For attaining ecologically sound land use or for increasing efficiency of soil resources utilization, the disharmonies in matching plant cover with SC or biodiversity with pedo(geo)diversity should be overcome. The environmental protection ability of soils

Table 13.6 Characterization of forest site conditions by the large soil groups (LSG)

LSG No	Mg SOC per 1 ha of SC[a]	Thickness, in cm		Dominant humus cover type	Dominant texture of SC	pH_{KCl} of forest floor	Dominant tree species	Quality class[c]
		HC[b]	SC					
I	84	17–23	24–56	Fresh and moist calci-mull	Ryhky loams on ryhk or limestone	4.9–5.0	*Pinus svlvestris, Picea abies*	III–IV
II	98	19–24	43–70	Fresh and moist forest-mull; fresh and moist moder-mull	Loams on ryhky (or pebble) loam	4.5–5.0	*P. abies, Betula pendula*	Ia–II
III	82	17–25	72–92	Fresh and moist moder	Loamy sands on loam	3.6–4.0	*P. abies, P. svlvestris*	Ia–II
IV	52	4–6	62–72	Fresh and moist mor; fresh and moist moder-mor	Sands	2.8–3.2	*P. sylvestris, P. abies*	II–III
V	143	23–29	34–44	Wet calci- and forest-mull	Loams on ryhky loam	5.0–5.8	*P. abies, B. pendula, Alnus incana, Populus tremula*	Ia–II
VI	138	22–28	50–60	Wet moder-mull; wet moder	Loamy sands, sandy loams, loams, clays	4.5–5.0	*B. pendula, P. tremula, A. incana*	Ia–III
VII	88	13–19	65–75	Wet moder; wet moder-mor; wet mor	Sands, loamy sands	2.7–3.1	*P. sylvestris, B. pubescens*	II–IV
VIII	230	20–26	40–50	Peaty mull	Eutric peats on loams	5.0–6.0	*B. pubescens, A. glutinosa*	II–IV
IX	200	16–20	46–56	Peaty moder	Mesic peats on loams and sands	3.5–4.8	*B. pubescens, A. glutinosa, P. svlvestris*	II–IV

(continued)

Table 13.6 (continued)

LSG No	Mg SOC per 1 ha of SC[a]	Thickness, in cm		Dominant humus cover type	Dominant texture of SC	pH_{KCl} of forest floor	Dominant tree species	Quality class[c]
		HC[b]	SC					
X	97	11–17	70–80	Peaty mor	Dystric peats on sands	2.4–3.0	*P. sylvestris*	III–IV
XI	315	30	50	Eu-and mesotrophic peat	Well and moderately decomposed peats	4.5–6.0	*B. pubescens, A. glutinosa*	III–IV (I–II)[d]
XII	202	30	50	Oligo-and mesotrophic peat	Slightly and moderately decomposed peats	2.3–4.2	*P. sylvestris*	IV–Va (III)[d]
XIII	66	<20	<50	–	Miscellaneous, mixed textures	–	*P. sylvestris*	–
XIV	41	<10	<30	–	Various mixtures	–	*P. sylvestris*	–

[a]SC—soil cover; [b]HC—humus cover; [c]By quality class scale of Lõhmus (2004): from Ia (highest) to Va (lowest); [d]In brackets—quality of drained soils

as an intrinsic property of the whole ecosystem level may be attained by the ecologically sound management of landscape (Kõlli et al. 2010). With land-use change (from natural to arable and vice versa), the more drastic changes occur in the fabric and properties of HC, whereas the SS rests in an almost unchanged state (Köster and Kõlli 2013).

The HS of natural forest landscapes or SOC throughout flux of SC is tightly connected with plant cover composition, productivity and diversity. Therefore, the awareness on the composition and properties of HC types and their relationship with plant cover and SOM decomposition potentiality are the basis of ecologically proper and sustainable management of land (soil) resources and protection of forest landscapes.

13.7 Conclusions and Outlook

- Comparative analysis of soil–plant mutual relationships on the background of pedo-ecological conditions' matrix revealed that (1) the vegetation diversity of an ecosystem depends on soil properties, being, therefore, a soil type-specific feature, and (2) the type of HC is a good ecological indicator in characterizing outlines of the biological turnover between soil and plant.
- In Estonian forest land's (23,306 km^2) soil cover totally 367 Tg of soil organic carbon is sequestrated, whereas 66.2% of it is located in biologically active humus cover and 33.8% in the subsoil.
- The pedodiversity of the landscape is an abiotic base for formation of optimal (specific to soil type) biodiversity. The ecologically sound matching of soil and plant covers is of pivotal importance in the reaching of sustainable ecosystem functioning and of good environmental status of the ambient area.
- In the formation and fabric of HC and HS of the whole forest landscape are clearly seen regional singularities, caused by soils and climatic conditions; consequently, in complex researches of landscapes a determination and analysis of humus cover types are necessary.

References

Arold I (2005) Estonian landscapes. Tartu Ülikooli Kirjastus, Tartu (in Estonian)

Astover A, Reintam E, Leedu E, Kõlli R (2013) Field survey of soils. Eesti Loodusfoto, Tartu (in Estonian)

Baritz R, Seufert G, Montanarella L, Van Ranst E (2010) Carbon concentrations and stocks in forest soils of Europe. For Ecol Manag 260:262–277

Bazilevich NI, Titljanova AA (2008) Biotic turnover on five continents: element exchange process in terrestrial natural ecosystems. Publishing House SB RAS, Novosibirsk (in Russian)

De Vos B, Cools N, Ilvesniemi H, Vesterdal L, Vanguelova E, Carnicelli S (2015) Benchmark values for forest soil carbon stocks in European: results from a large scale forest survey. Geoderma 251–252:33–46
Dixon RK, Brown S, Houghton RA, Solomon AM, Trexler MC, Wisniewski J (1994) Carbon pools and flux of global forest ecosystems. Science 263:185–190
Estonian Agri-project (1983) Metsamullad. Eesti NSV mullastik arvudes III:26–91 (in Estonian)
Estonian Agri-project (1985) Metsamullad. Eesti NSV mullastik arvudes V:3–71 (in Estonian)
Estonian Land Board (2012) Explanatory letter for the large scale digital soil map of Estonia (in Estonian). http://geoportaal.maaamet.ee/docs/muld/mullakaardi_seletuskiri.pdf
IUSS Working Group WRB (2015) World reference base for soil resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps, world soil resources reports no 106. FAO, Rome
Kachinsky N (1965) Soil physics, vol I. University Press, Moscow (in Russian)
Kõlli R (1992) Production and ecological characteristics of organic matter of forest soils. Eurasian Soil Sci 24:78–91
Kõlli R (2002) Productivity and humus status of forest soils in Estonia. For Ecol Manag 171:169–179
Kõlli R, Ellermäe O (2001) Soils as basis of Estonian landscapes and their diversity. In: Mander Ü, Printsmann A, Palang H (eds) Development of European landscapes. Conference proceedings, vol II. Publicationes Instituti Geographici Universitatis Tartuensis, 92. IALE, Tartu, pp 445–448
Kõlli R, Köster T (2018) Interrelationships of humus cover (pro humus form) with soil cover and plant cover: humus form as transitional space between soil and plant. Appl Soil Ecol 123:451–454
Kõlli R, Asi E, Köster T (2004) Organic carbon pools in Estonian forest soils. Balt For 10(18):19–26
Kõlli R, Astover A, Noormets M, Tõnutare T, Szajdak L (2009a) Histosol as an ecologically active constituent of peatland: a case study from Estonia. Plant Soil 317:3–17
Kõlli R, Ellermäe O, Köster T, Lemetti I, Asi E, Kauer K (2009b) Stocks of organic carbon in Estonian soils. Est J Earth Sci 58(2):95–108
Kõlli R, Köster T, Kauer K, Lemetti I (2010) Pedoecological regularities of organic carbon retention in Estonian mineral soils. Int J Geosci 1:139–148
Kõlli R, Tõnutare T, Lang M, Szajdak LW, Kauer K, Rannik K (2018) Evaluation of the soils' humus status in Estonian forest landscapes. In: Sychev VG, Mueller L (eds) Novel methods and results of landscape research in Europe, Central Asia and Siberia, vol III. Landscape monitoring and modelling. Moscow, Russian Academy of Sciences, pp 60–64
Köster T, Kõlli R (2013) Interrelationships between soil cover and plant cover depending on land use. Est J Earth Sci 62(2):93–112
Laasimer L (1965) Vegetation of the Estonian SSR. Valgus, Tallinn (in Estonian)
Lang M, Kõlli R, Nikopensius M, Nilson T, Neumann M, Moreno A (2017) Assessment of MODIS NPP algorithm-based estimates using soil fertility and forest inventory data in mixed hemi-boreal forests. For Stud 66:49–64
Lang M, Kaha M, Laarmann D, Sims A (2018) Construction of tree species composition map of Estonia using multispectral satellite images, soil map and a random forest algorithm. For Stud 68:5–24
Lõhmus E (2004) Estonian forest site types. Eesti Loodusfoto, Tartu (in Estonian)
Lutter R, Kõlli R, Tullus A, Tullus H (2018) Ecosystem carbon stocks of Estonian premature and mature managed forests: effects of site conditions and over storey tree species. Eur J For Res. https://doi.org/10.1007/s10342-018-1158-4
Mander Ü, Palang H, Tammiksaar E (1995) Landscape changes in Estonia during the 20th century. Year-Book of EGS, vol 29
Peterson U, Püssa K, Liira J (2004) Issues related to delineation of forest boundaries on landsat thematic mapper winter images. Int J Remote Sens 25(24):5617–5628. https://doi.org/10.1080/0143116041233129131 4
Peterson U, Liira J, Püssa K (2008) Metsaga alade ning lageraiete ja nendega sarnaste häiringute kaugseire. In: Väljataga K, Kaukver K (eds) Kaugseire Eestis. Tallinn (in Estonian), Iloprint, pp 48–68

Raukas A (ed) (1995) Estonia. Nature. Valgus, Tallinn (in Estonian)
Raukas A, Teedumäe A (1997) Geology and mineral resources of Estonia. Estonian Academy Publishers, Tallinn
Reintam L, Kull A, Palang H, Rooma I (2003) Large-scale soil maps and supplementary database for land use planning in Estonia. J Plant Nutr Soil Sci 166:225–231
Tjurin IV (1935) Comparative study of the methods for the determination of organic carbon in soils and water extracts from soils. In: Materials on genesis and geography of soils, ML Academy of Science USSR, pp. 139–158 (in Russian)
Valk U, Eilart J (1974) Estonian forests. Valgus, Tallinn (in Estonian)
Yearbook Forest 2017 (2018) Keskkonnaagentuur, Tallinn
Zanella A, Jabiol B, Ponge J-F, Sartori G, DeWaal R, Van Delft B, Graefe U, Cools N, Katzensteiner K, Hager H, Englisch M (2011) A European morpho-functional classification of humus forms. Geoderma 164:138–145