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ELECTRICAL ENGINEERING, MINING ENGINEERING D46

# **Dependence of Estonian Peat Deposit Properties on Landscape Types and Feeding Conditions**

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Declaration:

Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

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ENERGEETIKA. ELEKTROTEHNIKA. MÄENDUS D46

**Eesti turba omaduste sõltuvus  
maastikutüüpidest ja turbalasundi  
toitumistingimustest**

MALL ORRU



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## ORIGINAL PUBLICATIONS

- I. Orru, M. 1997. Peat. In *Geology and Mineral Resources of Estonia* (Raukas, A. & Teedumäe, A., eds), pp. 337–346. Estonian Academy Publishers, Tallinn.
- II. Orru, M. & Orru, H. 2008. Sustainable use of Estonian peat reserves and environmental challenges. *Estonian Journal of Earth Sciences*, 57, 87–93.
- III. Orru, H. & Orru, M. 2006. Sources and distribution of trace elements in Estonian peat. *Global and Planetary Change*, 53, 249–258.
- IV. Orru, M. H. & Systra Y. J. 2009. Geochemical anomalies in the peat deposits of valley and slope peatlands. In *Materialy VIII Mezhdunarodnoi Konferentsii 14.-18.09.2009* (Vorobjev A. E., ed.), pp. 327–330. Moscow–Tallinn.
- V. Orru, M., Übner, M. & Orru, H. 2011. Chemical properties of peat in three peatlands with balneological potential in Estonia. *Estonian Journal of Earth Sciences* 60/1.
- VI. Orru, M. Re-vegetation of abandoned peat production fields in Estonia and environmental conditions affecting the processes. Submitted to *Mires and Peat*.

## 1. INTRODUCTION

Peatlands are peat forming ecosystems and peat is organic matter accumulating at ground surface and containing a high proportion of water (92–94%). Scientists have presented different definitions of peat. According to Brownlow (1996), peat is a mixture of plant remains at different stages of decay, containing five main groups of organic compounds: proteins, lipids, hydrocarbons, pigments and lignin. Another classification by Fuchsman (1980) divides peat organic matter into four groups: bitumens, carbohydrates, lignins and humic substances. Besides these, peat contains nitrogen components, inorganic substances, etc. According to Estonian legislation, sediment is classified as peat when dry matter of peat contains up to 35% of mineral matter (Instruction for peat investigations, 1998). Peat is well humified if over 25% of its organic mass has decayed, and poorly humified when the decayed constituents form less than 25%. This definition is used also in the current doctoral thesis.

Composition and properties of peat depend on a number of factors under which it was formed (Varep, 1975; Kink et al., 1998; Succow & Jeschke, 1986; Heathwaite et al., 1993; Hughes & Heathwaite, 1995; Loopmann, 1988, 1996; Allikvee, 1988; Allikvee & Ilomets, 1995; Masing, 1968). Among these the most important are:

- type of feeding (groundwater, precipitation, or mixed);
- position of the deposit in landscape (lowland, depression, river valley, etc.);
- vegetation;
- climate conditions;
- geological, geobotanical and microbiological processes.

To clarify the confusing terminology, the term “peatland” has been introduced. A peatland is an area with or without vegetation with a naturally accumulated peat layer at the surface, comprising areas with both natural and drained peat layers. When defining and distinguishing the peatlands, the so-called zero-contour of peat thickness is considered, i.e. all areas covered with peat in spite of its thickness are considered as peatlands (Orri et al., 1992). The term “mire” is used for an undrained area with peat layer over 30 cm thick. Peatlands are generally categorized based on their feeding conditions as raised bogs (feeding from precipitation – oligotrophic peat), transitional mires (mixed feeding – mesotrophic peat), and fens (feeding from groundwater – eutrophic peat).

The peat types (oligotrophic, mesotrophic and eutrophic) are further categorised by their botanical composition. The commonly used classification was worked out by S. Tjuremnov (1949). Oligotrophic, mesotrophic and eutrophic peat are divided into three sub-types: forest, forest–moss-grass, and moss-grass peat. Characteristically, the forest peat contains at least 40% of fragments of wood, 15–35% in forest–moss-grass peat and in moss-grass peat that has accumulated in open peatlands fragments of wood are generally not found (Allikvee & Ilomets, 1995). The subtypes are divided into groups, and these in turn into peat varieties. In Estonia, altogether 55 peat varieties have been distinguished. The above mentioned classification has been used also in the current study. Peat varieties of different composition that overlie each

other form a peat deposit. The latter are categorised as eutrophic, mesotrophic, oligotrophic-mixed and oligotrophic peat deposits. In oligotrophic deposit oligotrophic peat makes up at least half of its total thickness, and in oligotrophic-mixed deposits – a half or at least 0.5 m of the deposit's total thickness. In eutrophic and mesotrophic deposits the whole deposit is made of eutrophic and mesotrophic peat, or they make up at least half of the deposit (Ministerstvo RSFSR, 1973).

Peatlands are an important landscape element in Estonia, covering 22.3% of its territory (Orru et al., 1992). Peat has been widely used throughout several centuries, e.g. as fuel, bedding in stock-rising, in horticulture (Valk, 1988). The study of peatlands in Estonia goes back to the 18<sup>th</sup> century. The first description of Estonian mires was compiled by A. Huppel in 1774, it was followed by the works by L. Mellin (1798–1810), C. Rücker (1839), C. Schmidt (1844), A. Hueck (1845); whereas the last-mentioned author used Estonian word “*raba*” in his paper written in German (Valk, 1995). A. Bode composed a review of peatlands and peat in 1837 in Tartu, where he discussed on fuel peat, use of peatlands for agricultural and silvicultural purposes, and described peat varieties. The first paper in Estonian on peatlands by J. Sõggel was issued in 1896. In late 19<sup>th</sup> century the peatlands of Estonia were investigated by Danish and German scientists. A new period began in 1910 when an experimental station headed by A. Vegesack was founded at Tooma with an aim of studying the perspectives of peatlands usage for agricultural purposes. In the 1920s these investigations were continued by L. Rinne (Valk, 1995). The station has been active with short breaks until today and is now operated in the Endla Nature Reserve (was established in 1985). A. Wellner (1922) published data and a map of 517 largest mires in Estonia. Later studies dealt with peat increment, palynology, vegetation, geomorphology hydrology, genesis and ecology of mires (Thomson, 1925, 1933; Markus, 1925; Paasio, 1939; Kildema, 1951, 1958; Laasimer, 1965; Kurm, 1966; Allikvee, 1966, 1995; Allikvee & Masing, 1988; Masing, 1988; Ilomets, 1995). More detailed data on the distribution, area, thickness, characteristics, and reserves of peat deposits are available mainly in manuscript exploration reports (Truu et al., 1947–1963) and in generalized form also in several publications (Raudsepp, 1946; Üksvärav, 1960, Veber et al., 1961; Truu, et al., 1964; Etverk, 1974; Valk, 1988).

The peatlands of Estonia and peat have been investigated at a different level, especially considering the properties of peat, its genesis and reserves. Primarily the investigations focussed mainly on the largest peat deposits (Veber et al., 1961). In connection with the development of peat industry in the 1970s, the demand for agricultural, horticultural and fuel peat increased. Consequently, by the request of the government the inventory of peatlands was launched at the Geological Survey of Estonia in 1971–1987 (Orru et al., 1971–1987). According to the regulations of that time, the research incorporated the landscape areas covered with a layer of peat (Ministerstvo RSFSR, 1973). The author supplemented, specified and adjusted the above regulation to Estonian conditions. The aim of the above investigations was to study and register all peatlands with an area over one hectare. The investigations supervised by the author of the current thesis focussed on the relationship of peat



properties (varieties composition and technical properties, i.e. content of mineral matter, moisture content, degree of humification and pH) as well as hydrological and feeding conditions, vegetation, landscape types, geological settings and drainage were studied.

Summarised results of investigations have been published in Estonian Peat Resources (Orru et al., 1992), Map of Estonian Mires 1:400 000 (Eesti soode kaart, 1993), Handbook Estonian Mires (Orru, 1995), and book Trace elements in Estonian peat (Orru & Orru, 2003) and are the basis for the current doctoral thesis.

Total 9,836 peatlands have been investigated in Estonia; however, the majority of them are small (8,238), covering 1–10 hectares (Orru et al., 1992). Altogether 10,091 km<sup>2</sup> is taken up by such peatlands in Estonia, which play an important role in the biosphere. Moreover, they interact with fundamental life-supporting processes, involving biochemical cycling, water quality and ecosystems. Considering that peatlands spread on 22.3% of Estonia's territory, Estonia holds the second position in relative peatlands covering in Europe after Finland, where peatlands cover 30% of the territory (Lappalainen, 1996). The Estonian peat deposits are at their thickest (16.7 m) in Vällamäe bog (Punning et al., 1995) and average thickness is usually 3–4 m (Orru et al., 1992). Globally peatlands cover over 4 million km<sup>2</sup> or 3% of the land and freshwater surface of the Earth (Maltby & Procter, 1996).

Depending on its composition, peat is used for several purposes, e.g. horticulture, agriculture, as fuel, removal of hazardous substances from environment, etc. Peat extraction is a long tradition in Estonia – since late 18<sup>th</sup> century (Etverk, 1974) until today. Presently the area of peat production fields is about 20,000 hectares and the annual average production amounts to 1.2 million tonnes (Ramst & Orru, 2009). Geological peat resources in Estonia are 2.37 billion tonnes (Orru et al., 1992), while total peat resources of the planet amount to approximately 700 billion tonnes (Clymo, 1983), according to the newest data 5,000–6,000 billion m<sup>3</sup> (Lappalainen, 1996).

Considering the information obtained on the properties of peat in the process of inventory of Estonian peatlands, it appeared that in addition to the traditional fields of use (fuel, horticulture) there are more sustainable ways of utilisation and one of the new alternative fields is balneology. The traditions of balneological utilisation of peat are long in Germany, Austria, Czech Republic, and during the last 20 years in Finland (Naucke, 1980; Lüttig, 1984; Goecke, 1994; Korhonen & Lüttig, 1996; Uosukainen, 2002). In Estonia, peat balneology was introduced by the author in the 2000s (Orru, 2007, 2009, 2010). Balneology is a science of using natural substances (peat, sea and lake mud) for medical purposes. The intricate complex influence on human organism is based on its physical and chemical properties (Jurcik, 1994; Groven, 1999). Peat contains various chemical compounds (Riede, 1992; Pietrovskaja, 2000) that interact with various organic and inorganic compounds (Stevenson, 1994). The effect of balneology is mainly based on humic substances found in peat (Pena-Menden, 2005; Klöcking et al., 2005). Humic substances are high-molecular multifunctional organic compounds of sophisticated structure con-

taining nitrogen, they comprise amino acids, hexoses, pentoses, aromatic and heterocyclic groups and several functional groups (–COOH, –OH, –CHO). The content of humic substances could depend on properties of peat deposits and its feeding conditions. It is related to the sustainable and wise use of peatlands and peat reserves which is currently topical worldwide (Joosten & Clark, 2002). The respective draft of legislation is now being worked out in Estonia.

Problems related to environmental pollution create several environmental challenges in peat usage (agriculture, horticulture, balneology, water purification, etc.), as it is important to use ecologically clean peat. However, due to its composition and structure, peat has an ability to bind trace elements (Coupal & Lalancette, 1976; Twardowska, 1996). This could be a factor that limits the use of peat resources. When the content of trace elements in horticultural peat is high, these may accumulate in plants growing on peat and reach human organisms via the food chain. Moreover, it is important to know the content of trace elements in fuel peat to minimise their emission into the atmosphere, and it is even more crucial in balneology. Investigation of the contents of elements in peat carried out during several years have shown that they are related to the chemical composition of bedrock underlying the peat and the feeding conditions of peat deposits (Virtanen, 1994, 2004; Nieminen, 2002; Le Roux et al., 2003; Syrovetsnik et al., 2003). Peat has been used in monitoring of trace metals in the atmosphere (Stewart & Fergusson, 1994). T. Kiipli (2003) has found the anomalous concentrations of redox-sensitive elements in the peat of Raudna Valley, Viljandi County. High concentrations of uranium in this peat were also identified in previous investigations (Oru et al., 2001). Petersell et al. (1997) investigated the geochemistry of the humus horizon of Estonian soil. Thus, it became topical to elucidate the content of trace elements and the regularities of their distribution in the peat deposits of Estonian peatlands of different genesis and location.

As a result of long-term peat production, several abandoned milled peat fields are found in Estonia. According to the catalogue of mineral deposits of environmental register (<http://register.keskkonnainfo.ee/envreg> – 07.10.2010), in Estonia there are 154 abandoned peat fields registered with total area of about 9,000 hectares. However, harvesting changes the original mire ecosystem completely and removes the viable seed bank (Salonen, 1987). For this purpose, the Geological Survey of Estonia carried out investigations of abandoned peat fields in 2005–2008. Re-vegetation of Estonian abandoned peat production fields is mainly the result of natural processes, which is slow due to unfavourable water regime. Most peat production fields have been abandoned 20–30 years ago. Just a small part of these (less than 10%) have been reclaimed (reforesting, berry-growing). Optimal conditions for the formation of new vegetation would be permanently high (0.2–0.3 m below ground surface) groundwater level. In other countries, re-vegetation has been most successful in small peat pits, where peat was extracted mainly manually with spades (Wind-Mulder et al., 1996, Klemetti, 2008).

## **2. OBJECTIVES**

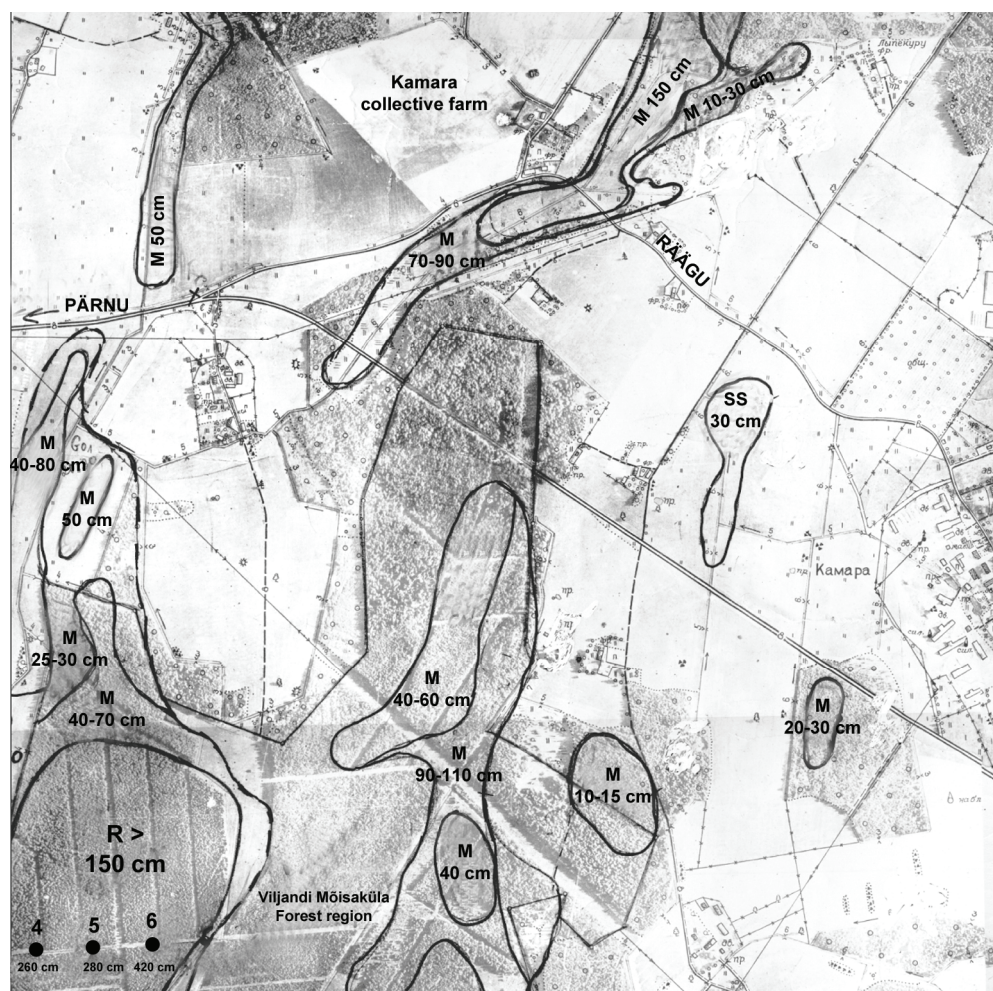
The objectives of the current thesis were:

- to work out and implement scientifically grounded method of typical peat deposits, and their analogues and introduce this method into peat investigations;
- to distinguish new specified peat districts based on the genetic types of peat based as well as botanical composition, moisture, and content of mineral matter, pH, feeding conditions and connection with landscape types.
- to study the main factors affecting sustainable and alternative use of peat in Estonia according to the environment of peat deposits;
- to identify the abundance of hazardous trace elements in Estonian peat and main aspects affecting it;
- to determine the chemical composition of organic fraction of balneological peat in Estonia and the factors controlling it;
- to recognize the key factors influencing re-vegetation on abandoned peat production fields.

### 3. METHODS

#### 3.1. Analysis of previous investigations

Prior to fieldwork (Paper I, II), the author revised all previously compiled manuscript reports stored at the Depository of Manuscript reports of the Geological Survey of Estonia, as well as the published works (Torfjanõi fond, 1961; Eesti sood, 1964) and marked these data on aerial photographs. Furthermore, the information concerning peatlands shown on soil maps of arable land (compiled by State Designing Office Estonian Rural Project (Eesti Põllumajandusprojekt)) was included. Paludified parts of forest soils (Designing Office Metsaprojekt and Agricultural University) and the habitat types of helophytes were supposedly related to the peat layers (Figure 1).



**Figure 1.** An example of data from previous studies (M – eutrophic, SS – mesotrophic, R – oligotrophic peat; — boundary of peat layer; 150 cm – thickness of peat layer).

The results of vegetation mapping carried out at the Institute of Zoology and Botany were used as well. The above data served as the base for the inventory of peatlands carried out at the Geological Survey of Estonia (Eesti Geoloogiakeskus, EGK) in 1972–1987 (Paper I, II).

The results obtained by the inventory of peat properties and genesis (Paper I, II) were used as a basis for further chemical analysis of the organic fraction and trace elements in peat (Paper III, IV, V). For the study on abandoned peat production fields (Paper VI), data from the catalogue of peat deposits of the environmental register (<http://register.keskkonnainfo.ee/envreg> – 07.10.2010) were used.

## **2.2. Fieldwork**

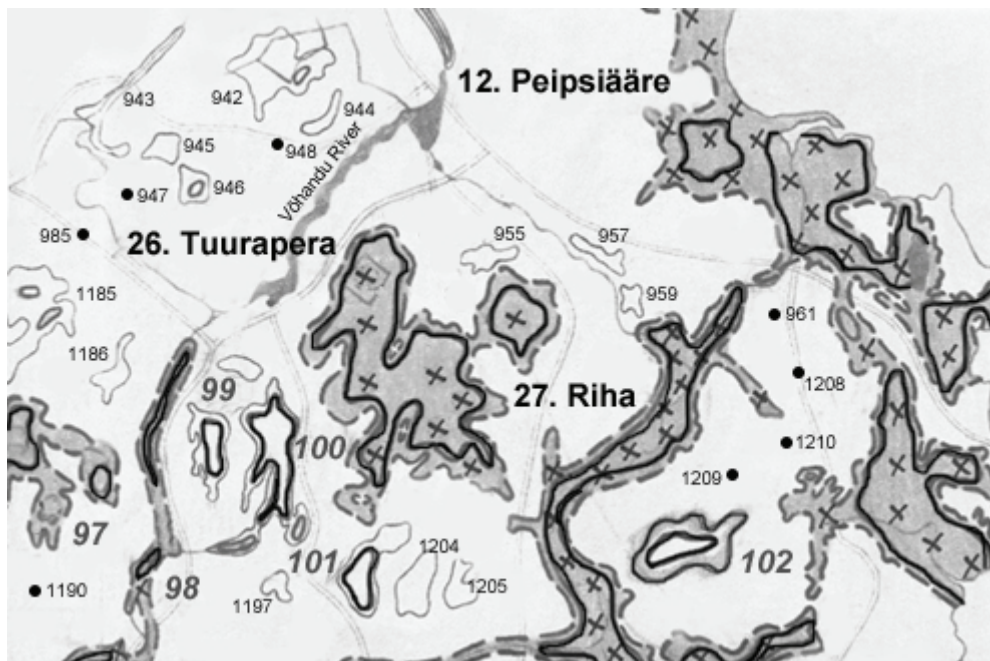
### **2.2.1. Inventory of peatlands**

Fieldwork was commenced on the basis of the above-described investigation material prepared with analysing of previous studies. For the peatland investigation aerial photographs at a scale of 1:10 000 and topographic maps at 1:25 000 and 1:100 000 were used. The fieldwork included measuring of the total thickness of a peat deposit with hand auger TBG-66. In the process of sounding the botanical composition and degree of humification of different peat types were visually determined in accordance with the guidelines for assessing the thickness of poorly and well humified peat. Visual determination of botanical composition of peat served as a basis for further sampling for laboratory analyses.

Sounding of peat deposits was carried out during 15 years under the supervision of the author of the current doctoral thesis. The thickness of peat was measured in 16,500 peatland areas in an extent that assured adequate results (Orru, 1987). In the process of compilation of the book “Estonian Peat Resources“ (Orru et al., 1992) all the peatlands with thin peat deposit (0.1–0.2 m) were revised, and those in which the peat had mineralised and the proportion of organic matter was less than 35% were deleted from the catalogue of peat deposits. Thus, today the number of peatlands is 9,835. The sounding was made and samples were taken with hand auger TBG-66. The fieldwork showed quite good reliability (65%) of former geological studies of peat deposits (reports at the Depository of Manuscript reports of the Geological Survey of Estonia) and data of soil mapping, carried out at the State Designing Office Estonian Rural Project, which had included determination of distribution areas of peat to a depth of 1 m, as well as the distribution of eutrophic, mesotrophic and oligotrophic peat. The boundaries of paludified areas indicated on forest soil maps were more inaccurate. In many cases, the inspection sounding carried out on the spot showed that the peat layer marked on the map actually did not exist. The reliability of these maps was only 30%.

To reduce the volume of work at inventory of peatlands, for the first time in Estonia the author elaborated the method of typical peat deposits (Paper II). Altogether 539 typical peat deposits have been chosen that are important from the standpoint of

peat development, feeding conditions, elucidating environmental conditions and water regimen for peat excavation (Figure 2, Tuurapera, Peipsiääre and Riha peat deposits). Such typical deposits are the biggest peatlands with thick layer of peat and are the most representative for each peat district. In the typical peat deposits the thickness of peat was measured, laboratory analyses were carried out, peat reserves were calculated, technical map of the deposit (1:10 000, 1:12 000, 1:50 000) was drawn and explanatory notes were compiled. All typical peat deposits were shown on a working map at a scale of 1:100 000. The technical characteristics obtained by the laboratory analyses of the peat of typical deposits (botanical composition, degree of humification, natural moisture content, content of mineral matter, pH) were used for characterising also the remaining 1,059 analogue peat deposits (Figure 2, peatlands 97–102) with genesis, feeding conditions and position in landscape similar to the typical deposit. In these 1,059 peat deposits the thickness of peat deposit was measured, but peat samples were not collected. The characteristics of the peat of the above typical peat deposits were also used for distinguishing the peat districts and calculating the reserves of the 1,059 peat deposits. For this purpose, the typical peat deposits with similar feeding conditions, genesis and peat characteristics were grouped and for each region the average arithmetical characteristics of all peat deposit general analyses of this region were calculated.



**Figure 2.** Excerpt from the map of peatlands in Põlva County (Orru et al., 1976).

*Typical peat deposits* (26. Tuurapera – proved reserves, 12. Peipsiääre, 27. Riha – inferred reserves), *peat deposits analogue* with prognosticated reserves (97, 98, 99, 100, 101, 102), small and *thin peatlands* where peat resources are not calculated (e.g. 942, 943, 944, 945, etc.).

The introduced method of typical peat deposits has proved that such approach considerably reduces the number of laboratory analyses needed. Later investigations have confirmed the reliability of this method. In the process of compiling the catalogue of mineral deposits of environmental register, it turned out that the areas of peat deposits and reserves practically coincided.

#### 2.2.2. Investigations of trace elements in peat deposits

Based on previous investigations (Paper I, II), it had emerged that in Estonia there might be considerable concentration of trace elements in some peatlands and the abundances might be extremely variable within deposits as well as in different parts of a peat sequence. Since peat is used in several industries, it is important to know the regularities of distribution and concentration of trace elements. Altogether 64 peatlands were selected for these investigations (Paper III, IV).

#### 2.2.3. Chemical properties of peat with balneological potential in Estonia

Considering the investigations and laboratory analyses carried out within the inventory of peatlands in 1971–1987 (Paper I, II), three peatlands were selected for further investigation (Paper V). First, the peat layers from which samples for laboratory analyses were taken were determined by sounding.

#### 2.2.4. Re-vegetation in abandoned peat production fields

In the course of fieldwork, the surveyed milled peat fields were investigated in a complex manner (Paper VI). The field boundaries were specified using GPS. First, in single points (on an average one point per 10 hectares), the thickness of peat deposit was measured by sounding. The botanical composition of peat and the degree of humification were determined visually. The state of drainage system and surface water level were assessed. The vegetation of different parts was described (coverage by different layers, varieties composition) and more than 300 plants were collected for later identification. Geological and hydrogeological conditions as well as the feeding conditions of peat deposit were studied.

### 2.3. Sampling

During the inventory of peatlands in 1971–1987, altogether 33,611 samples were taken for analysing the general characteristics of peat (natural moisture content, content of mineral matter, degree of humification, botanical composition), and 18,794 samples were collected for determining the acidity of peat (Paper II). The sampling interval of the whole peat deposit was 0.25 m (for pH 0.5 m). Additional 460 samples were taken for determination of microelements in peat (Orru et al., 1992), with a sampling interval of 0.5 m from the whole peat section. All samples were taken with a hand auger TBG-66 following the recommendations established for Estonia in “Guidelines for prospecting of peat deposits of the USSR” (Ministerstvo RSFSR, 1973) (Paper I, II, III, IV, V, VI).

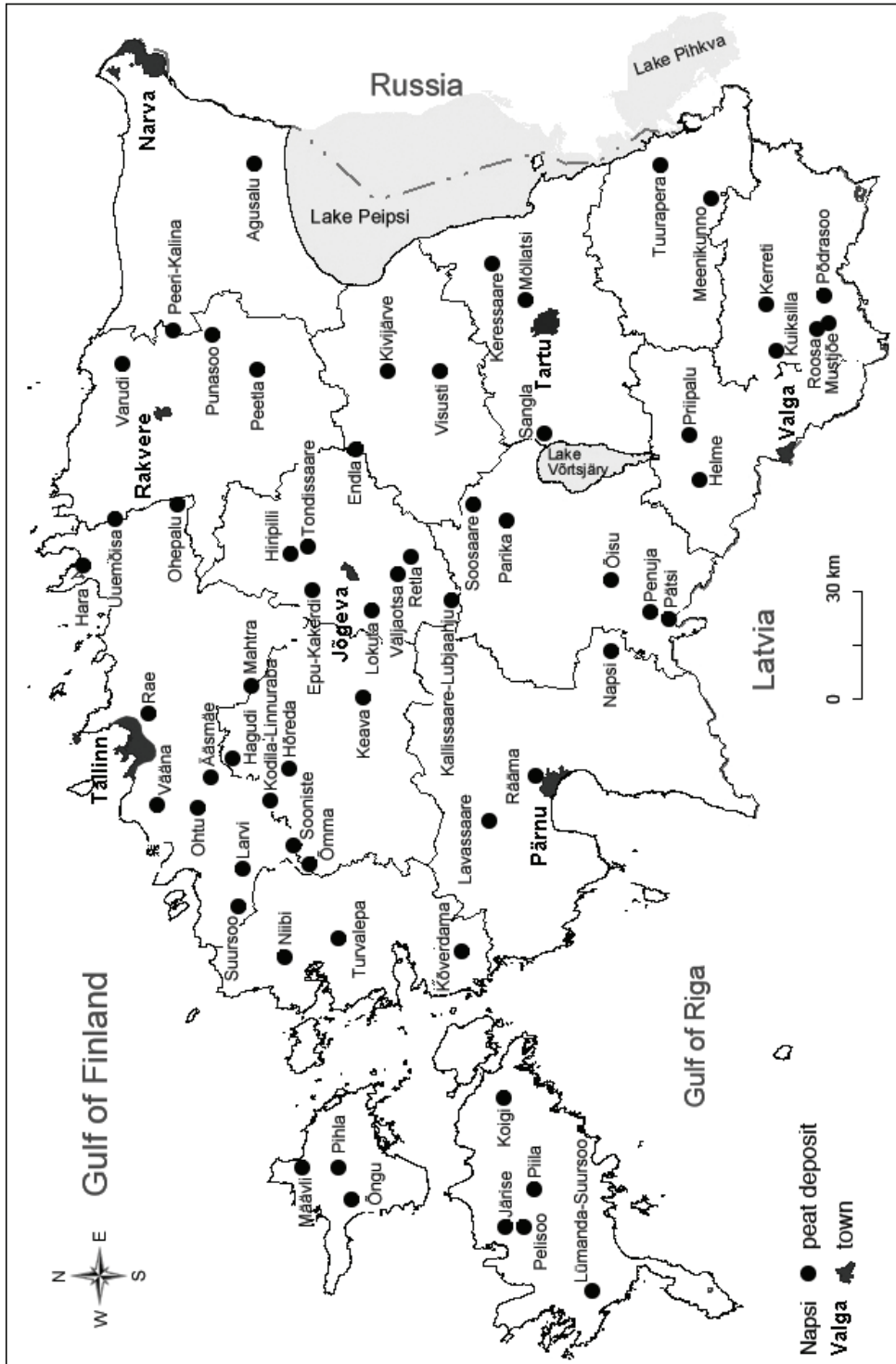


Figure 3. Peatlands in which the content of trace elements in peat was determined.



For studying the content of trace elements in peat, altogether 684 samples in selected 64 peatlands were taken (Figure 3) (Paper III, IV). Samples were collected from the whole peat section every 0.5 m per one coring, both in natural mires and in peat production areas.

Altogether 6 samples were taken for the analyses of the organic part of peat in three study areas (Paper V). The interval of samples was 0.4–0.5 m depending on the composition of peat.

In 81 largest abandoned milled peat fields (Paper VI) altogether 524 peat samples were taken at 0.5 m intervals at one point in each homogenous abandoned peat production area.

### **3.4. Laboratory analyses**

#### **3.4.1. General analyses**

General analyses of natural peat include determination of moisture content, content of mineral matter (ash content), botanical composition (all plant varieties found in peat), pH, and degree of humification.

The moisture content of peat was determined by gravimetric analysis, by heating the sample in a porcelain mortar at 105–110 °C until the weight stayed constant. Results were given in percentage terms as the average of two replicates; when two determinations differed by more than 2%, a third determination was made and averaged (GOST 11305).

Content of mineral matter was determined by gravimetric analysis from the same sample, after heating the sample at 450±10 °C till constant weight. Results were given in percentage terms as the average of two replicates (when two determinations differed by more than a 2%, a third determination was made and averaged). The obtained loss on ignition represented the proportion of organic matter in the sample (GOST 11306). In case information is required on the loss of substance in kilns, the samples were heated at 800±25 °C.

Acidity as pH was determined in KCl extracts, with a peat solution volumetric ratio 1:2.5. The electromotive force was determined with a pH-meter after 18 hours. Analyses were done in replicates and if the values differed by more than 1%, a third determination was done (GOST 11623).

The botanical composition as content of different varieties was determined by an experienced botanist using a microscope. The sample was cleaned from humus on a sieve under running water so that the plants were unharmed. Until the determination was performed the sample was preserved moist. The results had to take into account also the content of mineral matter of peat and according to the table submitted in methodological guidelines correction had to be made. The moisture content of the peat taken for analysis had to be 65% or more; in case it was less, the sample was

moistened with water. Results were given in percentage terms as the average of four parallel determinations.

For the determination of the degree of humification the double-stage centrifuge method was used to separate precipitate of coagulated humus from non-humified components of plants (GOST 10650).

#### 3.4.2. Analyses of trace elements in peat

The analyses of trace elements were made from peat ash. The peat ash was homogenized and milled in a porcelain mortar. Five techniques (Paper V) were used to determine the concentrations of different elements: 1) AAS flame (AA-1475) for Cr, Mn, Ni, Cu, Zn and Pb; 2) ETA-AAS (AA-475) for Cd; 3) AAS cold vapour (Simatsu equipment) for Hg; 4) XRF (VRA-30) for V, Co, As, Sr, Mo, Th and U; and 5) gravimetric method for S (description: N<sup>o</sup> 155-X.C.). Before analyses the ashes were digested in a mixed acid solution (one part HCl and three parts NO<sub>3</sub>H). Becker's standard solution was used for calibration. The determination of trace elements by XRF was carried out in sample cups made of organic film. Background and peak theoretical areas were mathematically fitted. This enabled an immediate taking into account the disturbing factors in determination of the abundance of trace elements. Standard reference materials were used for calibration (LKSD-4, 40% organic substances, lake sediments; ES-2, 20% organic substances). For Hg measurements, the samples were incinerated in microwave digester, in high pressure and temperature. Sulphur content was determined by heating the sample at 800±10 °C.

#### 3.4.3. Chemical analysis of peat organic matter

The natural peat (30g) was stirred for 4 h with 100 ml of 0.2 M NaOH for determination of humic, hymatomelanic, and fulvic acids and then allowed to stand for 20 h at room temperature. The suspension was centrifuged at 5000 rpm for 30 min. The alkaline extract contained humic substances. The humin (insoluble part of peat) was separated as precipitate and was washed repeatedly with distilled water to separate soluble humic substances and dried. The alkaline extract was acidified to pH 2 by addition of 6 M HCl. After 20 h the soluble fulvic acids and insoluble humic, and hymatomelanic acids were separated. The precipitate was repeatedly washed with distilled water until Cl<sup>-</sup> free (control with AgNO<sub>3</sub>). The solid residue was repeatedly treated with 96% ethanol to separate the soluble hymatomelanic acids and insoluble humic acids. Both fractions were dried. The fulvic acids solution was cleaned through the Amberlite XAD-7 resin column for desalination. After removal of salts with 0.01 M HCl, the pure fulvic acids fraction was recovered by elution with 0.1 M NaOH solution directly onto the strong cation exchanger Amberlite IR-120. The gathered fraction was dried. For the determination of the content of lipids, dry peat was repeatedly treated with mixture of chloroform, and ethanol (2:1) to separate the soluble lipid fraction and dried.

### 3.5. Statistical methods

The statistically processed (arithmetic mean) results of investigations obtained during the peatland inventory (Paper I, II) were used for distinguishing the peat districts. The peat deposits with similar genesis, feeding conditions, and peat properties were grouped and after that the average values of all results of laboratory analyses (content of mineral matter, natural moisture content, degree of humification, pH) were calculated. The obtained technical results were connected to the peat varieties, peat deposit geomorphological, landscape, genesis and feeding conditions, which was one of the procedures at distinguishing the peat districts. The data of all 9,836 investigated peatlands were taken into account.

Statistical analyses for elucidating the content of trace elements and regularities of their distribution in peat (Paper III) were performed using STATISTICA 6.0. As the first step, fitting to normal distribution was checked with Kolmogorov–Smirnov, Lilliefors and Shapiro–Wilk tests. Since earlier studies showed that the feeding conditions (whether ombrotrophic or mesotrophic) and the depth of the sample in the peat column are significant factors to explain the chemical composition of peat, these were also taken into account in our comparisons. In further analyses non-parametric methods were used. The Spearman rank correlation matrices by feeding condition (precipitation, different sources, groundwater, ground- and spring water) and peat layer (surface, middle, bottom) were computed and the statistical effects assessed using Duncan test (Paper III). In all cases the significance level was  $p=0.05$ .

For studying the relationship between the content of HS (humic substances) fractions and different metals in balneological peat, the Pearson correlation coefficients were calculated (Paper V).

### 3.6. Dividing peat deposits into peat districts

The author elaborated new improved division of peatlands into peat districts based on quantitative as well as qualitative analyses of several factors (Paper I, II):

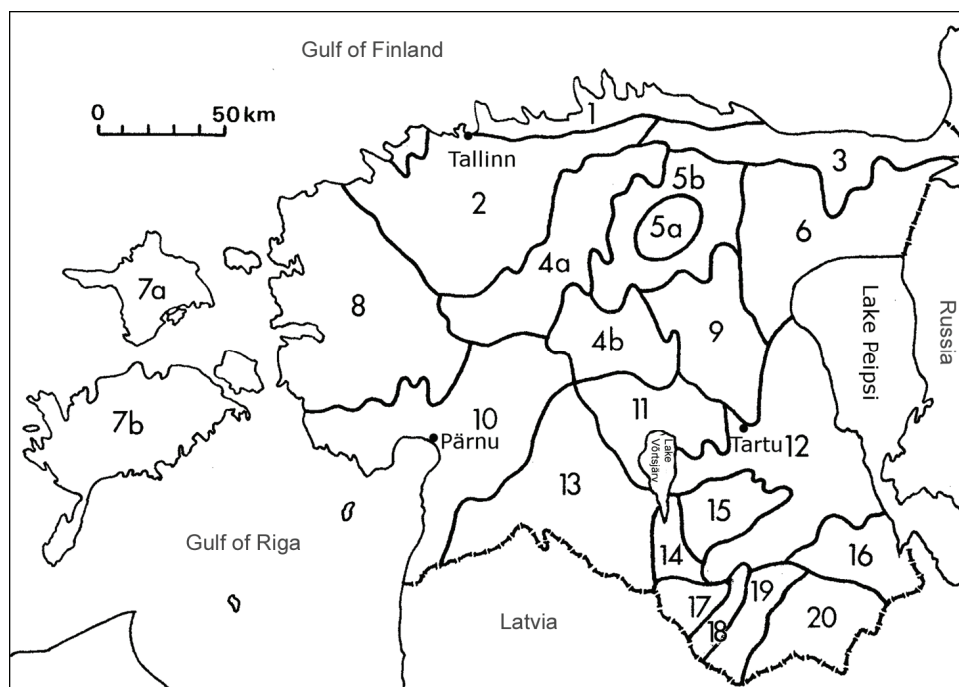
- position in landscape and relief;
- feeding conditions;
- botanical composition of peat and technical characteristics of peat deposit;
- number and area of peatlands;
- geological setting of a region;
- character of Quaternary cover.

Based on the genesis, feeding conditions, setting of a peat deposit and properties of peat the author divided Estonian peatlands and peat deposits into 20 districts (Paper I). In the process of distinguishing the districts, also statistical processing was applied (arithmetic means were calculated in the peat deposits with similar genesis, feeding conditions and setting that were previously grouped). Besides, at distinguishing the above districts the results of about 33,600 laboratory analyses were taken into account (Paper II) and the graphs of average values of peat characteristics of districts were compiled (Figures 223–228 in Paper I).

#### 4. CHARACTERISATION OF PEAT DISTRICTS

The formation and setting of a peat deposit as well as the development stage of peatland depends largely on its feeding conditions. Changes in the latter are due to exterior reasons as well as growth of peat, and normally during the development of peatland the primary feeding from groundwater is replaced by feeding from precipitation. In the development of peatlands this means transition from fen (eutrophic peat) to transitional mire (mesotrophic peat) and raised bog (oligotrophic peat) stage. However, the feeding regime and consequently, the structure of peat are also influenced by exterior factors such as the dissection of relief, position of peatland in relief, geological setting of region and character of the Quaternary cover. Considerable variability of these conditions has led to diversity of peatlands in Estonia in different stage of development with different areas and properties of peat.

Based on these exterior factors as well as characteristic properties of peatlands and peat deposits, 20 peat districts were distinguished (Figure 4). Main peat deposits, rivers and lakes mentioned in this chapter are represented on Figure 5.



**Figure 4.** Peat districts in Estonia: (1) North-Estonian Coastal Lowland; (2) Northwest Estonian Plateau; (3) Northeast Estonian Plateau; (4) Kõrvemaa ((4a) watershed area, (4b) upper course of Pärnu River; (5) Pandivere Upland ((5a) central part, (5b) slopes); (6) Alutaguse; (7) West Estonian Archipelago ((7a) Hiiumaa, (7b) Saaremaa); (8) West Estonian Lowland; (9) Vooremaa; (10) Pärnu Lowland; (11) Võrtsjärv Lowland; (12) Southeast Estonian Plateau; (13) Sakala Upland; (14) Väike-Emajõgi River Valley; (15) Otepää Heights; (16) Palumaa; (17) Valga Lowland; (18) Karula Upland; (19) Võru–Hargla Depression; (20) Haanja Heights.

North Estonian Klint and the waterline of the Gulf of Finland is bordered with **North Estonian Coastal Lowland (1)**. In the depressions between coastal formations (dunes) occur mesotrophic and ombrotrophic peat deposits feeding from precipitation and mixed-feeding type. Besides, thin layers of eutrophic peat (0.2–0.3 m) is related to flowing out of groundwater with high content of mineral matter at the klint foot. The North Estonian coastal lowland borders in the south with the **North Estonian (2) and Northeast Estonian (3) Plateaus** with generally flat appearance and small differences in elevations. Here the distribution of peatlands is especially related to bedrock relief.

On the **North Estonian Plateau** with the thin Quaternary cover, the formation of peatlands is considerably influenced by the carbonate bedrock. It crops out also on the territory of the **Northeast Estonian Plateau** where karst occurs and groundwater is important source of feeding. In the areas with numerous alvars thin eutrophic peat deposits dominate, whereas the proportion of peat layers over 1 m thick is only 10%. The occurrence of major peatlands is related to extensive paludified depressions on the **North Estonian Plateau** and glacier sediments, and coastal relief in **Northeast Estonian Plateau** as well as eskers hindering the outflow of groundwater. The eutrophic and mesotrophic peat layers of both plateaus consist of forest and forest-reed peat with high content of mineral matter (10–25%). Apart from the **Northeast Estonian Plateau**, where the majority of oligotrophic peat layers are represented by poorly and medium-humified *Sphagnum fuscum* peat, on the **North Estonian Plateau** the oligotrophic-mixed and oligotrophic deposits have higher degree of humification and higher content of mineral matter (Paper I). Since the eutrophic and mesotrophic peat deposits in the **North Estonian Plateau** feed from groundwater with high concentration of total dissolved solids originating from carbonate rocks, the above peat types are among the richest in varieties in Estonia.

The thinnest and youngest peat deposits spread in the **West Estonian Archipelago (7)**, embracing **Hiiumaa (7a) and Saaremaa (7b)** (Orru et al., 1992; Allikvee & Ilomets 1995). If the average thickness of peat deposits in Estonia is 3–4 m (Orru et al., 1992), here they are only 2.0–2.5 m thick and the accumulation of peat began just 3,000 years ago (the sea retreated here the latest). In Saaremaa the Quaternary cover is largely 2–5 m thick, whereas in Hiiumaa the cover is thicker (generally 5–10 m). The relief of Hiiumaa is dissected by glacier marginal formations (Kõpu Peninsula), eskers and dunes (where peatlands plain is alternating with them).

In Saaremaa, the major peatland massifs are found in the central part. Both in Saare- and Hiiumaa, peat deposits are mostly represented by eutrophic reed, sedge and forest-reed peat feeding from groundwater or are mixed feeding type. Oligotrophic peat deposits occur less; their upper portion is in Saaremaa and Hiiumaa represented by *Sphagnum fuscum* peat, in the middle part of Saaremaa the cottongrass-rich layers are common (PAPER I). The characteristic feature of peatlands in Hiiumaa is that they reached the oligotrophic stage quite fast (Allikvee and Ilomets 1995), probably due to the dune sands that are poor in nutrients.

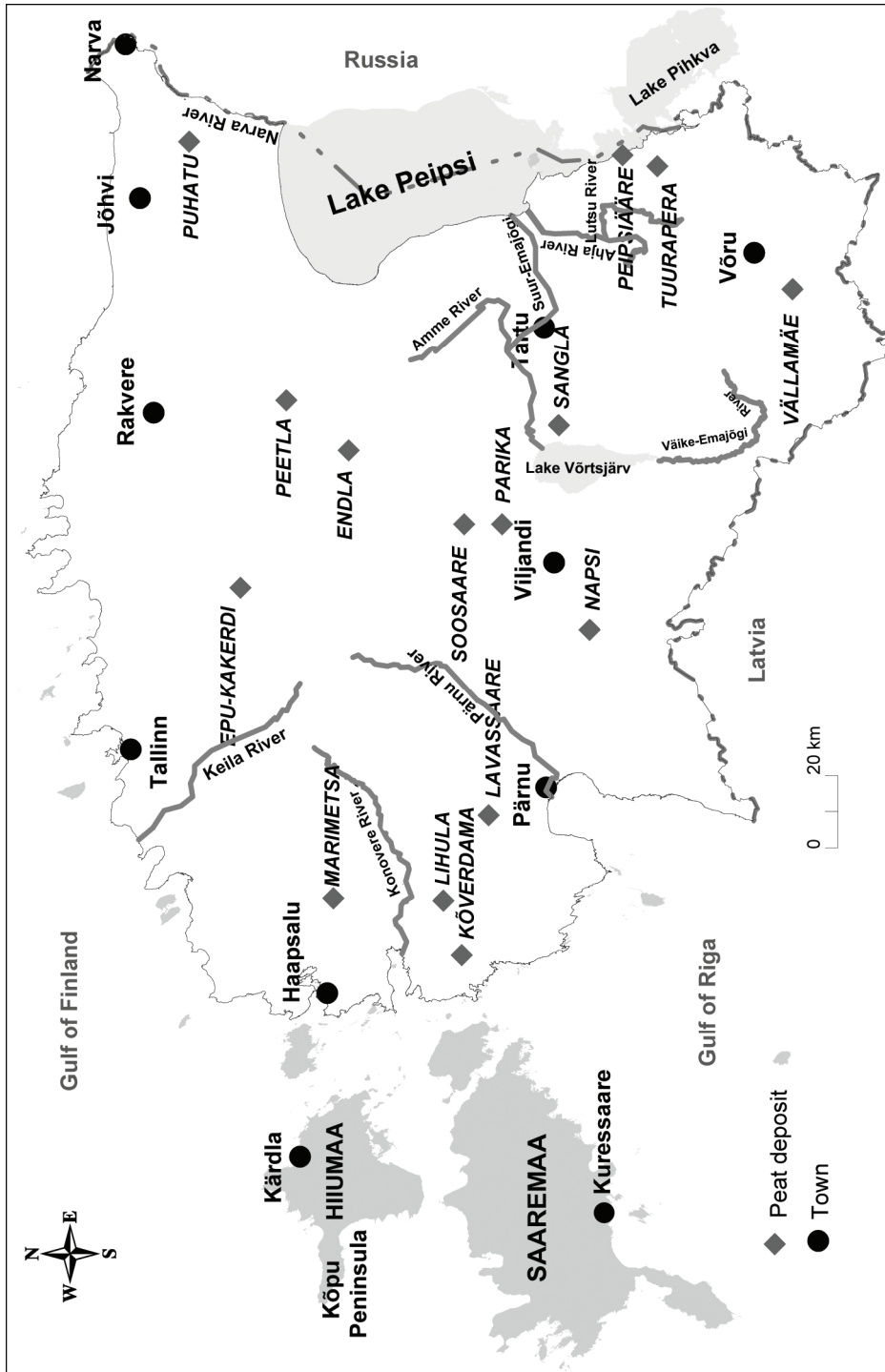


Figure 5. Main peat deposits, rivers and lakes mentioned in chapter 4.

**Lowlands** occupy 46% of the territory of Estonia (Raukas & Rõuk, 1995) and they are the most paludified regions in Estonia. Depending on their geological development, the following districts are distinguished: **West Estonian (8), Pärnu (10) and Võrtsjärv (11) lowlands, and Alutaguse (6)**, where the peatlands spread on the distribution area of the Baltic Ice Lake and Ancylus Lake. Major oligotrophic peatlands have formed as a result of overgrowing of residual lakes.

Most of the **West Estonian and Pärnu Lowlands** emerged from the Baltic Sea during the Litorina and Limnea Stages and in this area paludification started much later than in Upland Estonia. The formation of peatlands has been influenced by the eskers, end moraines, small drumlins, dune-covered beach ridges and varved clay plains near river basin. The runoff is hindered and accumulation of peat favoured by flat relief, and the positive landforms intersecting here and there.

The proportion of peatlands is higher in **Pärnu Lowland** (32%) compared to the **West Estonian Lowland** (16%); the Estonia average is 22.3% (Oru et al., 1992). In **West Estonian Lowland** the oligotrophic peat deposit occurs mostly in major peatlands (Marimetsa, Lihula), but in **Pärnu Lowland** oligotrophic peat makes up 72% of peat deposits. The majority of peat deposits are poorly humified with small content of mineral matter because the depressions in **Pärnu Lowland** are filled with thick sand beds underlain by clayey waterproof deposits (Paper I). Here is also situated one of the largest peatlands in Estonia – Lavassaare which covers 21,868 ha and the peat deposit is among the thickest in Estonia – 9.1 m.

In central and eastern Estonia are located **Võrtsjärv Lowland** and **Alutaguse**. **Võrtsjärv Lowland** includes the area north of Lake Võrtsjärv with slight elevations inclination towards the lake, therefore the areas bordering with the lake are almost entirely paludified. The Quaternary cover (thickness 5–10 m) is represented mostly by till and varved clay. Glaciofluvial gravel and sand are less common. Apart from the Pärnu and West-Estonian lowlands, the most widespread peatland type is eutrophic peatland on floodplains of rivers. Large mixed-feeding peatlands form peatland complexes – Sangla, Parika, Soosaare, etc. where the share of oligotrophic peat is only 31% (Kink et al., 1998). In Võrtsjärv Lowland the eutrophic and mesotrophic peat is represented by heather-*Sphagnum*, forest-sedge, forest-reed and forest peat. Like in Pärnu Lowland, in Võrtsjärv Lowland oligotrophic peat is dominated by *Sphagnum* and *Sphagnum fuscum* peat (Paper I).

**Alutaguse Peat District** is located on the lowland north of Lake Peipsi. The relief and composition of the Quaternary cover of this region has been influenced by the late-glacial glacier-dammed lakes. In the northern part of the district, from where the glacier retreated rather fast, the relief is flat and the base of peat deposits generally follows the bedrock relief. In the central and southern part of the district the relief is dissected by eskers, kames and numerous ancient beach ridges of Lake Peipsi that have transferred into dunes. In these areas occur abundant small paludified pockets, often with oligotrophic peat as the first peat layer. Alutaguse is the area richest in peatlands in Estonia – the peatlands cover approximately 50% of its territory. Here occurs the largest peatland complex in Estonia, Puhatu (57,000 ha).

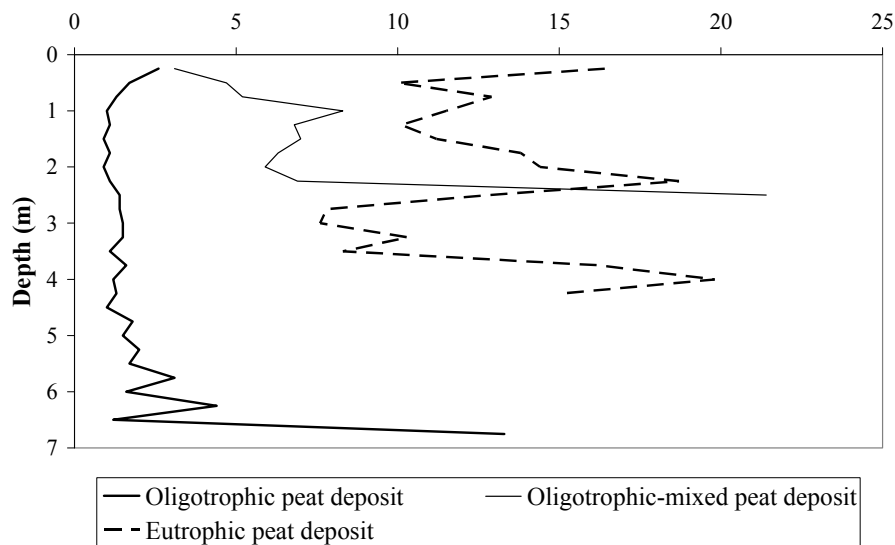
In places esker chains form long peninsulas of mineral land extending into mires, with eutrophic and mesotrophic peat layers spreading along their margins. In comparison with the eutrophic peat layers of other districts, the degree of humification is relatively small (up to 30%), but due to feeding from groundwater, the content of mineral matter is high, reaching 12%. Mesotrophic peat layers are of limited distribution and rather thin (0.3–0.4 m). Oligotrophic peat is represented mostly by *Sphagnum* and *Eriophorum-Sphagnum* peat (Paper I). In southern Estonia between the uplands occur lowlands, depressions and valleys. **Väike-Emajõgi Valley (14)** includes the area between Otepää and Sakala uplands in the environs of Väike-Emajõgi River, through which the Väike-Emajõgi ancient valley passes. Here one can find kame fields, small lakes and abundant peatlands. Depending on the relief, most common are elongated eutrophic peatlands with thick layer of eutrophic peat. Among peat types medium and well humified forest and forest-reed peat dominate, with content of mineral matter of 10% (Paper I). **Valga Lowland (17)** is the southern continuation of the valley of Väike-Emajõgi River up to the Karula Upland. The relief is characterized by small hollows and depressions, in the central part of the lowland occur flood plain peatlands with well humified eutrophic peat that has formed in nutrient-rich conditions. So the content of mineral matter in relation to flooding waters reaches 24%. In somewhat higher outskirts occur small peatlands with oligotrophic peat layer. Characteristically, according to the feeding conditions the oligotrophic-mixed peat layer is almost completely missing (Paper I).

**Võru–Hargla Depression (19)** is located between the Haanja, Karula and Otepää uplands. The depression is visible in the pre-Quaternary relief and the ice-melt water flowed in it during the late glacial. In the lowest part of the depression, in the area of current rivers occur floodplain peatlands with eutrophic peat with high content of mineral matter (10–24%) as the dominating peat type. Oligotrophic peatlands occur on the slopes of the depression where the conditions for runoff surface water are good and precipitation is the main feeding agent. It is characteristic that about 30% of the peatlands on the slopes of Võru–Hargla Depression are oligotrophic (content of mineral matter is 1–2%) and 30% are mesotrophic (the average in Estonia is 10%).

North of the previous district **South Estonian Plateau (12)** (with large interior valleys) that encompasses the low depression-like areas around the Suur-Emajõgi River and its tributaries (Ahja, Konsu, Amme, etc.) and the western part of the depression of Lake Peipsi. All major river valleys are largely paludified and eutrophic peat deposits dominate. The character of eutrophic peat is variable – grass, forest-grass as well as forest-*Hypnum* moss peat occur. The content of mineral matter in them is changing (7–17%), since it has been carried by flowing water. Oligotrophic peat is represented mostly by *Sphagnum fuscum* and *Sphagnum medium* peat, lower layers are composed by mesotrophic *Sphagnum* and forest-cottongrass peat. The share of mineral matter in oligotrophic peat is small – 2% (Paper I). Characteristically, by the quality of peat deposits the mesotrophic deposits resemble more the oligotrophic-mixed peat, while normally they are similar to eutrophic deposits. The district is interesting because here one can find grass eutrophic peatlands as well as typical wooded oligotrophic peatlands.



In watershed areas of **Kõrvemaa (4a)**, **upper course of the Pärnu River (4b)** and **Palumaa (16)** oligotrophic peat deposits feeding from precipitation dominate. In Kõrvemaa watershed area and upper course of the Pärnu River the runoff occurs into the rivers located to the north, west and south (Keila, Konovere, Pärnu, etc.), which creates favourable conditions primarily for the formation of oligotrophic peat. The peat often overlies the glaciolacustrine sand which has good permeability, therefore in the development of mires the transition from eutrophic to oligotrophic stage was fast. Oligotrophic peat deposits with very small content of mineral matter (1–1.5%) dominate, forming 80% of all peat deposits and area of peatlands in the district. Prevailing peat type is poorly humified (12–15%) *Sphagnum* and *Eriophorum-Sphagnum* peat (Paper I). **Palumaa** is situated between Lake Pihkva and Haanja Upland. The abrasion and accumulation plains are here frequent and general appearance of relief is even, with few valleys dissecting it into plateau-like parts. Therefore most of the peatlands between the river valleys fed from precipitation instead of groundwater and the development started in the oligotrophic stage (covering ~80% of peatlands in the district). Here the content of mineral matter in oligotrophic peat (0.8–1.0%) is the smallest in Estonia (Figure 6). The poorly humified (20%) *Eriophorum-Sphagnum* and grass peat dominate.



**Figure 6.** Content of mineral matter (%) in the Palumaa district.

**Uplands** play an important role in the formation of peatlands and accumulation of peat deposits. Uplands cover approximately 15% of the territory of Estonia (Raukas & Rõuk, 1995). Major uplands can be divided into two types based on their formation: abrasional ice-shed uplands (**Pandivere, Sakala**) and accumulational island-uplands (**Otepää, Karula, Haanja, Saadjärv drumlin field (Vooremaa)**).

Considering the formation of peatlands and peat, the **Pandivere Upland** is divided into two parts: **central part (5a)** and **slope (5b)**. In the central part of the Pandivere Upland the groundwater level lies deep and surface waters flow into the karstified

bedrocks. Thus, the network of watercourses is poorly developed and only 3% of the district is covered by peatlands. Peat deposits are represented mainly by mesotrophic and eutrophic forest and forest-sedge peat. Oligotrophic peat deposit is of restricted distribution because most of mires have not reached the oligotrophic stage (Paper I). The surface water infiltrated into bedrock on the roof of the upland, flow out on its slopes as springs and form extensive eutrophic peatlands on the **slopes of the upland**. Moreover, the peatlands with thick peat deposits that formed in small depressions and reached oligotrophic stage have joined and formed mosaic peatland complexes (Epu-Kakerdi, Endla, Peetla). Typically, the transition from eutrophic to oligotrophic stage occurred fast – oligotrophic peat with small content of mineral matter (1.5%) forms 75% of the whole sequence. Dominating peat type is cotton-grass and *Sphagnum*, *Sphagnum medium*, and *Sphagnum fuscum* mosses (Paper I).

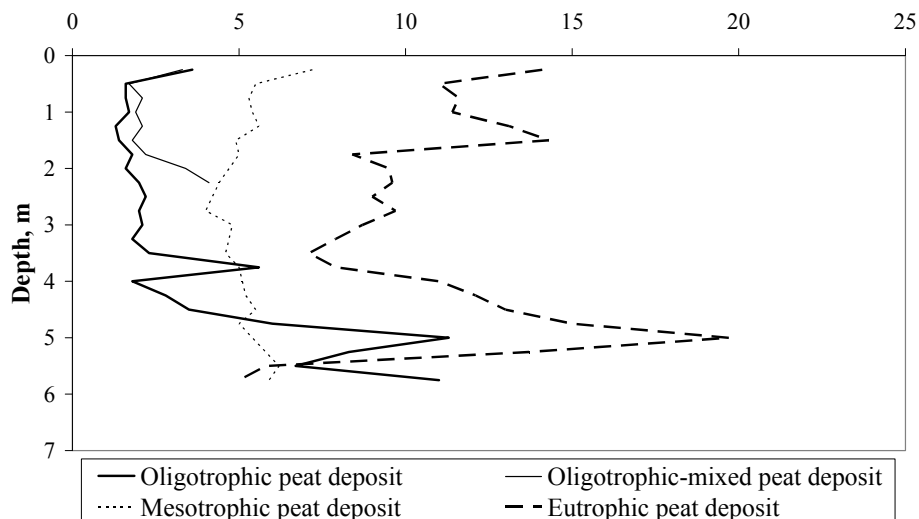
Majority of the relief of the **Sakala Upland (13)** is plateau-like and modest dissected (Raukas & Rõuk, 1995), so the number of peatlands is smaller compared to more dissected Otepää, Karula and Haanja districts. Napsi peatland, one of the deepest in Estonia (11 m), is located in the depression, which formation began already 9,000 years ago in late Preboreal. In upland's eastern part, on the undulating till plains bordering the Väike-Emajõgi River valley occur large raised bogs where all types of peat deposits are present. The eutrophic and mesotrophic deposits are represented by grass, forest and forest-sedge peat with varying content of mineral matter – 3–12%, reaching 21% in floodplain peatlands in river valleys. Presence of oligotrophic-mixed and oligotrophic deposits is related to the watersheds in central part of the upland and to undulating till plain in eastern part and deposits are composed of cottongrass-grass and moss peats, with content of mineral matter 1–4% (Paper I).

To the south from Pandivere is located **Vooremaa (9)** district. The area is dissected mostly by drumlins and is rich in lakes (Rõuk, 1973). Part of the former lake depressions is partly or completely paludified. In the depressions between drumlins and ridges eutrophic peatlands dominate. Only few oligotrophic peatlands occur in the area of local watersheds. The peat deposits formation is a result of overgrowing of lake depressions. Eutrophic peat is represented by forest and forest-reed peat, rather high content of mineral matter in it (up to 15%) due to the surface water inflow from the slopes of drumlins. Oligotrophic peat is represented by moss peat (*Sphagnum fuscum*, *angustifolium*, *medium*) with low degree of humification. Here the oligotrophic–mixed deposit is more widespread than in other districts, since the hydrological regime has not enabled the transfer to feeding solely from precipitation (Paper I).

In southeastern Estonia are located **Karula Upland (18)**, **Otepää (15)** and **Haanja (20) Heights**. Karula Upland is located at the border of Estonia and Latvia, in the southeastern part of Valga County. The relief is dissected, mainly till-covered hillocks alternate with small closed depressions with lakes in the lowlands. The peatlands are mainly small and medium by size. Both oligotrophic and eutrophic peatlands occur, whereas the latter are more frequent since many peatlands feed from the surface water seeping from the slopes of hillocks. In small peatlands the

thickness of eutrophic peat deposit is on average 4.5–5.5 m (max 6.5 m). Oligotrophic deposit spreads on restricted area, only at the southern boundary of the district. It consists of mainly *Sphagnum fuscum* peat with average thickness is 3.5–4.5 m.

**Otepää Heights** is characterised by abundance of many small peatlands due to dissected relief with large number of closed (or with only temporal runoff) depressions. Thickness of the Quaternary cover is 40–60 m, so bedrock does not influence the formation of peatlands. Eutrophic peatlands dominate, the proportion of oligotrophic peatlands is small. The inflow of groundwater feeding the peatlands occurs via the inter-layers within and inside till complex. Inflow of water into peatlands can be temporary or permanent, depending on the size of groundwater recharge area and thickness of the water-bearing layer. The eutrophic and mesotrophic peat deposits are mainly 3–4 m thick and reed rich forest-sedge peat with high content of mineral matter dominates (Figure 7). Oligotrophic–mixed and oligotrophic deposits occur only in few peatlands on small areas, their thickness is small (1.7–2.1 m). Oligotrophic peat is composed mostly of *Sphagnum* peat (Paper I).



**Figure 7.** Content of mineral matter (%) in Otepää district.

The relief of **Haanja Heights** is very dissected and dome-like hillocks and ridges dominate, with many extensive depressions between them. The Quaternary cover is represented by till as well as clayey sands, sands and gravels. Peatlands in small closed depressions are feeding mainly from the intra-till groundwater abundant. The eutrophic peat deposit makes up about 80% and oligotrophic deposits only 20%. In ancient valleys the peatlands are larger and with more complicated configuration. Eutrophic peat is dominated by well humified (40%) forest peat. Mesotrophic peat deposits are represented by very thin (0.3–0.4 m) peat layer or is missing at all. Also the oligotrophic–composite deposit spreads on restricted territory; however, it has very limited distribution in these three uplands. Oligotrophic peat spreads somewhat more widely in the outskirts of the Karula and Haanja uplands, where small watersheds have formed and consist mostly of cottongrass-*Sphagnum* peat (Paper I).

## 5. SOURCES AND DISTRIBUTION OF TRACE ELEMENTS IN ESTONIAN PEAT

Peat is continually used in horticulture, litter and as fuel. In recent years also the alternative uses of peat have become topical – e.g. balneology, cosmetics, rehabilitation, textile and chemical industries (waxes, pigments, filters of purification facilities). From the standpoint of peat industry, agriculture, horticulture and environmental protection it is important that the peat does not contain high concentration of trace elements.

The results of our studies (Paper III, IV) show that concentration of trace elements in Estonian peat is generally low (Table 1). However, in some places considerably high concentrations of trace elements have been recorded (Table 1). This is mostly the case for peatlands fed from springs, which are situated on the flood plains of river valleys.

**Table 1.** Contents of some trace elements in Estonian peat

	$\mu\text{g g}^{-1}$				$\mu\text{g g}^{-1}$		
	average	min	max		average	min	max
As	2.4	0.16	23.3	Mo	1.2	0.01	27.5
Cd	0.12	0.01	3.00	Pb	3.3	0.02	48.1
Co	0.50	0.03	3.4	S	2500	100	82000
Cr	3.1	0.01	33.8	Sr	21.9	0.20	314.2
Cu	4.4	0.02	62.2	Th	0.47	0.01	21.0
Hg	0.05	0.01	0.10	U	1.3	0.01	61.0
Ni	3.7	0.10	61.2	V	3.8	0.09	48.0
Mn	35.1	0.53	409.6	Zn	10.0	0.30	117.8

Formation of peat deposits, peat growth rate and current state of peatlands depend mainly on their feeding regime. The feeding conditions of a peatland and consequently the structure and character of its peat layers are also controlled by position of the peatland in landscape, geological setting and character of the Quaternary cover. Thus, the geology of the area and the groundwater flow are very important factors. In southern Estonia, peatlands have formed in deep valleys with considerable influence of slope springs. These kinds of peatland usually show the highest concentrations of trace elements; the author is on the opinion that these elements have been carried into peat by groundwater from the Devonian sandstones via tectonic fracture zones. In comparison Syrovetsnik et al. (2004) observed high accumulations of heavy metals (Cd, Cu, Mn, Ni, Pb and Z) in Oostriku peat deposit (in Endla mire complex). The water feeds the Oostriku peat deposit from below, so most likely metals are leached by sulphide oxidation in carbonate rocks upstream of the peat.

The lowest concentrations of most studied elements (Table 1) were found in middle layers of raised bogs (ombrotrophic peatlands). Their average concentrations can be considered as the “natural background” for atmospheric deposition in Estonian peat.

Hazardous levels of trace elements occur when certain concentrations have been reached in the peat. They can be transferred to organisms via the food chain or through drinking water. Peat with high concentration of trace elements should neither be used in horticulture nor as a fuel.

Statistical analysis showed the influence of the position of a peat layer (surface, middle, bottom) in different feeding types (feeding from precipitation – oligotrophic peat, from different sources – mesotrophic peat, from groundwater – eutrophic peat, from ground- and springwater – spring fen communities) on the concentration of trace elements. It appeared that the influence of peat layer decreases in the following order: mesotrophic peatlands > oligotrophic peatlands > eutrophic peatlands. The highest concentrations were found in eutrophic peat. In other types of peat, the concentrations of trace elements were as a rule significantly smaller. It appeared that the significance of the peat type in determining the concentration of trace elements decreases towards: surface layer > middle layers > bottom layer. It has to be emphasised that within the humificated bottom layer the plants have lost their initial structure and as a consequence, the differences between peat types have disappeared.

As a general conclusion, the statistical analyses indicated that the factors influencing the concentrations of trace elements in peat settle in a following ranking in the direction of decreasing importance: feeding type > peat type > peat layer.

In accordance with Estonian legislation (Regulation of the Minister of the Environment no. 38 of 11<sup>th</sup> August 2010: Maximum Limits Values for Dangerous Substances in Soil, <http://www.riigiteataja.ee/ert/act.jsp?id=13348997> – 07.10.2010) it is important to know the content of heavy metals in soils as well as in peat, since peat is used as growing media. The limits in soil for elements are the following:

Hg – 0.5  $\mu\text{g g}^{-1}$ ; Cd – 1  $\mu\text{g g}^{-1}$ ; Pb – 50  $\mu\text{g g}^{-1}$ ; Zn – 200  $\mu\text{g g}^{-1}$ ; Ni – 50  $\mu\text{g g}^{-1}$ ; Cr – 100  $\mu\text{g g}^{-1}$ ; Cu – 100  $\mu\text{g g}^{-1}$ ; V – 50  $\mu\text{g g}^{-1}$ ; As – 20  $\mu\text{g g}^{-1}$ ; U – 1  $\mu\text{g g}^{-1}$ .

## 6. CHEMICAL PROPERTIES OF PEAT WITH BALNEOLOGICAL POTENTIAL IN ESTONIA

Special studies of physical and chemical properties of peat for using it for balneological purposes were carried out by the author at the Geological Survey of Estonia in 2005–2007 in order to introduce scientifically well founded alternative fields of peat utilisation, which would assure sustainable use of peatlands and peat reserves.

The results of the investigations revealed that the abundance of humic substances in studied peatlands in Estonia (Kõverdama, Parika, Sangla) was relatively high (Paper V). All three acids (humic, hymatomelanic, and fulvic) could be found. The highest concentration of humic substances (up to 60%) was found in Parika peatland. This is higher compared to the results from Finland, where Uosukainen (2002) determined the concentration of humic, hymatomelanic acids 20–40% and fulvic acids 4–12%. The highest concentrations were found in well humified (45–50%) *Sphagnum* peat and less in *Carex*, and *Sphagnum-Carex* peat. Thus, both degree of humification and peat type seem to be important factors affecting the concentration of humic substances in peat.

The peat used in balneological practice must also be clean from trace elements. In general, the abundance of analysed elements in these three peatlands was lower than on average in Estonian peatlands (Paper V). However, the content of S was slightly higher. Moreover, the small differences between peatlands could be related to humic substances. It is known that humic substances (HS) have the ability to react with cations because of strong association of HS with organic and inorganic compounds in soil and water, acting both storage and transport agents for these varieties (von Wandruszka, 2000). If the HS is acting as transport and storage agent, the content of metals and HS fractions must be correlated. For this purpose, the Pearson correlation coefficients were calculated for each HS fraction (Paper V).

Balneologically usable peat was found in all three studied peatlands. The biggest resources (0.47 million tons) are in Sangla, but in Parika, where the highest content of HS was found, the resources are 0.11 million tons. The genesis of peat deposits was mainly lake paludification, mineral subsoil sand-clay, vegetation pine forest, nutrition precipitation, degree of humification 40–50% and moisture content 85–90%. Peat type varied, but *Eriophorum* and *Sphagnum* were dominating.

More humified peat has higher concentrations of humic substances, it is related to the age of peat layers, as formation of bioactive substances is a time-consuming process. The transformation of peat organic matter by chemical, biochemical and biological decay leads to the formation of a number of chemical substances from which humic and fulvic acids and their salts, cellulose, lignite, bitumens, peptides, enzymes and fats are the most common (Szajdak et al., 2007). Among the different peat types the forest (pine)-cottongrass seems to increase the levels of humic substances the most. The lipids in peat could be associated with hymatomelanic

acids, because of high correlation coefficients. Several trace elements were well correlated with fulvic acids, and some of them correlated with humic acids negatively.

As peat and various peat preparations have been successfully used in the balneological practice of clinical medicine (Beer et al., 2007), the later studies have been induced by that fact. As the content of bioactive substances is high (up to 60%), the Estonian peat gave good effect in balneology. Most of the patients with Heberden-Bouchard disease (*Osteoarthritis deformans*) in fingers received improvements with balneological peat (Oru et al., 2010). The results in International Classification of Functioning, Disability and Health scale showed: pain decreased in 95% of the patients; mobility of finger joints improved 74% of the patients; the minimal distance between III finger and the centre of the palm improved in 35% of the patients; the catching improved in 42% of the patients.

## 7. PEAT PRODUCTION, ABANDONED PEAT FIELDS AND THEIR RE-VEGETATION

As a result of continuing peat production (around a century), according to catalogue of mineral deposits of environmental register (<http://register.keskkonnainfo.ee/envreg> – 07.10.2010), there are 154 abandoned peat fields in Estonia. From these, 81 large and representative milled peat fields with a total area of about 9,000 ha were investigated (Paper VI). Just a very small part of this area has been reclaimed – either forested or used for growing berries. The re-vegetation of Estonian abandoned peat production fields is mainly the result of natural processes, which are generally very slow due to unfavourable water regime or thin remaining peat layers. The fields are mostly covered by cottongrass and birches. Often sparse vegetation covers 10–20% of a peat field, but some fields have turned into heaths or grasslands with plant coverage up to 60%.

Presently 77 production areas (205 km<sup>2</sup>) are included in the environmental register, with the total resources of 0.24 billion tonnes of poorly humified and 0.75 billion tonnes of well humified peat (Paper II).

In the last decade, 0.33–1.5 million tonnes of peat has been extracted (40% air-dry peat) annually (Ramst & Orru, 2009). In the nearest future the amount will not increase, because the recent milling technology does not enable extraction of larger quantities from the existing mining claims. As protection of mires has become a priority, annual production up to 1.5 million tonnes can now be considered optimal, in spite of the quota of 2.6 million tonnes per year.

Presently, peat production in Estonia is regulated by the Sustainable Development Act (<https://www.riigiteataja.ee/ert/act.jsp?id=13148461> – 07.10.2010), according to which the quota is 2.6 million tonnes of 40% air-dry peat per year. The volume of produced peat must not exceed its natural accumulation. Ilomets (1994) has estimated the annual average accumulation rate of peat to be 0.5 mm in fens and 1.5 mm in raised bogs in Estonia; according to (Orru et al., 1992) it is 1.28 mm in raised bogs and 0.86 mm for the whole peat layer.

Investigation of abandoned peat production fields showed that when the natural state and environmental and feeding conditions with peat properties of peatlands have been changed, new varieties have been detected. This is evidenced by several interesting findings made during the inventory. In 2005, a second locality of *Polia elongata* was reported for western Estonia. In 2006, *Ephemerum serratum*, last found in Estonia in the middle of the 19<sup>th</sup> century, was identified in central Estonia. In 2007, *Campylopus introflexus* and in 2008, *Bryum oblongum*, both unknown in Estonia, were identified in the material collected from two localities (Paper VI).

The optimum condition in abandoned production peat fields is a permanently high (0.2–0.5 m below the ground surface) groundwater level, permitting successful re-vegetation of the fields within ten or even less years. However, the water-table in



abandoned mined peatlands is lower and more variable than in natural sites (Price, 2001; Fay & Lavoie, 2009).

In Estonia distinctive sites are small peat pits, where poorly humified peat was extracted manually with spades. Special drainage ditches were not made, as they were located mostly in the peripheral parts of peatlands, where natural drainage occurs. Characteristically for this extraction type the chemical composition of water changed relatively little, because peat was taken out with natural moisture content. Now such pits are almost completely overgrown with peat moss, mostly because the chemical composition of groundwater was just little changed, the re-vegetation occurred faster and the growth of peat moss started first (PAPER VI). Similar results have been obtained also by Wind-Mulder et al. (1996) in Canada.

## 8. ACHIEVEMENTS AND PERSPECTIVES

The current thesis includes a number of originalities that make it important in the field of science. First and foremost, the author developed the typical peat deposits and analogues method for Estonia. The characteristics of the peat were analysed in 539 typical peat deposits and the peat quality in 1,059 analogues were assessed based on typical peatlands. This method is applicable for studying peat deposits (PAPER I) elsewhere as well.

For the analysis of the content of trace elements in peat, the whole peat sequence with different feeding types as well as natural and production areas were analysed. The results were based on much larger number of samples (684) and peatlands (64) compared to previous studies. This clarified the understanding that compared to the atmospheric pollution; trace elements are carried into peat in much larger amounts with groundwater from underlying bedrock (PAPER III, IV).

In the analysis of the chemical properties of peat, also the content of humatomelanic acids among the other humic substances was determined. It is very important component; however, it is not usually analysed and the information on humatomelanic acids in curative mineral resources is very limited (PAPER V).

The great number (81) of revised abandoned peatlands (usually small number is studied) showed a large variety of re-vegetation processes in previous peat production areas. Main factors affecting re-vegetation are the water regime, and other environmental conditions and the peat type, and properties (PAPER VI). Furthermore, several moss species new or rare in Estonia were found in abandoned peatlands that shows the available niche for new species with changed environmental conditions.

The current research has already led to several practical applications. First, the typical peat deposits and analogues methods gave economical benefit in the inventory of Estonian peatlands. Especially it reduced the number of required expensive laboratory analysis. Second, the typical peat deposits have been basis for compiling the catalogue of peat deposits (currently includes 279 peatlands) of the environmental register. Third, the typical peat deposits have also been one of the important factors in planning the protection of peatlands and peat production as well as sustainable use of peatlands in Estonia (PAPER II). Recently they have been used to compile development plan for peatlands and peat by the Ministry of the Environment Estonia. Fourth, the analyses on the organic substances in peat have helped to introduce peat balneology in practice.

However, there are also several perspectives that can be developed in the future. One of the most important target are the numerous of data. About 34,000 determinations of the peat types and composition of peat by plant species by the entire peat sequences (from late Preboreal until present) are stored at the Depository of Manuscript reports of the Geological Survey of Estonia (PAPER II). In further investigations this material could be used, for instance, for assessing the climate changes during the Holocene as well as anthropogenic influence.

## 9. CONCLUSIONS

A new, more detailed distribution of peat districts (altogether 20 peat districts) and their characterisation were worked out and the method of typical peat deposits and their analogues was elaborated. Adequacy of the method of typical peat deposits was proven during later digitising work, carried out when compiling the catalogue of peat deposits of the environmental register.

The studies (Papers I–VI) included in the thesis show that the peat types and their technical characteristics (degree of humification, content of mineral matter, pH, natural moisture content) and chemical characteristics (trace elements, content of humic substances, cellulose, lignin, etc.) are closely related to the feeding conditions of a peat layer. Sufficient knowledge of the peat properties and its feeding conditions allows previous planning of its field of utilisation, including sustainable and alternative uses.

Concentration of trace elements in Estonian peat was in general low. However, in some places considerably high concentrations were recorded, mostly in the case of peat layers fed from springs situated on flood plains of river valleys. It is probably related to disturbances in bedrock through which the groundwater enriched with elements enters the peat layer (e.g. Raudna, Penuja, Mustjõe), first of all via the springs. Feeding type appeared to be the factor affecting the concentration the most; followed by peat type and peat layer. It is recommended not to mine the above peat layers with very high concentrations of trace elements.

Balneologically usable peat can be found in the peatlands, where peat is feeding mainly from precipitation. The biggest resources (0.47 million tonnes) are in Sangla peatland, but the largest content of humic substances in Parika (59.9%). Analyses showed that in all investigated peat layers humic, humatomelanic and fulvic acids can be found. Also the distribution of peat suitable for balneological treatment is related to the genetic type of peat. Probably the age of peat is important here as well.

Re-vegetation of Estonian abandoned peat production fields is mainly the result of natural processes, which are generally very slow due to unfavourable water regime or too thin remaining peat layers. At re-vegetation the most important factors are the following: water level, peat composition, thickness of peat layer and its character, geological settings of the region as well as changing environmental conditions.

Moreover, several moss varieties new or rare in Estonia have been identified in these areas, e.g. *Polia elongata*, *Ephemerum serratum*, *Campylopus introflexus* and *Bryum oblongum*, resulting from changes in environmental conditions and peat characteristics. In the process of inventory of Estonian peatlands, in addition to the existing 55 peat varieties two new ones were identified: eutrophic *Scheuchzeria* peat and eutrophic *Scheuchzeria-Sphagnum* peat.

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## **ABSTRACT**

Peatlands occupy 22.3% of the territory of Estonia. The peat deposited in them has been actively used and investigated for scientific as well as practical purposes for the last 150 years. The government policy requires economical and sustainable use of peat as valuable mineral resource and introducing the protection of peatlands and alternative ways of using peat.

The aim of the doctoral thesis was to estimate the dependence of the properties of peat and formation of peat layers on the feeding conditions of peat and typological dissection of landscape districts. The feeding conditions of a peatland are influenced by the position in relief, geological setting of bedrock of the region and character of Quaternary cover. The development of a peatland starts from eutrophic stage, continues as mesotrophic and finally reaches oligotrophic stage. This is accompanied by changes in feeding conditions and properties of peat.

Based on the formation conditions of peat deposits and characteristic properties of peat the author has distinguished 20 peat districts on the territory of Estonia.

Distinguishing of the above districts based on the results of peat investigations carried out at the Geological Survey of Estonia in 1971–1992 where the peat layers were assessed on the grounds of large number of investigation points. Altogether 33,600 analyses were made to determine the properties of peat. In Estonia, there are 9,836 peatlands with an area over 1 hectare, peat reserves were calculated for 1,598 peatlands in which the peat layer over 0.9 m thick spreads on at least 10 hectares. Total peat reserves in Estonia amount to 2.37 billion tonnes. The remaining 8,238 peatlands were included in a list presenting the area of peatland, thickness of peat and peat variety. These data are stored at the Depository of Manuscript Reports of the Geological Survey of Estonia.

In the process of the inventory of peatlands on integrated investigation method was worked out – prior to fieldwork the results of previous investigations and the data on the peatlands shown on soil maps of arable land and woodlands were marked on aerial photographs at a scale of 1:10 000. Such preliminary work is especially important at mapping of small peatlands.

To reduce the volume of work at the inventory of peat deposits, the author introduced the method of typical peat deposits. Altogether 539 typical peat deposits have been chosen that are the biggest peatlands and mires with thick peat deposits and are the most typical for each peat district. These peatlands were thoroughly investigated and their data were used for characterising the quality and reserves of peat of the remaining 1,059 peatlands. The peat deposit-analogues served as the basis for compiling the list of peat deposits of the environmental register, so far including 279 peatlands.

Since the peat is used as fuel, growth substrate in horticulture and litter in cattle breeding, as well as in balneology; it must not contain trace elements. For studying the content of trace elements in peat, in total 684 samples in selected 64 peatlands

were taken. Samples were collected from the whole peat section every 0.5 m per one coring. Statistical analyses for elucidating the content of trace elements and regularities of their distribution in peat were performed using STATISTICA 6.0. It appeared that an important factor at the formation of the chemical composition of peat is the feeding of a peat layer and its position in peat sequence (top, middle, bottom). The results of statistical analyses showed the differences by feeding types and position of the peat layer in upper, middle and lower part of a peat deposit.

Further data processing allowed determination of the Spearman rank correlation matrices by feeding condition and assessing the influence of a peat layer using Duncan test. The highest concentrations of trace elements were found in eutrophic peat of a spring-fed peatland located on a slope. The author considers that this is due to the fissured rocks in the area of tectonic dislocations, from which trace elements are carried into peat by groundwater. The lowest concentrations of most studied elements were found in middle sections of ombrotrophic mires, since the global inflow of contaminants, and inflow of elements by groundwater are missing.

The chemical composition of organic component of peat, primarily the content of humic substances depends on the varieties of peat and degree of humification. The investigations carried out in peat deposits of the Kõverdama, Sangla and Parika peatlands showed that the concentration of bioactive substances is the highest in forest-cottongrass peat – up to 60%. The reserves of balneological peat in Estonia are 0.8 million tonnes and later clinical tests have shown good curative potential of the bioactive substances of Estonian peat.

Only a small part of the 81 investigated abandoned peatlands (milled peat production fields) have been reclaimed (reforested or arranged for berry-growing). Large part of abandoned peat production fields in Estonia have naturally re-vegetated. The optimum condition in abandoned production peat fields is permanently high (0.2–0.5 m below the ground surface) groundwater. In most part of the abandoned milled peat fields the groundwater lies deeper (up to 1.1 m), which creates unfavourable conditions for the re-vegetation.

The manuscript database compiled in the process of peat investigations is stored at the Depository of Manuscript Reports of the Geological Survey of Estonia. It comprises more than 33,000 determinations of botanical composition of peat in which all plant species have been determined starting from the Preboreal up to today. The database provides valuable information on the impact of postglacial climate and human activity on environment and therefore would need further profound analysing.

Summing up, the setting of Estonian peat deposits, vegetation, peat characteristics, trace elements in peat and the chemical composition of peat's organic components depend on feeding conditions. It is always important to study the whole peat section since the detailed investigations have shown that the characteristics of different layers of peat are quite variable.

## KOKKUVÕTE

### **Eesti turba omaduste sõltuvus maastikutüüpidest ja turbalasundi toitumistingimustest**

Sood ja turbaalad on Eesti maastiku tähtis element, kattes 1 009 101 ha (22,3%) Eesti pindalast. Turbavaru on 2,37 miljardit tonni (Orru et al., 1992). Kuna turvas on üheks tähtsamaks maavaraks Eestis, on sel pikaajalised kaevandamise traditsioonid ning ta leiab jätkuvalt laialdast kasutamist kütte-, aiandus- ja allapanuturbana. Eesti aastane turbatoodang on 1,1–1,2 miljonit tonni, mida eksporditakse ka paljudesse välisriikidesse. Viimastel aastakümnetel on lisaks päevakorda kerkinud turba alternatiivsed kasutusalaad, nagu balneoloogia, keemiatööstus (vahad, värvained), puhastusseadmete filtrid jne. Kuid nii põllumajanduses, aianduses kui ka turba põletamisel on tähtis, et kasutataks vaid vähesel määral kahjulikke elemente sisaldavat turvast. Samuti näeb Eesti riigi poliitika ette turba kui hinnalise maavara säästlikku kasutamist ning turbaalade kaitse ja alternatiivsete kasutusalaade juurutamist. Teatavasti on soodel ja turbaaladel tähtis keskkonnaaspekt, eelkõige veevarude reguleerija ja säilitajana. Selleks on muu hulgas vaja tundma õppida turbalasundite (madalsoo, siirdesoo- ja rabalasad) ning nendes kujunenud turba tekketingimusi, omadusi ja toitumist.

Doktoritöö eesmärkideks oli:

- töötada välja tüüpsode ja nende analoogide uurimismeetod ning juurutada see, et vähendada Eesti soode inventuuriga kaasnevat suurt töömahtu;
- jagada inventuuri käigus uurimistulemuste põhjal kogutud sood sõltuvalt turbalasundi kujunemis- ja toitumistingimuste ning iseloomulike turba omaduste (botaaniline koostis, niiskus, lagunemisaste, mineraalainete sisaldus, pH) alusel piirkondadeks;
- analüüsida kahjulike elementide sisaldust erineva tekkeloo ja asukohaga turbalasundites ning selgitada leviku seaduspärasused;
- turba balneoloogilise kasutamise eesmärgil määrata turba orgaanilise osa keemiline koostis ja analüüsida seda mõjutavaid faktoreid;
- õppida tundma põhilisi keskkonnatingimusi, mis mõjutavad mahajäetud turbaalade taastaimestumist.

Soode inventuuri ajal töötati välja uuringu kompleksmeetod, mille kasutamise käigus kanti välitöödele eelneval perioodil fotoplaanidele (1:10 000) varasemate uurimistööde tulemused ning põllu- ja metsamulla kaartidelt turbaga kaetud alad. Tüüpsodeks valiti 539 suuremat ning sügavalasundilist ja igale maastikutüübile iseloomuliku geneesiga sood. Turba omaduste väljaselgitamiseks tehti neis 33 600 laboratoorset määrangut ning tehti kindlaks turbakihtide paksus, arvutati turbavarud ning koostati plaan ja lühikirjeldus. Tüüpsode andmeid kasutati nende analoogiks oleva 1 059 turbaala turba kvaliteedi iseloomustamisel. Analooigidel reeglina turba-proove ei võetud. Neil määrati turbakihi paksus ja arvutati turbavaru.

Kahjulike elementide sisaldust uuriti 64 turbamaardlas. Kokku analüüsiti 684 proovi, mis võeti ühtse meetoodika alusel kogu läbilõike ulatuses, intervalliga 0,5 m. Kahjulike elementide sisalduse seaduspärasusi analüüsiti, kasutades Spearmani astakorrelatsioonikordajaid ning Duncani testi. Turba orgaanilise osa keemilist koostist ja seal leiduvate humiinainete sisaldust turba balneoloogilise kasutamise eesmärgil uuriti Kõverdama, Sangla ja Parika turbalasundis. Mahajäetud freesturba kaevandamise aladest olid uurimise all 81, kus selgitati nende taastaimestumist ja keskkonnaseisundit ning säilinud turba omadusi.

Eestis on kokku 9 836 sood, mille pindala on suurem kui 1 ha, neist turbavaru arvutati 1 598 kohta, kus üle 0,9 m paksust turbalasundit on vähemalt 10 ha. Ülejäänud väikese- ja õhukeselasundilise (8 238) kohta koostati nimekiri, kus on esitatud pindala, turba paksus ja liik. Andmed asuvad Eesti Geoloogiakeskuse geoloogiafondis.

Turbalasundite kujunemis- ja toitumistingimuste ning turba omaduste alusel eristas autor Eestis välja 20 piirkonda: Põhja- Eesti kliendieelne tasandik, Põhja-Eesti lavamaa, Kirde-Eesti lavamaa, Kõrvemaa veelahkmeala, Pandivere kõrgustiku keskosa ja nõlv, Alutaguse, Lääne-Eesti saarestik, Lääne-Eesti madalik, Vooremaa, Pärnu madalik, Võrtsjärve madalik, Kagu-Eesti platoo, Sakala kõrgustik, Väike-Emajõe orund, Otepää kõrgustik, Palumaa, Valga madalik, Karula kõrgustik, Võru-Hargla madalik ja Haanja kõrgustik.

Kahjulike elementide leviku statistilisel analüüsil selgus, et olulisteks teguriteks, mis mõjutavad elementide sisaldust, on soode toitelus ja turbakihi asend lasundis. Ilmesid erinevused toitumisviiside ja kihi paigutuse suhtes turbalasundi ülemises, keskmises ja alumises kihis. Suurim kahjulike elementide sisaldus tuvastati allikalise toitumisega nõlvasoo madal soo turbalasundis. Arvatavasti on see seotud aluspõhja tektooniliste rikkevööndite lõheliste kivimitega, mille kaudu kantakse põhjaveega turbasse erinevaid, sh kahjulikke elemente. Kõige puhtam on sademetoiteliste turbalasundite keskmiste kihtide turvas – seal on kahjulike elementide sisaldust suurendavate tegurite (saaste atmosfäärist, elementide sissekanne põhjavee ja allikatega aluspõhja kivimitest, voolu- või tulvaveega ümbritsevast keskkonnast) mõju kõige väiksem.

Balneoloogilisel eesmärgil tehtud uuringud näitasid, et suurim humiinainete sisaldus oli puu-villpeaturbas, kuni 60%. Võrdluseks Soomes on sama näitaja 29% (Uosukainen, 2002). Eestis on balneoloogilist turvast 0,8 miljonit tonni ning hilisemad kliinilised katsed on näidanud Eesti turba humiinainete head tervendavat potentsiaali (Orru et al., 2010).

Uurimise all olnud 81-st mahajäetud freesturba kaevandamise alast on korrastatud (metsastatud, rajatud marjakasvatuse jms) vaid väga väike osa. Enamikul juhtudel on taastaimestumine olnud looduslik, kusjuures väga oluline osa on veerežiimil. Optimaalseks võib pidada püsivalt kõrget (0,2–0,5 m maapinnast allpool) veetaset. Aladel, kus see oli sügavamal (kuni 1,1 m), olid taimestiku taastekkeks ebasoodsad tingimused ning need alad on kaetud ainult hõreda (15–20%) taimestikuga. Uute

toitumis- ja keskkonnatingimuste tõttu ilmusid uued samblaliigid: *Polia elongata*, *Ephemerum serratum*, *Campylopys introflexus*, *Bryum oblongum*.

Käesolevas doktoritöös kombineeriti kompleksseid meetodeid, et selgitada üsna keerukat Eesti turbalasundite ehitust, turba omadusi, temas leiduvate kahjulike elementide sisaldust ning turba orgaanilise osa keemilist koostist mõjutavaid tegureid. Rohkete väli- ja laboratoorsete uuringute analüüsi põhjal selgus, et turba omadused sõltuvad kõige enam toitumistingimustest.

Antud doktoritöö tulemused on juba leidnud kasutamist. Näiteks tüüpsoode (539) alusel koostati keskkonnaregistri turbamaardlate nimistu, kuhu neist on kantud 279. Tüüpsoode andmestikku kasutatakse ka Keskkonnaministeeriumis turbaalade kasutamise ja kaitse kontseptsiooni väljatöötamisel. Veelgi enam, turbateaduse edasiarendamiseks võiks rohkemgi kasutada Eesti soode inventuuri käigus kogutud ja koostatud käsikirjalist andmebaasi, mida säilitatakse Eesti Geoloogiakeskuse geoloogiafondis. Andmebaasis on näiteks üle 33 000 turba liigilise koostise määrangu Preboreaalist tänapäevani, mis sisaldab hinnalist teavet pärastjääaegse kliima ja inimese mõjust loodusele viimastel aastasadel.



## **CURRICULUM VITAE**

### **1. Personal data**

Name: Mall Orru  
Date and place of birth: 28<sup>th</sup> of February 1943, Viljandi County, Karksi municipality, Estonia  
Citizenship: Estonian

### **2. Contact information**

Address: Järveotsa tee 9-40, Tallinn, 13520, Estonia  
Phone: +372 520 4956  
E-mail: orru@egk.ee

### **3. Education**

2009–2010 Power Engineering and Geotechnology, PhD studies, Tallinn University of Technology  
1985–1989 Estonian Academy of Science (postgraduate courses)  
1963–1968 University of Tartu, chair of geology (geological mapping and exploration for mineral resources)  
1954–1961 Nuia Secondary school  
1950–1954 Saaretsi Primary school

### **4. Language skills**

English: good in spoken and written  
Russian: fluent in spoken and written  
Finnish: moderate in spoken and written  
Germany: moderate in spoken and reading

### **5. Special Courses**

1992, 1995 Special courses of peat investigations in the Geological Survey of Finland and Sweden  
1994–1996 Manager of the BITS programme (peat investigations collaboration between Estonian and Swedish Geological Surveys)  
1997 Environmental Impact Assessment course (Emi-Eco)  
2001 Special courses of peat studies and production (Irish Peat Society and Bond na Mona)  
2002 Special courses in Austria, Bad Wimsbach, Neithardynng Peat Balneological Centre  
2008 Special courses in Dneprovetrovsk University of Life Sciences, Ukraine about humic substances in peat  
2009 Environmental impact assessment course (Tallinn Technical University); licence no. KMH 0125, valid until 3<sup>rd</sup> August 2013

## **6. Professional employment**

- |      |                                                                                      |
|------|--------------------------------------------------------------------------------------|
| 1968 | Until presently employed at the Geological Survey of Estonia (EGK), senior geologist |
| 2010 | Tallinn University of Technology, Department of Mining, Assistant                    |

## **7. Investigation and scientific experience**

She has investigated the reserves of oil shale, phosphorite, and peat. In 1972–1992 she was responsible for the revision of Estonian peatlands

Current fields of activities: trace element in peat, sustainable use and protection of peatlands, hydrogeology, and hydrology of mires, balneological studies of peat

## **8. Administrative responsibilities**

Estonian Peat Society – member of Managing Board

Geological Society of Estonia – member

International Peat Society (IPS) – head of Peat Working Group, member of IPS Commission IV (physical and chemical properties of peat), vice-chairman of IPS Commission VI (peat balneology)

## **9. Honours and awards**

- |            |                                                                                                                        |
|------------|------------------------------------------------------------------------------------------------------------------------|
| 1986       | Medal “For Bravery at Work”                                                                                            |
| 1994       | Farve Ltd scholarship                                                                                                  |
| 1996       | Grants by Phare and Eesti Energiaamet                                                                                  |
| 1996       | Peat Association of Germany scholarship                                                                                |
| 2000       | Canadian Peat Association scholarship                                                                                  |
| 2000       | II price on the congress “Peat in Horticulture. Quality and Environment Challenges”, International Peat Society, Pärnu |
| 2004, 2008 | Estonian Peat Association scholarships                                                                                 |
| 2009       | Kristjan Jaak scholarship                                                                                              |
| 2010       | Archimedes scholarship                                                                                                 |

## **10. Defended theses**

- |      |                                                                                    |
|------|------------------------------------------------------------------------------------|
| 1992 | M. Sc., University of Tartu, Landscape dissection and protection of Estonian mires |
|------|------------------------------------------------------------------------------------|

## **11. Main publications**

- |      |                                                           |
|------|-----------------------------------------------------------|
| 1992 | Monograph “Estonian Peat Reserves” (main author)          |
| 1993 | “Estonian Mires” (map at scale 1:400 000, with Regio Ltd) |
| 1995 | Handbook “Estonian Mires” (author)                        |
| 1996 | Monograph “Global Peat Resources” (co-author)             |
| 1998 | Book “Geoecology of Estonian Mires” (co-author)           |
| 2003 | Book “Trace elements in Estonian Peat” (main author)      |
- Papers in international conferences, meetings and scientific journals

## **ELULOOKIRJELDUS**

### **1. Isikuandmed**

Ees- ja Mall Orru  
perekonnanimi:  
Sünniaeg ja 28. veebruar 1943, Viljandimaa, Karksi vald, Eesti  
-koht:  
Kodakondsus: Eestlane

### **2. Kontaktandmed**

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### **3. Haridus**

2009–2010 Tallinna Tehnikaülikool, Energia- ja geotehnika doktoriõpe  
1985–1989 Teaduste Akadeemia aspirantuur  
1963–1968 Tartu Ülikool, geoloogiainseneri diplom geoloogilise  
kaardistamise ja maavarade otsingu erialal  
1954–1961 Nuija Keskkool  
1950–1954 Saaretsi Algkool

### **4. Keelteoskus**

English: kesktasemel  
Russian: kõrgtasemel  
Finnish: kesktasemel  
Germany: algtasemel

### **5. Täiendusõpe**

1992, 1995 Turbaalane täiendusõpe Soome ja Rootsi Geoloogiakeskuses  
1994–1996 Eesti ja Rootsi Geoloogiakeskuste koostöö programmi BITS  
koordinaator  
1997 Keskkonnamõju hindamise koolitus (Arenguprogrammide keskus  
Emi-Eco)  
2001 Soode ja turbaalane täiendusõpe Iirimaa (Iiri Sooselts ja AS Bord  
na Mona juhendamisel)  
2002 Raviturba alane täiendusõpe Austrias, Bad Wimsbach  
Neithardynge balneoloogiakeskuses  
2008 Humiinainete alane koolitus Ukrainas, Dnepropetrovski  
Põllumajandusülikoolis  
2009 Keskkonnamõju hindamise koolitus (TTÜ keskkonnatehnika  
instituut); litsents nr KMH 0125, kehtib kuni 04.06.2013.

## **6. Teenistuskäik**

1968 kuni käesoleva ajani vanemgeoloog, Eesti Geoloogiakeskus  
2010 assistent, Tallinna Tehnikaülikool, Energeetikateaduskond, mäeinstituut, rakendusgeoloogia õppetool

## **7. Uurimissuunad**

Turba genees ja omadused, maavarade geoloogia ja rakendus, kahjulike elementide sisaldus turbas ning turbaalade jätkusuutlik kasutamine ja kaitse. Soode hüdrogeoloogia ja hüdroloogia, turba balneoloogia, keskkonnamõju hindamised

## **8. Teadus- ja organisatsiooniline tegevus**

Eesti Geoloogia Seltsi liige  
Eesti Turbaliidu juhatuse liige  
Rahvusvahelise Turbaühingu (IPS) turbageoloogia töögrupi koordinaator, IPS IV komisjoni (turba füüsilised ja keemilised omadused) liige, IPS VI komisjoni (turba balneoloogia) asejuhataja

## **9. Tunnustused**

1986 autasustatud medaliga "Töövapruse eest"  
1994 AS Farve stipendium  
1996 Phare ja Eesti Energiaameti stipendium  
1996 Saksa Turbaliidu stipendium  
2000 Kanada Turbaliidu stipendium  
2000 II preemia konverentsil „Peat in Horticulture. Quality and Environmental Challenges”, International Peat Society, Pärnu  
2004, 2008 Eesti Turbaliidu stipendium  
2009 Kristjan Jaagu stipendium  
2010 Archimedese stipendium

## **10. Kaitstud tööd**

1992 M. Sc., Tartu Ülikool, "Landscape dissection and protection of Estonian mires"

## **11. Tähtsamad publikatsioonid**

1992 Monograafia "Eesti turbavarud" esimene autor  
1993 Kaardi „Eesti sood (1:400 000)“ koostajaid  
1995 Teatmiku "Eesti turbasood" autor  
1996 Kogumiku "Global Peat Resources" autoreid  
1998 Raamatu "Eesti soode geoökoloogia" autoreid  
2003 Raamatu "Kahjulikud elemendid Eesti turbas" esimene autor  
Artiklid rahvusvahelistel konverentsidel, kohtumistel ja teadusajakirjades

## PAPER I

Orru, M. 1997. Peat. In *Geology and Mineral Resources of Estonia* (Raukas, A. & Teedumäe, A., eds), pp. 337–346. Estonian Academy Publishers, Tallinn.



## PEAT

A mire is part of the landscape where owing to permanent abundance of water and deficiency of oxygen some of organic matter remains decomposed and is deposited as peat. Peat is a fibrous substance, produced by the decay of vegetation in mires and it contains a high proportion of water (80...94%). Peat consists of oxygen, carbon and hydrogen; it also contains nitrogen, phosphorus and non-burning substances (Table 59).

**Table 59. Characteristics of Estonian natural peat (Orru 1995, manuscript report)**

	Deposit		
	Möllatsi	Keressaare	Laukasoo
C, %	52.4	52.9	58.6
H, %	5.7	6.8	6.9
N, %	2.7	1.0	2.2
S, %	0.27	0.13	0.22
Ash content, %	9.5	3.9	5.6
Calorific value (MJ/kg) at 50% moisture content	7.5	8.0	9.2

The composition and characteristics of peat depend on the conditions under which it was formed (nutrition of soil by groundwater, precipitation, or both), and on the location of the deposit in the landscape (lowland, hollow, river valley, etc.).

In comparison with the fuel peats of Ireland which belong to those most intensively studied in the world, Estonian peats have a higher ash content (Table 60). They also contain a lot of stumps (Photo 65), while the peats of Ireland have almost none. The fuel peats are represented mainly by grass peat in Ireland and wood-grass peat in Estonia.

**Table 60. Fuel peat characteristics (Orru 1995, manuscript report)**

	Estonia	Ireland
C, %	53.5	57.5
H, %	6.2	5.5
N, %	2.4	1.5
S, %	0.23	0.3
Ash content, %	8.0	1.5
Degree of humification	H <sub>4</sub> -H <sub>5</sub>	H <sub>3.5</sub> -H <sub>4.5</sub>
Temperature of ash deformation	1100°C	1100°C
Calorific value, MJ/kg	7.8	7.7

According to E. Lappalainen, *Sphagnum* and *Hypnum* are the main peat-forming species in Finland, but also sedge, cotton-grass and wood peats occur. In raised bogs, *Sphagnum* peat with a degree of humification H<sub>3.5</sub> - H<sub>4.5</sub> and the ash content 1-3%, forms up to 70% of peat deposits in Finland; in fens, sedge peat is most widespread. The fens of Estonia contain besides sedge also reed and wood peats. The peat deposits of Estonian raised bogs are prevailed by poorly-humified

moss peat, well-humified peat being of a rather limited distribution. In Finland and Belarus, well-humified *Sphagnum* and pine-cotton-grass peat are most common.

Peat is used for making fuel briquettes, for soil improvement and as a substrate in horticulture. Potential fields of peat application are much more numerous (Fig. 221). In Estonia, peat has been used as fuel since long. From the beginning of the 19th century, it has also been used as litter. The very first peat industry was established at Ülemiste in 1913. However, about organized peat production one can talk not until 1919, when several peat societies were founded (Luha 1946). In the pre-war Estonia, there were two peat fuel based power stations - Ellamaa (1923-66) and Ulila (1923-55). The first peat briquette producing plant was put into operation at Tootsi in 1938, afterwards also at Oru (1964) and Sangla (1976).

Until the 1970s, during the years under Soviet occupation, 60% of the peat produced was used as litter for livestock and 40% as fuel. Of ca. two million tonnes produced annually in later years, some 10% was used as a substrate in horticulture and as a fertilizer.

Estonia is considered as a country richest (Fig. 222) in peatlands in North Europe. The total area, occupied by 9836 mires, covers one million hectares. Of 1626 peat deposits of commercial interest (ca. 0.9 million hectares), 520 are large mires with a thick layer of peat which are of major significance in a number of respects, including commercial and agricultural use, and nature conservation. The remaining 1106 peat deposits are mostly fens with a thin layer of peat. Peat deposits with an area of more than 10 ha and the thickness of peat layer over 0.9 m belong to the deposits of commercial importance (Orru 1995). The average thickness of the peat layer in Estonian mires is 3-4 metres.

Formation of mires started after the territory of Estonia was freed of the ice cover, first in Upper and later in Lower Estonia. Through the whole postglacial period, climatic conditions have favoured the rise and development of mires. In Estonia, mires formed mostly as a result of paludification of mineral soils or filling up of shallow bodies of water. On the basis of the origin and peat-forming species, mires are classified as fens and raised bogs with a transitional mire between them. A fen forms in a low-lying area where the soil is rich in nutrients, provided by groundwater, and a luxuriant carpet of



Photo 65. Estonian peat often contains stumps. Stump piles in the Imsi bog. Photo by M. Orru.

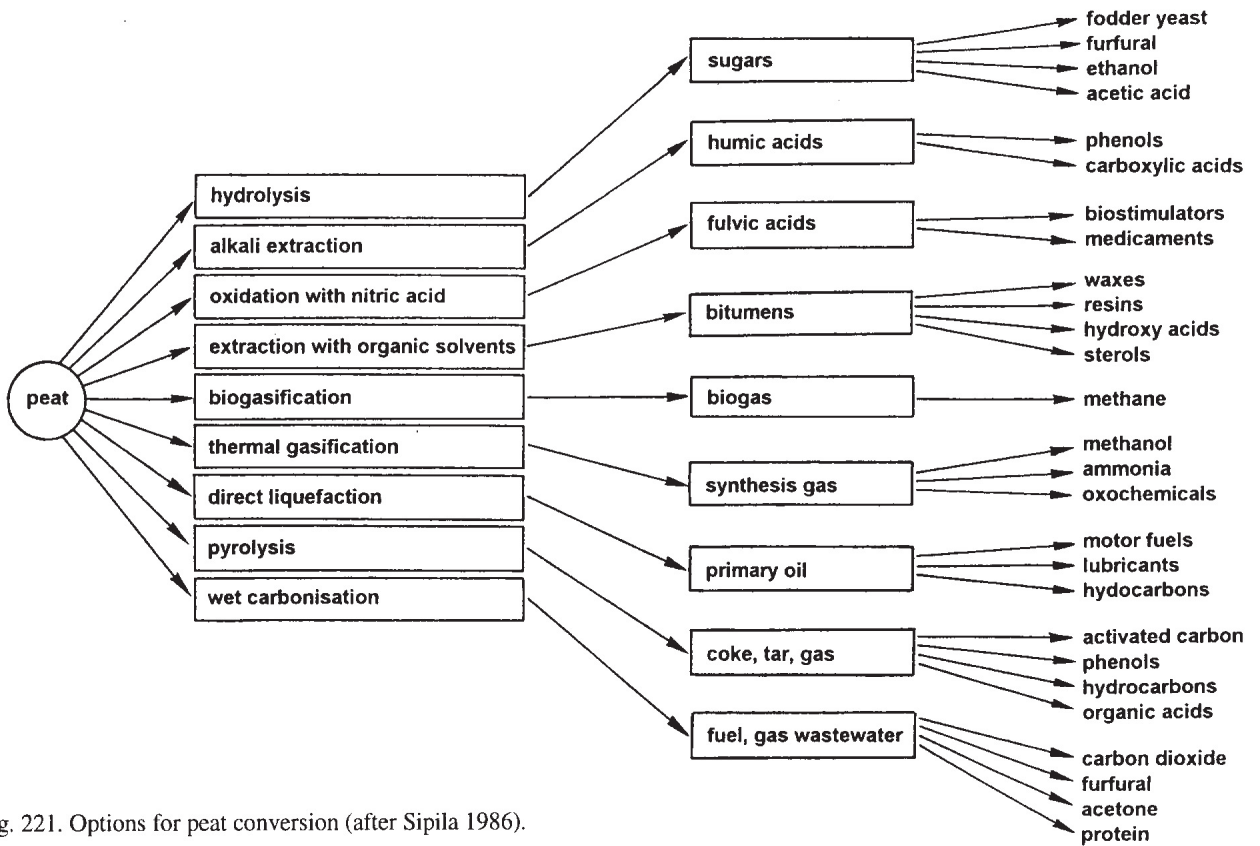


Fig. 221. Options for peat conversion (after Sipila 1986).

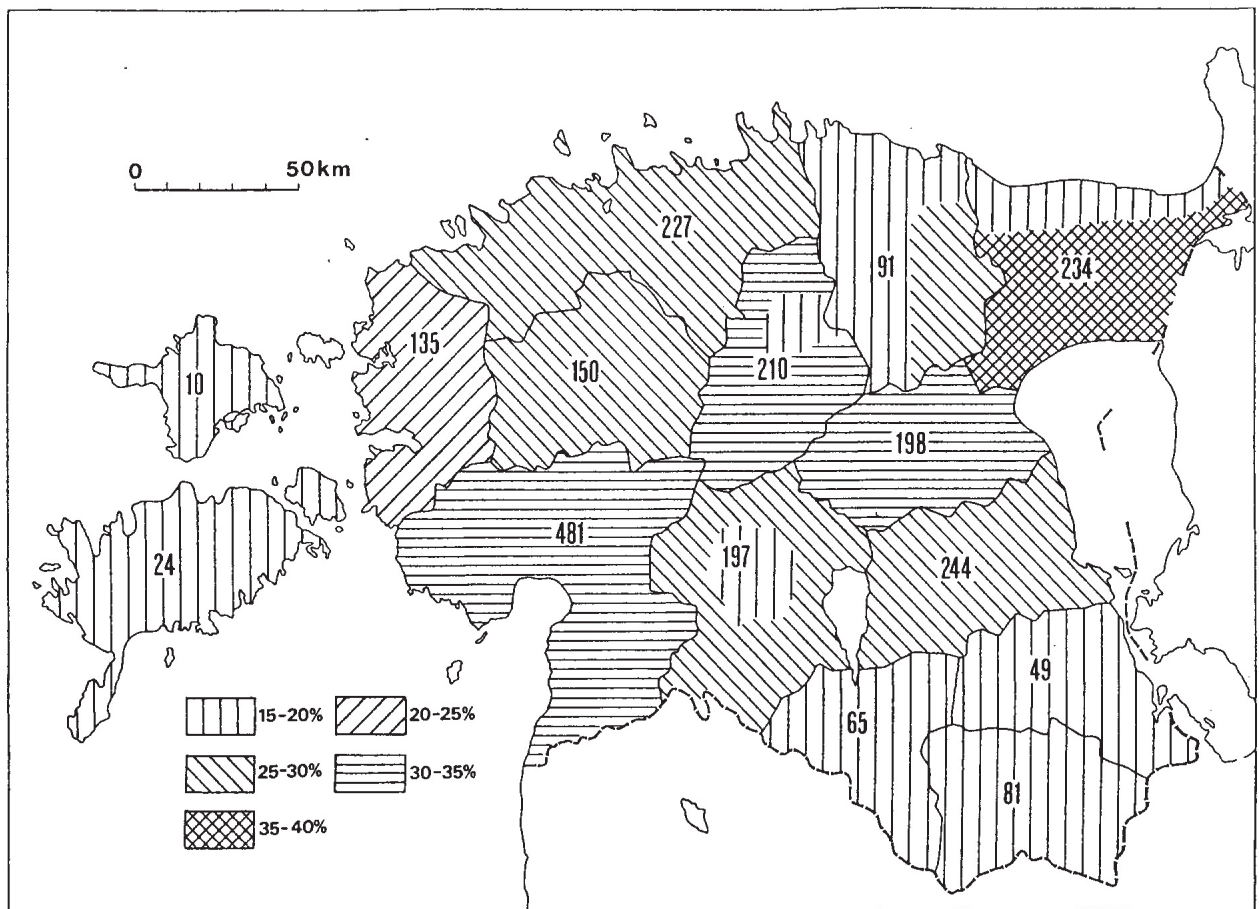


Fig. 222. Paludification (%) and the total amount of peat resources (million tonnes at 40% moisture content) in Estonia by counties (after Orru 1996).



numerous species of hydrophilous plants grows on it. The main peat-forming plants are sedges, reed, horsetails, mosses and several species of trees. The ash content of eutrophic peat is high. A raised bog's only supplementary source of minerals is precipitation, the nutrition provided by this kind of "air-lift" is inevitably rather meagre and all plants growing in bogs have to cope with a substrate that is extremely poor in nitrogen and lime. Peat mosses flourish under such conditions and provide the major ingredient for peat. To a lesser extent, there occur horsetail, *Scheizeria* and pine. The ash content of ombrotrophic peat is low. A transitional bog is fed by groundwater and precipitation, and promotes the development of both fen and raised bog plants. It also provides favourable habitats for cranberries.

The study of mires goes back to the 19th century. The first studies (Bode 1836, 1837) dealt mostly with the mire vegetation. In 1910, an experimental station was founded at Tooma with an aim of studying the prospectives of mire usage for agricultural purposes. Vellner (1922) published the data and maps on 517 largest mires in Estonia. The later studies dealt with peat increment, palynology, vegetation, hydrology, genesis and ecology of mires (Thomson 1933, Allikvee & Masing 1988, Masing 1988b, Ilomets 1995a). More detailed data on the distribution, area, thickness, characteristics and reserves of peat deposits are available mainly in manuscript exploration reports and, in generalised form, also in several publications (Raudsepp 1946, Трундр 1961, Valk 1988, Orru 1992, Eesti sood 1993, Orru 1995).

## PEAT DISTRICTS

A peatland is a multi-faceted and developing landscape phenomenon. Peatlands are classified on the basis of a variety of features, such as stratigraphical, geobotanical, the composition of peat layers, genesis, etc. The Estonian peatlands are divided into 20 districts (Orru 1992, Fig. 223).

### 1. North-Estonian Coastal Lowland

The district contains transitional mires, mixed and raised bogs with only a thin layer of peat. The eutrophic and mesotrophic deposit consists of well-humified (up to 50%) wood and reed peats, with the moisture content 78-84%, ash content 12-25% and a slightly acid reaction (pH 3-6). The mixed deposit is well humified (up to 40%). The moisture content is 88-92% and the concentration of minerals is low (ash content 1-2%). A somewhat higher mineral matter concentration (2%) in the upper part of the deposit is evidently due to the admixture of dust originating from the Kunda Cement Works. The ombrotrophic peat deposit consists prevalingly of poorly or moderately (8-28%) humified wood-*Sphagnum* and *Sphag-*

*num* peats with acid reaction (pH 3-4). The moisture content is constantly 90-91% throughout the deposit, the average ash content is 1%.

### 2. North-West Estonian Plateau

The eutrophic and mesotrophic peat in the district is made up of well-humified (38-40%) wood peat, rather low in moisture (80-88%), high in minerals (ash content up to 25%) and slightly acid (pH 5.5-6). The mixed and ombrotrophic deposit consists of medium- to well-humified *Fuscum* peat with a stable moisture content (93-94%) and high concentration of minerals (ash content up to 15%). Both the mixed and ombrotrophic peats are well humified - 28 and 40%, respectively.

Viru, Rae, Pääsküla, Valdeku, Ellamaa, Valgjärve, Kadasoo and Hagudi are the most characteristic mires in the area (Figs. 224, 225).

### 3. North-East Estonian Plateau

On the North-East Estonian Plateau, larger peat deposits occur only in the areas where the runoff on the flat terrain is obstructed, for instance, by kame fields. The eutrophic and mesotrophic deposit consists of well-humified (40-45%) wood-reed peat, in which the moisture content is low (72-85%), the concentration of minerals is high (ash content 10-24%) and the reaction is slightly acid (pH 5-6). The mixed deposit is rather thin (0.7-0.8 m), formed of well-humified (up to 40%) wood-*Sphagnum* peat, changeable in moisture content (72-88%). The concentration of minerals (ash content) is 2-10%, and the reaction is acid. Oligotrophic peat forms the major part of the area's peat reserves. The lower part of the deposit consists of moderately (25%) and the upper part of poorly (10%) humified moss peat. The moisture content of ombrotrophic peat is 90-92%, the ash content averages 2% and the pH value is around 3.

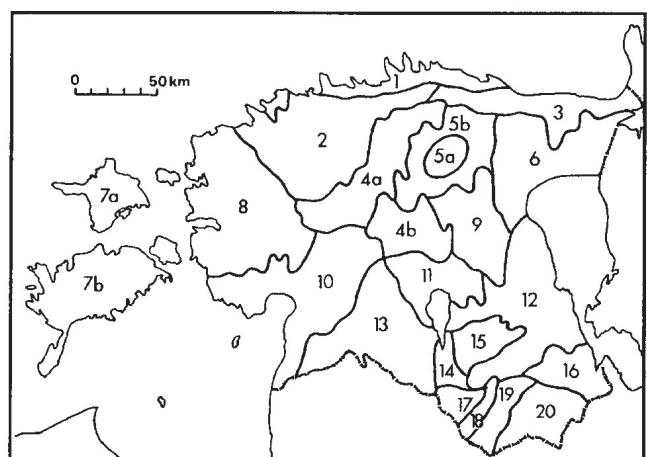
Rannu, Kõrgesoo, Uljaste, Hiie, Peeri, Kure, Voorepere, Kunda, Varuli and Laukasoo are the major mires in the area under consideration (Fig.224).

### 4. Kõrvemaa

The **Kõrvemaa watershed area** is a region of large mires, including Kastna, Mukre, Palasi, Selja and Nõlvasoo, where the thickness of the layer of peat reaches 5.0-5.5 m (Figs. 223, 224).

The eutrophic and mesotrophic deposit consists of a thin

Fig. 223. Estonian peat districts: 1 - North-Estonian Coastal Lowland; 2 - North-West Estonian Plateau; 3 - North-East Estonian Plateau; 4 - Kõrvemaa (4a - watershed area, 4b - upper course of the Pärnu River); 5 - Pandivere Upland (5a - central part, 5b - slopes); 6 - Alutaguse; 7 - West-Estonian Archipelago (7a - Hiiumaa, 7b - Saaremaa); 8 - West-Estonian Lowland; 9 - Vooremaa; 10 - Pärnu Lowland; 11 - Võrtsjärv Lowland; 12 - South-East Estonian Plateau; 13 - Sakala Upland; 14 - Väike-Emajõgi Valley; 15 - Otepää Heights; 16 - Palumaa; 17 - Valga Lowland; 18 - Karula Upland; 19 - Võru-Hargla Depression; 20 - Haanja Heights.



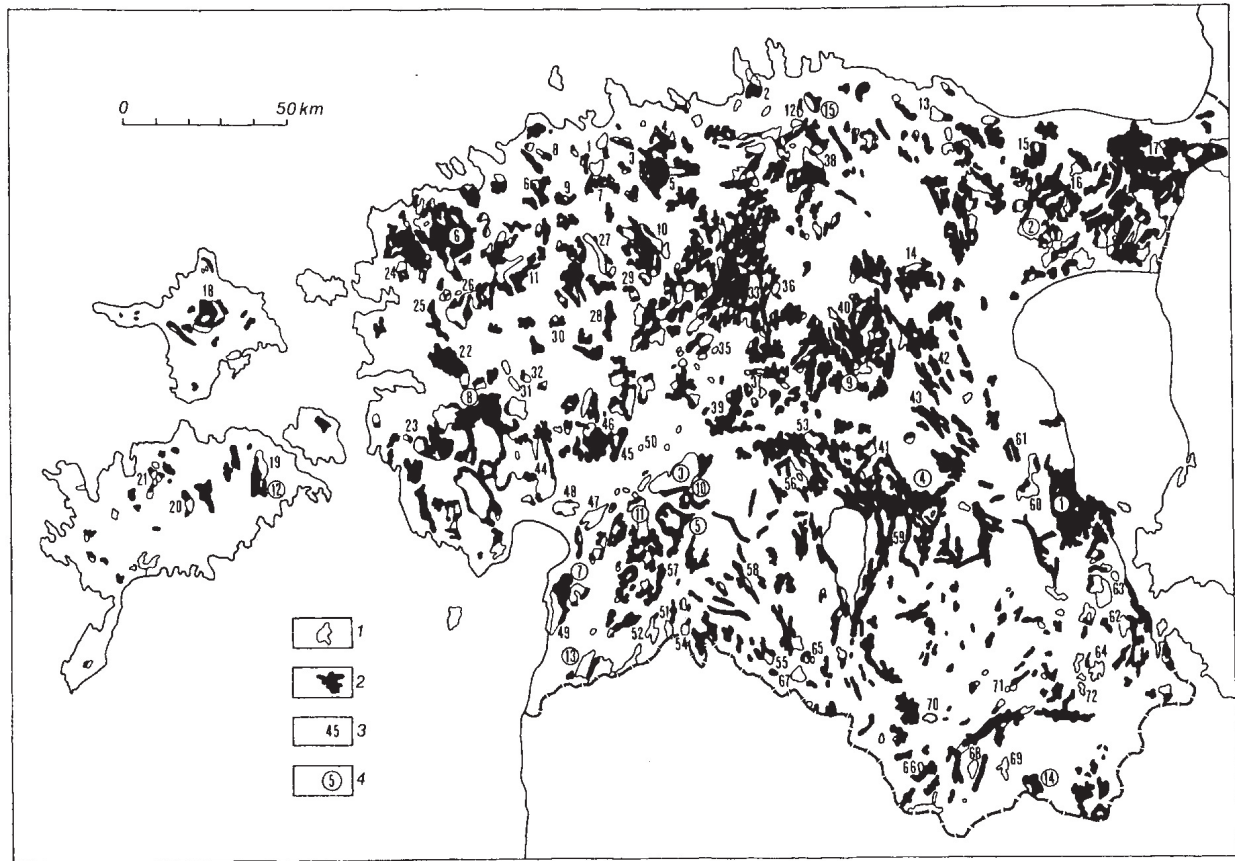


Fig. 224. Estonian peat deposits: 1 - fen, 2 - raised bog, 3 - number of the peat deposit in use; 4 - number of the protected mire. Peat deposits in use: 1 - Pääsküla; 2 - Hara; 3 - Rae; 4 - Kostivere; 5 - Peningi; 6 - Ohtu; 7 - Sausti; 8 - Väana; 9 - Ääsmäe; 10 - Mahtra; 11 - Ellamaa; 12 - Uuemõisa; 13 - Varudi; 14 - Peetla; 15 - Hiiesoo; 16 - Peeri; 17 - Puhatu; 18 - Pihla; 19 - Koigi; 20 - Piila; 21 - Pelisoo; 22 - Laiküla; 23 - Kõverdama; 24 - Niibi; 25 - Turvalepa; 26 - Ömma; 27 - Hagudi; 28 - Keava; 29 - Hõreda; 30 - Orgita; 31 - Tõnumaa; 32 - Päärdu; 33 - Epu-Kakerdi; 34 - Retla; 35 - Lokuta; 36 - Tondissaare; 37 - Epa-Vassaare; 38 - Ohepalu; 39 - Kallissaare; 40 - Endla; 41 - Umbusi; 42 - Kivijärve; 43 - Visusti; 44 - Lavassaare; 45 - Mõrdama; 46 - Pööravere; 47 - Kõrsa; 48 - Rääma; 49 - Tolkuse; 50 - Kavasoo; 51 - Viirasoo; 52 - Möksi; 53 - Soosaare; 54 - Pätsi; 55 - Ikepera; 56 - Parika; 57 - Napsi; 58 - Öisu; 59 - Sangla; 60 - Laukasoo; 61 - Keressaare; 62 - Tuurapera; 63 - Meelva; 64 - Meenikunno; 65 - Helme; 66 - Kantsi; 67 - Lagesoo; 68 - Roosa; 69 - Põdrasoo; 70 - Kungjärve; 71 - Kurgsoo; 72 - Pindi. Main protected mires: 1 - Emajõe-Suursoo; 2 - Muraka; 3 - Kuresoo; 4 - Emajõe-Pedja; 5 - Ördi; 6 - Suursoo; 7 - Tolkuse; 8 - Avaste; 9 - Endla; 10 - Valgaraba; 11 - Kikepera; 12 - Koigi; 13 - Nigula; 14 - Kellamäe (Vanamõisa), 15 - Laukasoo.

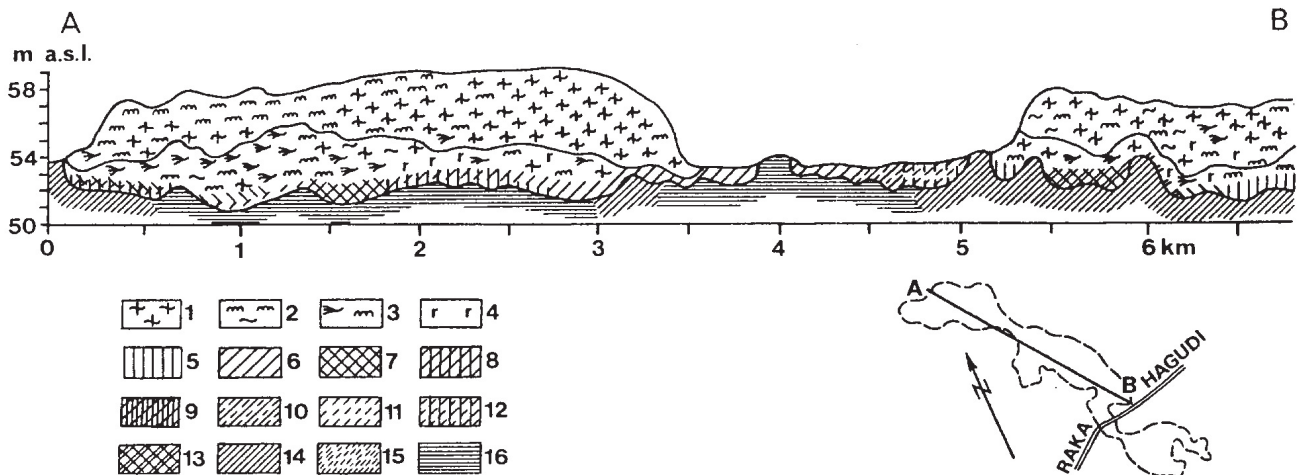


Fig. 225. Peat types profile of the Hagudi Mire, Rapla County: 1 - *Fuscum* peat; 2 - complex peat; 3 - cotton-grass - *Sphagnum* peat; 4 - heath peat; 5 - fen wood peat; 6 - fen sedge peat; 7 - transitional sedge peat; 8 - fen reed-sedge peat; 9 - fen wood-reed-sedge peat; 10 - fen sedge-*Hypnum* peat; 11 - fen *Hypnum* peat; 12 - fen wood-*Hypnum* peat; 13 - transitional grass peat; 14 - loam; 15 - sandy loam; 16 - clay.

(0.4-0.5 m) well-humified (40-45%) wood peat layer. Its moisture content reaches 80%, the content of minerals (ash content) is 3-14% and the pH value is 4-5. The layer of mixed peat is thin (0.7-0.8 m) and of limited distribution. Its moisture content averages 90%, the ash content is 1-4%, and the pH value is commonly 3. Ombrotrophic peat dominates forming some 80% of the deposits in most of the mires. It consists of poorly humified (11-15%) cotton-grass - *Sphagnum* and *Sphagnum* peats. The moisture content (90-92%), ash content (1-4%) and the pH value (3-4) are constant throughout the deposit and the district.

The area on **the upper course of the Pärnu River** (Fig. 223) holds the lands of the western and southwestern parts of the Järva County and the southeastern part of the Rapla County. In the region, raised bogs and ombrotrophic peat deposits cover about one third of the total area occupied by mires and peat deposits. In places, ombrotrophic peat forms the entire thickness of the deposit. Eutrophic and mesotrophic, mainly wood and wood-reed peats, form only a small part (0.5-0.6 m) of the deposit. The moisture content is 85-90%, the content of minerals is 3.5-11% and the reaction is acid (pH - 5). Mixed peat forms a thin (0.6-0.7 m) layer, which consists of medium- to well-humified wood-*Sphagnum* peat. The degree of humification fluctuates within a wide range (20-40%), while the moisture content is stable enough (88-92%), the ash content is low (1-1.5%) and the reaction is acid (pH 1.5-3).

Rumbi, Idva, Retla, Kallissaare - Lubjaahju, Nõmme, Matussaare and Laugasoo are the most typical mires in the area (Fig. 224).

### 5. Pandivere Upland

In the **central part of the Pandivere Upland** the ground-water table is deep below the ground, and the surface water percolates directly into the fissured and karsted bedrock. The hydrographic network is poorly developed and the number of peatlands is small. The largest, Savalduma Mire is situated in the vicinity of the Savalduma Karst Field. The other mires are concentrated in the area of the Neeruti eskers and the Loobu River. The eutrophic and mesotrophic deposit (0.9-1.2m) is represented by well-humified wood and wood-sedge peats. The deposit has a low moisture content (80-85%), the ash content is 1.5-1.7% and the reaction is acid (pH 4-5). Mixed and ombrotrophic peats are not so widespread as eutrophic and mesotrophic peats, because the majority of mires have not yet reached the raised bog stage. Only in larger mires the poorly humified *Sphagnum* peats form up to half of the deposit's thickness. The moisture content is 90% throughout the deposit, the ash content is 1.5-4% and the pH value is 3-4.

The **slopes of the Pandivere Upland** hold the lands of the central and eastern parts of the Järva County and the central part of the Lääne-Viru County. The area abounds in large mires. On the slopes of the upland, the water appears at the surface in the form of springs supporting the development of fens. The fens in small depressions, which have already reached the raised bog stage, have merged to form spacious mosaic mire systems. Epu-Kakerdi, Mahtra, Juuru, Viirika, Pakasjärve, Vistjärve-Jalametsa, Peetla, Punasoo, Sämi, Kabala, Tudu, Saara, Neeva-Prandi and Kallissaare-Lubjaahju are the most typical representatives of such fens (Fig.224).

The deposit of eutrophic and mesotrophic peat (1.2-1.4 m) consists mainly of medium-humified sedge and reed-sedge peats. The moisture content is constantly around 90%, the ash content is 4-12% and the pH value is 4-5. Mixed and ombrotrophic peats account for about two thirds of the total thickness of the deposit. They are made up of poorly decomposed (15-30%) cotton-grass and moss peats. The moisture content is constantly around 92%, the content of mineral substances is low (ash content 1.5-6%), the reaction is strongly acid (pH 2-3).

### 6. Alutaguse

The Alutaguse District extends over the northern part of L. Peipsi depression, the evolution of which was highly controlled by proglacial lakes located in this area. In the northern part of the area, which was freed from the waters of the ice-dammed lake rather rapidly, the bottom relief of the peat deposits is undulating and generally follows the bedrock topography. Puhatu (57,000 ha), the largest mire system in Estonia, and the Sirtsu (4680 ha) and Muraka (12,790 ha) mires are situated in the northern and eastern parts of the area. As to the percentage of land covered by mires (50%), the Alutaguse peat district ranks first in Estonia (Figs. 222, 223). The central and southern parts of the area are featured by eskers, kames and numerous old beach ridges of L. Peipsi, now covered with dunes. In places, the long esker ridges are jutting out into the raised bogs as long peninsulas of mineral soils. Fens and transitional mires occur on the fringe of the esker chains. Small mires where ombrotrophic peat forms the whole thickness of the deposit, are numerous in the area of dunes.

Eutrophic peat consists of poorly humified (30-31%) sedge and reed-sedge peat with the moisture content of 88-93%. Like in all eutrophic deposits, the ash content varies within a wide range (5-12%), the reaction is acid (pH 4-5). Mesotrophic peat forms thin (0.3-0.4 m) layers of limited distribution. The degree of humification is 30-35%, the moisture content is 90% and the reaction is acid (pH 4). The mixed and ombrotrophic deposits consist of cotton-grass - *Sphagnum* and *Sphagnum* peat layers. The degree of humification is 10-25%, the moisture content 90-93% and the reaction is more acid (pH about 3) than in the above-described deposits.

### 7. West-Estonian Archipelago

The eutrophic and mesotrophic deposits consist mostly of well-humified (35-50%) reed and wood-reed peats and, to a lesser extent, also of less-humified reed - *Sphagnum-Scheizeria* peats. The thickness of the peat deposit is 1.2-1.5 m, the moisture content 85%, the ash content 8-16%, and the pH value 4.5-5.5. Mixed and ombrotrophic peats in the uppermost part of the deposit are represented by poorly-humified (16%) *Fuscum* peat which in the lower part of the deposit is substituted by moderately (20-35%) to well (50%) decomposed mesotrophic wood peat. Throughout the deposit, the average degree of humification is 20-35%, the moisture content 90% and the ash content 2.5-2.6%. The ash content in ombrotrophic peat is higher than the average (1-2%).

Pihla, Määvli and Öngu are the largest mires in Hiiumaa, and Koigi, Piila and Pelisoo in Saaremaa (Fig. 224).

### 8. West-Estonian Lowland

The eutrophic and mesotrophic peats of the West-Estonian Lowland belong to the swamp and forest-swamp subtype. The thickness of eutrophic peat ranges from 2.5-3.0 m. Mesotrophic peat is either absent or forms a very thin (0.3-0.4 m) layer. Generally, the deposits consist of moderately- to well-humified (occasionally up to 40%) sedge, reed-sedge, sedge-*Sphagnum* and sedge-*Hypnum* peats. The degree of humification varies in a wide range throughout the deposit. As an average, the moisture content is 88%, the ash content is 5-8%, reaching 13-22% only in the bottommost layers. The reaction is slightly acid (pH about 5).

The mixed peat deposit in the mires of the West-Estonian Lowland belongs mostly to the swamp subtype and is variegated in structure. Peat of bog hollows and *Fuscum* peat make up most of the ombrotrophic deposit. The mesotrophic deposit consists mostly of *Sphagnum* and sedge-*Sphagnum* peats and occurs as a thin (up to 0.5 m) layer under the ombrotrophic deposit, or extends as far as the mineral land. The mixed deposit has an average moisture content 92-93%, it contains 6% mineral substances and has an acid reaction (pH 3-4).

The ombrotrophic deposit usually occurs in large mires - Marimetsa, Niibi, Mustjärv, Palivere (Fig.224) and consists mainly of *Fuscum* peat. In some places, the ombrotrophic peat is underlain by a thin (0.5-0.6 m) layer of mesotrophic peat, dominated by *Sphagnum* and heath-*Sphagnum* peats. Eutrophic peat, forming the lowermost part of the section, consists of sedge, wood-sedge and wood peats. The ombrotrophic deposit, as a whole, is characterised by an evenly high moisture content (up to 96%), the content of mineral substances is 2-3% and the pH value is 3-3.5.

### 9. Vooremaa

In the Vooremaa district, the eutrophic and mesotrophic deposit consists of wood and wood-reed peats, the moisture content is 85-86%. The content of ash varies significantly (6-15%), evidently due to the surface water percolating from the slopes of drumlins into the mires. The eutrophic and me-

sotrophic deposit has an average thickness of 2.5 m. The degree of humification ranges from 28 to 40%, the pH value is 4.5-5.5. In the region under consideration, mixed deposit is rather widespread. The upper and central parts of the deposit consist prevalingly of poorly-humified *Fuscum* peat, the bottommost layers of poorly decomposed mesotrophic sedge-*Sphagnum* or sedge peats, to a lesser extent, also of eutrophic sedge peat. The content of moisture and ash, as well as the pH value of the mixed peat is much the same as in ombrotrophic peat.

Practically in all mires, the lowermost 3.5-3.8 metres of ombrotrophic peat consist of well-decomposed wood, often also of reed-*Hypnum* and *Hypnum* peats. The remaining part of the deposit is made up of poorly-humified (10-12%) moss peat (*Fuscum*, *Angustifolium*, *Medium* etc.). The moisture content of ombrotrophic peat is usually 90-92%, the ash content is around 3%. Eutrophic peat prevails throughout the Vooremaa area, however, the mixed deposit is also rather widespread.

### 10. Pärnu Lowland

The Pärnu Lowland is primarily a region of large mires (32 % of its area), which include Lavassaare, Nigula, Võlla, Tolkuse, Rääma, Kõrsa (Figs. 224, 226), Avaste and Mõrdama. Ombrotrophic peat, mostly poorly humified, makes up 72% of the whole peat deposit in the Pärnu Lowland. In fens the peat layer is thin, with a dissected contour and islands of mineral soils. The eutrophic and mesotrophic deposit consists for the most part of rather poorly humified (20-30%) reed-sedge and sedge peats. The moisture content (88-90%) is stable throughout the section. The content of mineral substances is rather low (ash content 5.5-8%), the pH value is in a range of 3.5-4.5. The mixed and ombrotrophic deposits have formed of medium- to poorly-decomposed pine-cotton - *Sphagnum* and moss peats (*Sphagnum*, *Fuscum*, *Medium*). The moisture content of the deposit is constantly 90-91%, the concentration of mineral substances 20% and the reaction is strongly acid (pH 2-3).

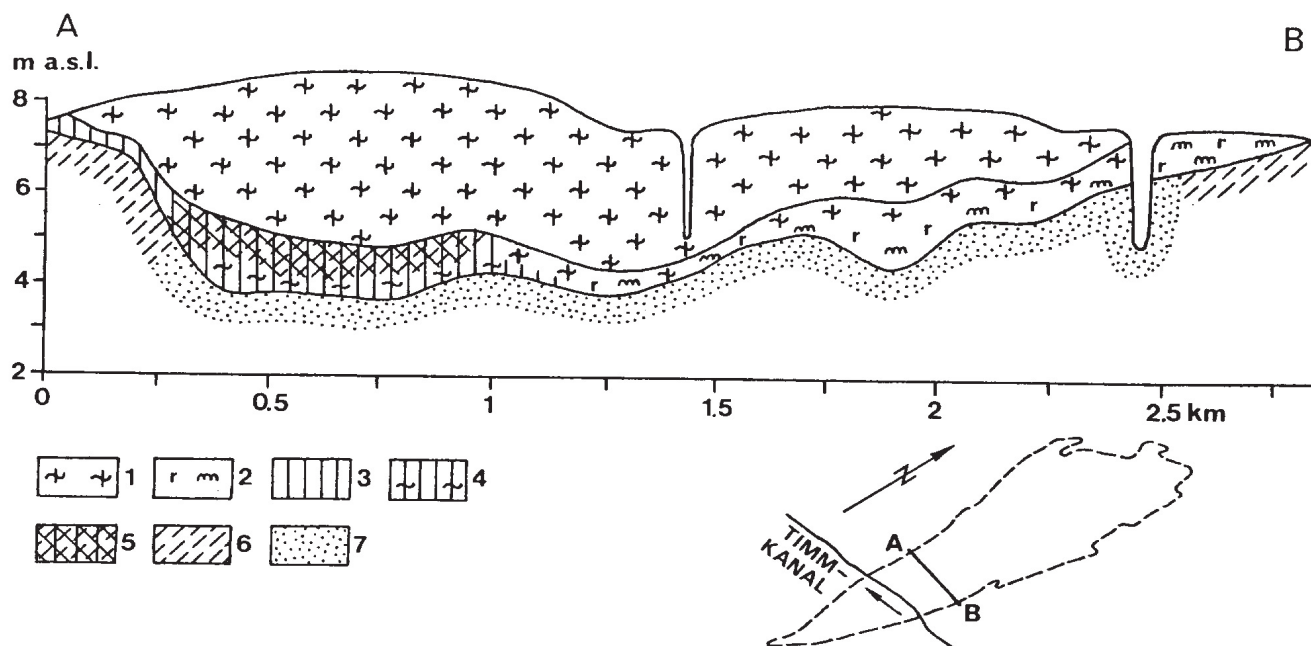


Fig. 226. Peat type profile of the Tolkuse Mire, Pärnu County: 1 - *Sphagnum-Fuscum* peat; 2 - heath-*Sphagnum* peat; 3 - fen wood peat; 4 - fen wood-*Sphagnum* peat; 5 - transitional wood-*Sphagnum* peat; 6 - loamy sand; 7 - sand.

### 11. Võrtsjärv Lowland

Mires cover some 30 per cent of the low-lying area around L. Võrtsjärv. The largest mires are Soosaare, Sangla, Parika, Umbusi and Kohvisoo (Fig. 224).

The upper layers of the eutrophic and mesotrophic deposit consist often of moderately humified heath-*Sphagnum* and wood-sedge peats, which are underlain by well-humified wood-reed and wood peats. The moisture content of eutrophic peat is rather high, reaching occasionally 90%. The ash content is generally 5.5-9.5%, but in the mires within river valleys it may even reach 21-22%. The pH value of eutrophic and mesotrophic deposits is 5-6.

In the Võrtsjärv Lowland, mixed peat is not so widely spread as ombrotrophic peat. The upper layers of the mixed deposit consist of moderately humified *Magellanicum* and pine-cotton peats underlain by well-humified wood-grass peat. The bottom layers of the deposit consist of moderately- to well-humified sedge peat. The moisture content of the whole deposit is ca 90%, the ash content is 1.5-4.5% and the pH value is about 3. The ombrotrophic deposit consists mostly of poorly humified *Fuscum* peat, followed by pine-cotton - *Sphagnum* peat. Ombrotrophic peat rests upon mesotrophic *Scheizeria*, grass-*Sphagnum*, sedge, wood-reed or *Hypnum* peat. The average moisture content of the ombrotrophic peat is 90%, the ash content is permanently 1.5-2.0% and the pH value is 3-3.5. In conclusion, it may be said that the ombrotrophic peat deposit in the Võrtsjärv Lowland is low in the moisture content and the proportion of the *Sphagnum* peats is high.

### 12. South-East Estonian Plateau

In this area, all larger valleys are occupied by mires, mostly fens like, for instance, Emajõgi-Suursoo. Raised bogs, including Laukasoo, Keressaare, Riitemetsa, and Essaksoo, have developed in the watershed areas dissected by valleys (Fig. 224). In raised bogs, the peat layer reaches 7.5 m in thickness.

Eutrophic peat, 1.9-2.7 m thick, varies in composition. In the Emajõgi-Suursoo mire it is represented by moderately humified swamp peat. In other fens, peats of the forest subtype are also encountered. Usually, the upper layers of the deposit consist of sedge, wood-sedge, wood-reed and occasionally also of wood and wood-*Hypnum* peat. The lowermost layers of the deposit are dominated by well-humified wood-reed, wood-*Hypnum*, reed and *Hypnum* peats. The moisture content of the eutrophic deposit is 80-85% and the pH value is 5.5-6.5. The concentration of mineral substances varies significantly within the section (7-17%) due to flood water.

The mesotrophic peat deposit is not so widespread as ombrotrophic peat and consists of wood-*Sphagnum* peat, 0.7-0.8 m in thickness. In terms of the quality indices, it is close to the mixed peat deposit.

The mixed deposit (average thickness 4.5-5.5. m) consists of poorly- to moderately-humified *Fuscum* and *Medium* peats in the upper part and pine-cotton and *Sphagnum* peats

in the lower part. The ash content is 4-5%, the pH value 3.5-4.5

### 13. Sakala Upland

In the Sakala Upland, which comprises the central and southern parts of the Viljandi County, mires cover some 15% of the land surface. The central part of the plateau-like upland is dissected by numerous ancient valleys. The thickness of the Quaternary cover ranges from 3-10 m in the northern to 40-50 m in the southern part of the upland (Paykac 1978). Most of the upland - the areas between the ancient valleys - has a plateau-like, poorly dissected topography. As a result, the number of mires in the upland is much smaller than in the areas with a highly dissected topography, e.g. the Otepää, Haanja and Karula heights. The most characteristic mires in the area include Raudna, Vennissaare, Öisu, Halliste, Saaretsi, Umbsoo, Veelikse, Napsi, Pahuvere and Lillesoo (Figs. 224, 227). Napsi, with the thickness of the peat layer up to 11.0 m, is one of the deepest mires in Estonia.

The topography of the eastern part of the upland is more levelled than in the central part. The areas with a greater relative height hold small mires, up to 10 hectares in area. Large raised bogs, like Rubina, Ikepera and Lagesoo have formed on the undulated till plains skirting the Väike-Emajõgi Valley. In the eastern part of the Sakala Upland, the eutrophic and mesotrophic deposit consists prevailing of well-humified (30-45%) wood-sedge peat. The thickness of the peat is usually 3.0-3.5 m, the content of mineral matter ranges from 8 to 19%, the pH value is 5-7, and the moisture content is around 80%.

In the central part of the Sakala Upland, the eutrophic and mesotrophic deposits consist of well-humified (up to 50%) swamp, wood and wood-sedge peats. The moisture content of the deposits is rather low (80-88%). The concentration of mineral matter fluctuates from 3 to 12.5%, in the river valley mires it may reach even 21% due to the input by flood water.

Mixed and ombrotrophic deposit occurs mostly in the watershed area (Umbsoo, Saaretsi, Pätsi, etc.). It is represented by poorly humified (18-28%) *Fuscum* or *Sphagnum* peat. The lowermost part of the deposit consists of eutrophic or mesotrophic peat (wood-sedge or sedge-*Sphagnum* peat). The moisture content of the mixed and ombrotrophic deposit is constantly around 90%, the content of mineral matter is 1.5-4% and the pH value is 3-4.

The mixed peat deposit (1.5-1.6 m) consists mainly of

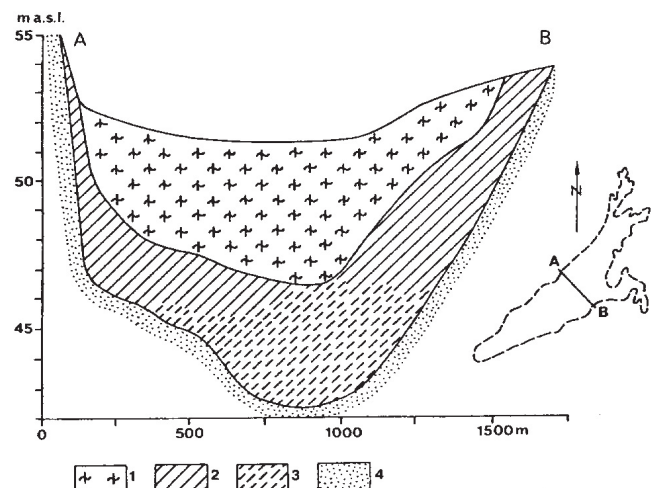


Fig. 227. Peat type profile of the Napsi Raised Bog, Viljandi County: 1 - *Sphagnum-Fuscum* peat; 2 - fen sedge peat; 3 - fen *Hypnum* peat; 4 - sand.

poorly (16%) humified ombrotrophic peat with a moisture content 85%. Its lower part is represented by moderately- to well-humified (20-45%) wood-sedge peat. In the mixed deposit the concentration of mineral matter is constantly 3-9% throughout the section.

The ombrotrophic deposit is composed of poorly-humified (10-20%) cotton-grass, grass and moss peats with an average thickness of 4.1-4.3 m. The moisture content is 85-89%, the concentration of mineral matter is 1-1.5% and the pH value is about 3.

#### 14. Väike-Emajõgi Valley

The Väike-Emajõgi Valley covers part of the low-lying area between the Otepää and Sakala highlands. Variety is added to the scenery by kames, small lakes and abundant mires. Mires cover about 26% of land surface (Fig. 222). Most common are fens, with a strongly elongated contour and a deep layer of peat; of those Väike Emajõgi is the largest (Fig. 224). Moderately to well humified (24-45%) wood and wood-reed peats are widespread, sedge peats are also encountered. The ash content of eutrophic peat is around 10%. Ombrotrophic deposit consists of *Fuscum* and complex peats, the degree of humification is 15-30% and the ash content 2-4%. In quality, the peats of the Väike-Emajõgi Valley are close to the peats of the Emajõgi Valley.

#### 15. Otepää Heights

Palupera, Maru, Pühajärve, Vidrike, Truuta and Pori are the most important mires on the Otepää Heights (Fig. 224).

The eutrophic and mesotrophic deposit (thickness 3-4 m, maximum 7.5 m) is dominated by wood-sedge peat rich in reed. The moisture content of the peats is rather low (78-85%), the content of mineral matter is variable (4-20%) but in general high. The reaction of the deposit is slightly acid (pH 5-5.5). The ombrotrophic and mixed peats form thin (1.7-2.1 m) layers in limited areas of single mires. The lower part of the deposit consists of well-humified eutrophic peats, which are overlain by ombrotrophic peats. In the mixed deposit the degree of humification is up to 40%, while in the ombrotrophic peat it is 20-25%. The moisture content of the whole deposit is around 90%, the content of mineral matter ranges from 2-5.5% and the pH value is 3-4.

#### 16. Palumaa

The Palumaa district is situated between the Haanja Heights and Lake Pihkva depression in the southeastern part of the Põlva County (Fig. 223). The Quaternary cover consists mostly of till and, to a lesser extent, of glaciolacustrine sediments. The terrain is flat owing to the wide distribution of abrasion and accumulation plains. Single valleys dissect the area into plateau-like patches. Under such conditions, the groundwater nutrition of the majority of mires between the river valleys was not possible and the only supplementary source of minerals was precipitation. Therefore, the development of the mires in this area started right from the raised bog stage. Raised bogs make up some 80% of the mires' total area in this region. Fens occur mostly in the river valleys rich in springs. The most typical mires in the area are Meelva, Meenikunno, Riha, Tedremäe, Timo and Valgesoo (Fig. 224).

The eutrophic and mesotrophic deposit in the Palumaa

area is represented by a thin (1.0-1.2m) layer of wood and wood-reed-sedge peats. The moisture content of the deposit is low (78-80%), the content of mineral matter ranges from 7 to 12%, the pH value is 5.5-6.5. The content of minerals in the lowermost part of the deposit is highly variable. Mixed and ombrotrophic peats make up about 80% of the deposits at Palumaa. The ombrotrophic peats are prevailed by poorly humified (20%) cotton-grass - *Sphagnum* and grass peats. The moisture content is more or less constant (92%) and the content of minerals is low (0.8-1.0%) throughout the section.

The Palumaa area is notable for its impressive raised bogs.

#### 17. Valga Lowland

The Valga Lowland, as a southward extension to the Väike-Emajõgi Valley, stretches up to the Karula Upland. Administratively, it is divided between the Valga and Võru counties. The generally hilly and hollow topography determines the location of different types of mires in the district. The central part of the lowland holds flood plain mires with well-humified eutrophic peat, formed in the nutrient-rich environment. Small raised bogs occur in the marginal areas. Larger mires, like Väike-Emajõgi, Priipalu, Rulli, Pedeli, Kohvisoo and Korva, are fed by groundwater, in some places also by flood water. The raised bogs, such as Mehiksoo and Struuga are fed by precipitation (Fig. 224).

The eutrophic and mesotrophic deposits (2.0-3.0 m) consist mostly of well-humified (40-45%) wood or wood-sedge-reed peats. As a result of partial draining of the mires in the river valleys (Korva, Pedeli, Priipalu), the moisture content of the deposits is rather low (78-80%). The eutrophic peat has a high but fluctuating mineral matter content (ash content 5-24%); the pH value is 5.5-6.

The ombrotrophic deposit occurs mainly in the southern part of the lowland (Mehiksoo and Struuga mires). The lower part of the deposit consists of wood-rich grass peat, while moss peat forms the middle and upper parts of the deposit. The average thickness of the ombrotrophic peat is 4.5 m, maximum 8.5 (in the Mehiksoo mire). The moisture content is 90-92%, the degree of humification 15-22%, the content of mineral matter is rather low (ash content 1.5-2.0%), the reaction is highly acid (pH 2.5-3). Mixed deposit does not practically occur in the Valga Lowland mires.

#### 18. Karula Upland

The Karula Upland has an extremely rugged topography, featured by numerous hills, tiny lakes and small and medium mires in the interstitial hollows. Both raised bogs and fens are encountered. Fens are numerous and fed by the surface water flowing down the steep hillsides. The most typical mires of the area include Kantsi, Lauksilla, Koobassaare, Kuutsi, Jahusoo and Sarbasoo (Fig. 224).

Eutropic and mesotrophic peats form the deposits with an average thickness of 4.5-5.5 m (max. 6.5 m) which consist mostly of wood and wood-reed peats. The moisture content of the deposits is generally 80-87%, the content of minerals is high and variable (5-13.5%), the reaction is slightly acid with the pH value being 5-5.5.

The lower part of the mixed deposit consists of moderately humified eutrophic peat, rich in sedge, overlain by cotton-grass or pine-rich ombrotrophic peat. The average thick-

ness of the deposit is 2.8 m, the moisture content is constantly 90% throughout the section, the pH value is 4-5.

Ombrotrophic deposit is of the most limited distribution, being worthy of mentioning only in the Kantsi and Koobassaare mires on the southern fringe of the Karula Upland (Fig. 224). The deposit has an average thickness of 3.5-4.5 m and consists mostly of *Fuscum* peat which is characterised by a low degree of humification (15-16%), high moisture content (90-91%), and a low mineral matter content (ash content 1%). The reaction is acid (pH 3-3.5).

### 19. Võru-Hargla Depression

The Võru-Hargla Depression, which runs from northeast to southeast through the Valga and Võru counties, separates the Haanja Heights from the Karula and Otepää highlands. It is also traceable in the pre-Quaternary topography. In the Late-glacial it served as a stream bed for the meltwater flow. In the lower part of the depression, the river valleys hold mires where eutrophic peat dominates. The slopes of the depression, *i.e.* areas with a greater absolute height, provide good conditions for the surface water flow and, therefore, the mires being mostly fed by precipitation are in the bog stage. Raised bogs of medium size are frequent north of Nõnova and south of Tsooru. About 30% of the mires on the slopes of the depression are raised bogs, the percentage of transitional mires is almost as high. The most typical mires of the area are Kääpa, Kerreti, Pindi, Paidra, Võru, Kaugjärve, Roosa, Kurgsoo, Mustjõe, Põdra, Kuutsi and Pärnika (Figs. 224, 228).

The eutrophic and mesotrophic deposits, with an average thickness of 2.9 m, have formed of well-humified (32-41%) wood peat. The moisture content of the eutrophic peat is 78-84%, in the mesotrophic peat it is a bit higher. The eutrophic peat is rich in minerals (10-24%), but their content varies with the parts of the section. The mesotrophic deposit is more acid than the eutrophic deposit, the pH values being 4-5 and 5-5.5, respectively.

In the area under consideration, mixed deposit is represented by well-humified (40%) wood-sedge peat and poorly-humified (16%) *Fuscum*, *Medium* or complex peats. The deposit has an average thickness of 2.4 m, the moisture content

90%, the ash content 1-2% and the pH value 3-4.5.

The ombrotrophic peat consists mostly of poorly humified (15%) *Fuscum* peat and, to a lesser extent, of up to moderately-humified (18-25%) wood-bearing ombrotrophic peat. Throughout the ombrotrophic deposit, the moisture content is constantly 90-91%, the content of minerals is low (ash content 1-2%) and the reaction is highly acid (pH 2-3).

### 20. Haanja Heights

The closed hollows in the Haanja Heights abound in small mires fed by groundwater. Eutrophic peats cover 80% and ombrotrophic peats 20% of the mires' area. The mires which are situated in ancient valleys and in larger depressions have a complex configuration. The mires in the contemporary river valleys are partially fed by flood water. The most characteristic mires of the Haanja Heights include Tika, Hino, Vanamõisa, Luha, Murati, Kirikumäe and Palu (Fig. 224).

The eutrophic deposit consists of forest and swamp peat subtypes, prevailed by well-humified (40%) wood peat. The moisture content of the layer is 85%, the content of mineral matter fluctuates within a wide range (ash content 5-15%) and the pH value is about 5. The content of mineral matter is, as a rule, highest in the lower layers of the deposit. The mesotrophic deposit is represented by a very thin (0.3-0.4 m) layer of peat or is non-existent. The mixed deposit is also of limited distribution. In mires, where it exists, it consists of moderately- to well-humified (35%) peats belonging to the swamp subtype. The ombrotrophic deposit is made up of cotton-grass - *Sphagnum* peat, with a thickness of 2.7-3.6 m. The moisture content of the deposit is 90%, the content of minerals 1-3% and the pH value is about 3.

In Estonia, peat is at its thickest (about 17 m) in the Vällamäe Mire at the foot of the Suur-Munamägi Hill in the Haanja Heights. The mire has an area of one hectare and has reached the raised bog stage. The deposit consists prevalently of moss peat.

### Peat resources

Estonia's total peat resources in 1626 deposits are estimated at 15.24 milliard m<sup>3</sup> or 2.37 milliard tonnes, of which

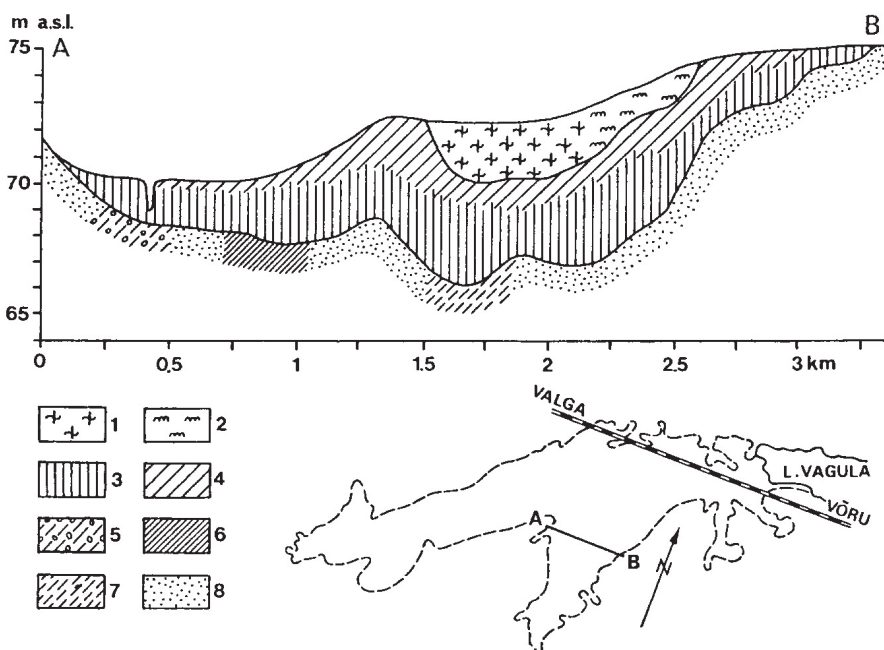


Fig. 228. Peat type profile of the Kerreti Mire, Võru County: 1 - *Sphagnum-Fuscum* peat; 2 - *Sphagnum-Medium* peat; 3 - fen wood peat; 4 - fen sedge peat; 5 - till; 6 - sandy loam; 7 - loamy sand; 8 - sand.

active (economically exploitable) resources constitute 1.52 milliard tonnes. 0.85 milliard tonnes occur under fields and meadows (Orru 1995). Currently, 69 mires (156 000 ha by area) are under conservation (Fig. 224, Kallas 1993). The reserves of peat suitable for use in horticulture and as litter are estimated at 0.2 milliard tonnes (Orru 1995). About 72 deposits are exploited. The peat is produced for litter, fuel and use in horticulture. The average thickness of peat is usually 3...4 m. The distribution of peat resources by counties is uneven ( Fig. 222).

Peat is produced for use as litter in animal husbandry, substrate in horticulture and for fuel. It is also mixed with manure and used for improving agricultural soils. The area of peat milling fields (Photo 66) is 16,000 ha. In 1994, 8300 tonnes of sod peat, 490,000 tonnes of milled peat for litter and use in horticulture and 555,000 tonnes for manufacturing peat briquettes were produced (Juske 1995). The annual output of fertilizer peat is still modest: 190,000 tonnes from 16 deposits. Every year about 50,000 tonnes of Estonian milled peat is exported to Norway, Netherlands, Belgium, Spain and other European countries. During the last 3 years, the production of peat for litter, horticulture and fuel has decreased some 50%. The current extraction and drainage technology enable to use only 0.80 milliard tonnes or 40% of peat resources. The lower part of the deposit is below the recipient-river level and its extraction is possible only in the event of complicated polder drainage system, however, this would cause several technical, economic and environmental problems.

Besides the above-mentioned peatlands, there are a lot of small mires with a thin layer of peat which cover an area of 107,453 ha. Peat reserves of those small mires have not yet been estimated.

In Estonia, 156,562 ha or 16% of the mires are under protection (Fig.224). The total peat reserves of the protected mires are estimated at 3.5 milliard m<sup>3</sup> (Orru 1995).

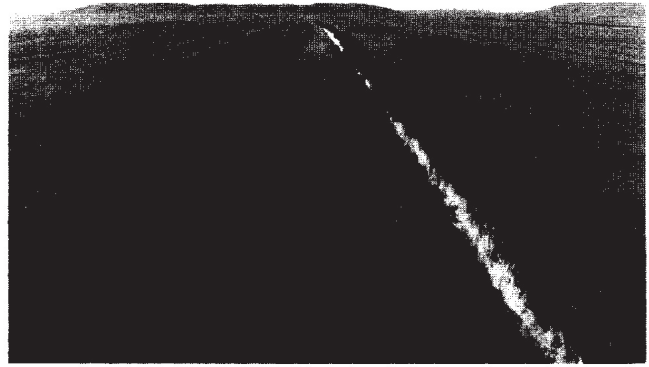


Photo 66. Milling field in the Puhatu Bog. Photo by M. Orru.

As the natural accumulation of peat in mires is slow and natural sites for its accumulation are dwindling rapidly, the Government of the Estonian Republic has adopted the Regulations of Sustainable Use of Peat which enacts annual output quotas for every county.

It is expected that peat will find new uses in future, since it shows a promise for producing growth stimulators and peat wax. There are rich resources of well-humified eutrophic peat suitable for making growth stimulators (about 57 million tonnes), and the production technology is not very complicated either. The resources of cotton-grass peat for producing peat wax are estimated at 1.6 million tonnes.

Extensive peat production may damage the natural ecological balance. When planning peat milling in new fields, one has to take into consideration the ground-water regime and other local conditions to avoid the destruction of natural cranberry bogs. Cranberry plantations are to be laid out in the exhausted peat milling fields. Experiments of this kind have already been made in Estonia.



## PAPER II

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## Sustainable use of Estonian peat reserves and environmental challenges

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**Abstract.** Estonia is rich in peatlands, which cover 22.3% of its territory. About 1/4 of them are under protection, ~2% have been assigned for peat production, and ~1% is abandoned. Several peatlands are drained, which poses a challenge to their sustainability. The use of Estonian peat resources is regulated following the principles of sustainable management. During the inventory of Estonian peatlands (1971–1987) the properties (i.e. botanical composition) and quantity of peat were specified. In this paper an overview of these studies is given and new research fields focussing on chemical components of Estonian peat, i.e. trace elements, balneological characteristics, as well as the usability of the abandoned peatlands, are discussed.

**Key words:** peat, peatland, production, protection, Estonia.

### INTRODUCTION

Peatlands cover over 4 million km<sup>2</sup> or 3% of the land and freshwater surface of the Earth (Maltby & Proctor 1996). Considering the area of peatlands, Estonia holds the third position in Europe after Finland and Sweden (Lappalainen 1996). Paludification of peat deposits began soon after the glacial epoch about 12 000 years ago (Tikkanen 2006), first in Upper and somewhat later in Lower Estonia. Through the postglacial period, climatic conditions have favoured the rise and development of mires. The oldest mires are Napsi, Kuiksilla, and Mehiksoo in Upper Estonia, where peat started to accumulate 9100–8800 years ago during Preboreal time (Orru et al. 1992).

Peat is organic matter accumulating at ground surface and containing a high proportion of water (92–94%). Its organic part is a mixture of plant remains at different stages of humification. The organic constituents of peat could be classified into four groups: a) bitumens, b) carbohydrates, c) lignins, and d) humic substances (Fuchsman 1980). Besides these, peat contains nitrogen components, inorganic substances, etc. Peat is well humified if over 25% of its organic mass has decayed, and poorly humified when the decayed constituents form less than 25%. Dry matter of peat can contain up to 35% mineral matter.

The chemical composition of peat depends on a number of factors:

- feeding type;
- geomorphological position;
- vegetation;
- geological, geobotanical, and microbiological processes.

To clarify the confusing terminology, the term “peatland” has been introduced, comprising areas with both natural and drained peat layers. When defining and distinguishing the peatlands, the so-called zero-contour of peat thickness is considered, i.e. all areas covered with peat in spite of its thickness are considered peatlands. Furthermore, the term “mire” is used for an undrained area with an over 30 cm thick peat layer (Masing 1988). Mires can be categorized as raised bogs (feeding from precipitations), transitional mire (mixed feeding), and fens (feeding from groundwater).

This paper aims to give an overview of systematic peat investigations carried out in Estonia and of results of more recent trace element analysis and balneological studies. We also discuss the challenges to sustainable managing of peatlands, relying on the experience of past decades and possibilities for future improvement in balancing the peat production and protection and restoration of mires.

### INVENTORY OF ESTONIAN PEATLANDS

In 1971–1987 an inventory of Estonian peatlands was carried out by the Geological Survey of Estonia (EGS). According to guidelines of that time, the research incorporated the landscape areas covered with a peat layer (MRSFSR 1973). The inventory was carried out by counties and its results showed that peatlands took up nearly 25.8% of Estonia’s territory (Orru 1987). Some small peatlands with a thin (0.00–0.30 m) peat layer have been excluded from the monograph *Estonian Peat Resources* (Orru et al. 1992) as at the time of the inventory

the organic matter had become even more mineralized due to drainage. Thus, according to its composition such peat was no longer a typical peat, but rather a mixture of peat and mineral soil. After recalculations the total number of peatlands was 9836 and their area was 10 091 km<sup>2</sup> (22.3% of Estonia's territory). The monograph is complemented by a map of Estonian peatlands at a scale of 1 : 400 000.

#### Methods used in the inventory and review of unpublished data

In the peat inventory all 9836 peatlands with an area over 1 ha were prospected – the thickness and area of the peat layer were determined. Most of the peatlands were fens with a relatively thin (0.9–1.6 m) peat layer. More typical 539 peatlands with a thick peat layer and typical genesis were investigated in more detail. Samples were taken for the determination of botanical composition, degree of humification, natural moisture content, ash content, and pH value of peat. In addition, the vegetation and hydrological conditions of peatlands were described.

All 9836 peatlands were marked on aerial photos at a scale of 1 : 10 000. The prognosticated resources were calculated in 1059 and inferred resources in 539 peat deposits. As the remaining 8238 peatlands have a thin peat layer (0.1–0.9 m) and small area (1–10 ha), the resources were not calculated there. After that technical plans of 539 peat deposits were composed, presenting peat types (eutrophic, mesotrophic, oligotrophic), thickness and range of peat deposits, areas suitable for peat production, and potential drainage network. Of those, 520 are included in the handbook *Estonian Mires* (Orru 1995). It appeared that these well-investigated 539 peatlands (7499.5 km<sup>2</sup>) form the majority of the total area of peatlands (10 091 km<sup>2</sup>) (Table 1). The peatlands with prognosticated resources cover 1520.1 km<sup>2</sup> and small peatlands 1071.4 km<sup>2</sup>.

During further investigation of Estonian peatlands and their peat deposits in 1987–1992 also the contents of trace elements and chemical composition of organic substances were analysed and samples for C<sup>14</sup> and pollen analyses were taken to determine the genesis and age of peat deposits.

The aim of the overview in Table 1 was to introduce data of manuscript reports stored in the archives of the EGS. It appeared that during the inventory altogether 33 611 samples were taken for analysing general characteristics of peat (natural moisture content, ash content, degree of humification) and botanical composition, and 18 794 samples were collected for determining the acidity of peat (Table 1). Systematic analysis of the obtained data could be useful for solving the topical problems

related to mires and peat, such as genesis of mires and peat, peat accumulation rate, influence of drainage, climate change, environmental protection and nature conservation issues. For example, such analysis has been made for Männikjärve bog (Sillasoo et al. 2007), but using the data obtained during the inventory, could also be compiled for different types of mires in many other regions.

#### Peat deposits

During the inventory of Estonian peatlands (1971–1987) and the following research (1987–1992) peat resources were calculated in accordance with the guidelines (MRSFSR 1973) for the investigation of the deposits with an at least 0.9 m thick peat layer in a more than 10 ha area. The peat deposits within the zero-contour cover 9016 km<sup>2</sup>, with the commercial resources occurring on 5382 km<sup>2</sup>, i.e. on 60% of the area (Table 1). The geological peat resources in Estonia are 2.37 billion tonnes (Orru et al. 1992), while the total peat resources of the planet amount to approximately 5000–6000 billion m<sup>3</sup> (Lappalainen 1996).

Altogether, 279 of the total of 1598 peat deposits are included into the environmental register compiled by the EGS. These deposits are vacant for peat production (Fig. 1). Peat resources included in the register amount to 1.60 billion tonnes, i.e. 67% of total peat resources established by the inventory.

#### PEAT PRODUCTION

The first written notes of using peat as a fuel in Estonia, at Sindi textile factory, date back to 1861. In 1876 peat from Laugesoo mire was used in Ilmatsalu and approximately at the same time in Lavassaare (Valk 1988).

Before the Second World War 140 km<sup>2</sup> in 422 mires were rented out to peat production companies or individual producers, mainly for production of litter peat. Presently most of these peat production areas are depleted. In 1939, a total of 1.7 million m<sup>3</sup> of peat was extracted (Raudsepp 1946). Among others, the extracted fuel peat was used at Meleski and Järvakandi glass factories and Kreenholm textile factory in Narva. Until 1936 the proportion of peat in country's fuel balance was 6.7% (Raudsepp 1946), since the trend was to use less timber for heating purposes to preserve forests.

Today peat production in Estonia is regulated by the Sustainable Development Act, according to which the quota is 2.6 million tonnes (40% air-dry peat) per year. The volume of produced peat must not exceed its natural

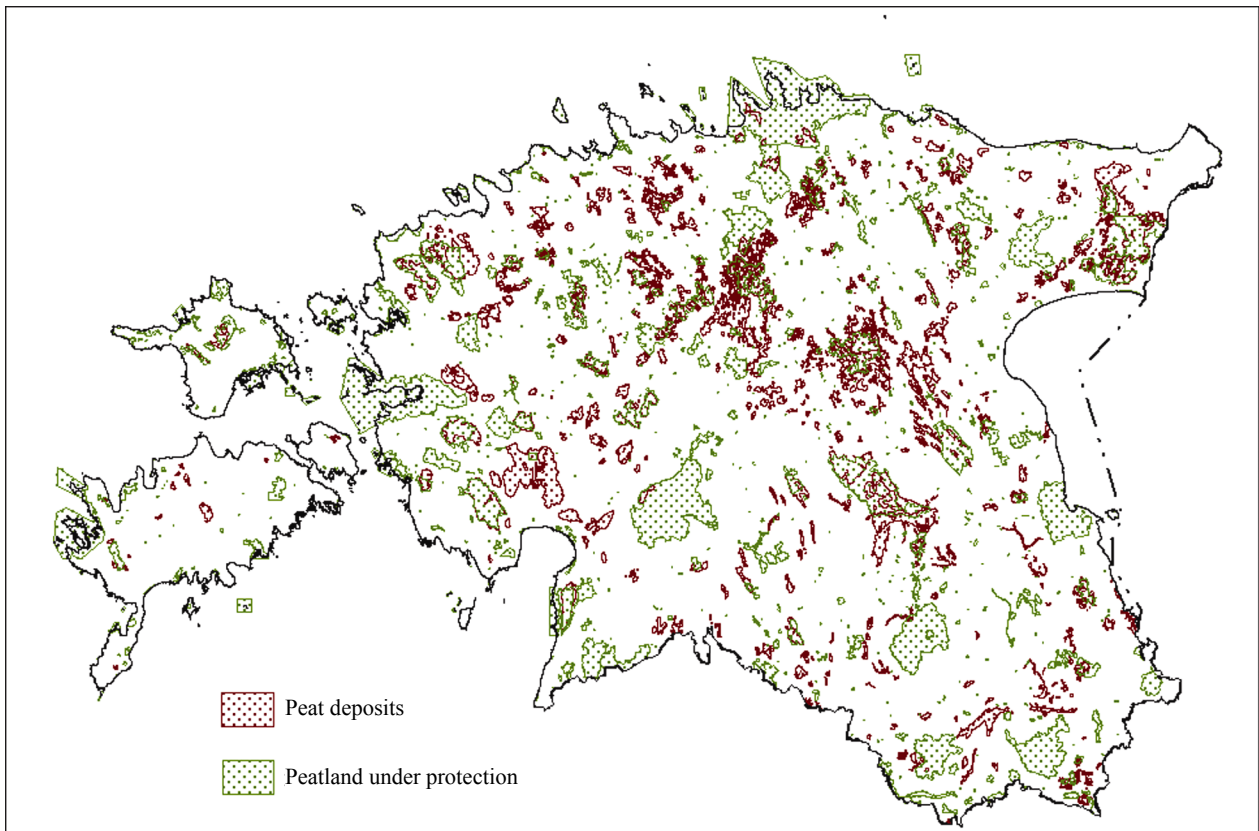


Fig. 1. Protected peat deposits and peatlands (with Natura 2000 areas) in Estonia.

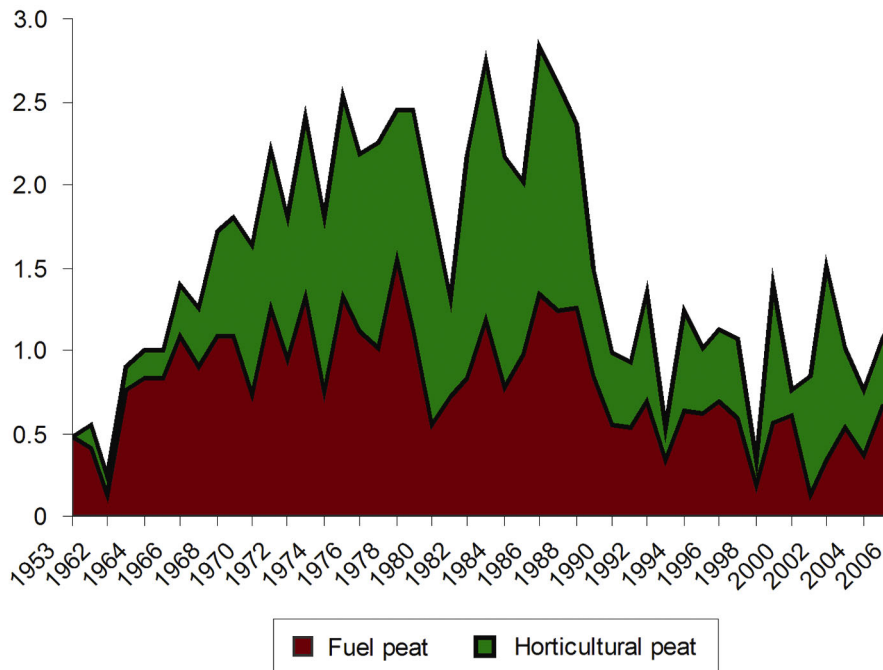


Fig. 2. Peat production (million tonnes) in 1953–2006.

**Table 1.** Overview of the data of the Estonian peatland inventory

County	Peatland area, km <sup>2</sup>				Peat reserves (million tonnes)	Number of samples in manuscripts				
	Well investigated 539 peatlands (inferred resources)	Other larger peatlands (prognostic resources)	Small peatlands (resources were not calculated)	Total		Peat deposits	Technical analyses (ash content, degree of humification)	Botanical composition	Oxides	Trace elements
Hiiu	73.5	0	0	73.5	38.5	203	203	62	36	203
Saare	158.4	5.00	0	163.4	87.5	652	652	74	44	0
Valga	202.4	67.1	81.8	351.3	152.0	2 310	2 310	48	24	2 310
Ida-Viru	804.6	77.4	137.0	1 019.0	530.1	2 123	2 123	32	12	1 775
Võru	189.9	76.4	94.6	360.9	176.6	1 665	1 665	26	32	832
Põlva	206.7	83.9	89.8	380.4	142.0	1 397	1 397	34	16	694
Lääne-Viru	417.1	65.3	59.3	541.7	233.8	1 660	1 660	26	56	855
Jõgeva	590.4	155.0	41.5	786.9	459.7	1 454	1 454	52	46	727
Tartu	711.0	99.6	59.1	869.7	543.0	2 181	2 181	38	44	1 080
Harju	833.3	251.4	162.4	1 247.1	506.8	2 562	2 562	32	114	1 129
Järva	712.4	100.7	23.0	836.1	489.2	2 400	2 400	34	53	1 700
Viljandi	617.7	174.1	66.7	858.5	474.5	3 150	3 150	54	65	1 575
Rapla	491.3	201.8	61.3	754.4	365.9	3 741	3 741	47	62	1 870
Pärnu	1 096.6	124.5	135.5	1 356.6	849.8	6 208	6 208	48	56	3 104
Lääne	394.5	37.8	59.3	491.6	332.7	1 905	1 905	38	24	940
Total	7499.8	1 520.0	1 071.3	1 0091.1	5 382.1	33 611	33 611	645	684	18 794

accumulation. The average accumulation rate of peat in fens is 19–100 cm and in raised bogs 12–300 cm per 1000 years (Maltby & Proctor 1996). It depends on climatic conditions; it has varied at different climate periods and may considerably vary between regions, even within one mire. Ilomets (1994) has estimated the annual average accumulation rate of peat to be 0.5 mm in fens and 1.5 mm in raised bogs in Estonia.

Systematic data about volumes of peat production have been collected since 1953. Peat production has ranged from 0.24 to 2.84 million tonnes (Fig. 2). In the increase of production three stages can be noted:

1. 1965 – Oru peat briquette factory was launched (nowadays closed);
2. 1967–1968 – a number of new deposits for litter peat production were taken into use;
3. 1985–1986 – production of peat fertilizers was started.

In the last decade 0.33–1.5 million tonnes of peat has been produced (40% air-dry peat) annually. In the nearest future these amounts will not increase because the recent milling technology does not enable extraction of larger quantities from the existing mining claims. As the protection of mires has become a priority, annual production up to 1.5 million tonnes can now be considered optimal, in spite of the quota of 2.6 million tonnes per year.

Presently 77 production areas (205 km<sup>2</sup>) are included into the environmental register, with the total resources of 0.24 billion tonnes of slightly humified and 0.75 billion tonnes of well humified peat. The currently operated production areas are in good condition. Many companies use modern equipment that has a low noise level and generates less dust. Recently several depleted peat fields have been newly taken into use.

## CONSERVATION OF PEATLANDS

In the 1960s peat extraction (40 deposits) was started in several raised bogs and in order to preserve the ecological balance, protection of mires became an issue.

There are several reasons for protecting the peatlands:

- preservation of biological and landscape diversity;
- preservation of natural resources (clean water, berries, herbs);
- as a habitat of threatened species;
- scientific value as a reference area in its uniqueness or typicality;
- recreational and educational value for humans;
- ecotourism.

Considering that Estonia has joined the European Union, it is important to see the protection of peatlands

in a broader context. Together with Natura 2000 areas ca 2500 km<sup>2</sup> of mires have been designated as protected areas (Fig. 1), 72% of which is represented by raised bogs (Ramst & Orru 2007). Especially important is the protection of natural fens that are extremely vulnerable to human activity due to their feeding type (groundwater, springs, floods).

Because of the importance of threatened species, the topmost part of peatlands has been recently studied (Paal et al. 1998; Karofeld & Pajula 2005; Kaakinen & Salminen 2006). The character and conditions of peatlands are often primarily connected to their vegetation. A more comprehensive view would consider also the hydrological conditions, composition of peat, and thickness of the peat layer, which influence the character of vegetation in a mire (Loopmann 1994). A considerable part of Estonian peatlands has been partly or completely drained, both peat production areas, and fields and forests with a thin peat layer. The exact area of such peatlands is presently under research and unambiguous data on the extent of the influence of draining are still missing. While Loopmann (1994) has suggested that non-drained peatlands make up nearly 71%, Ilomets et al. (2007, pp. 20–22) declare that only 30% of peatlands have not been drained. The authors of the present paper, relying on their extensive experience in peat investigations, suggest that the draining affects vegetation and groundwater generally down to the 200–500 m level. The more precise research on the extent and area of the influence is in progress.

## RECENT STUDIES

Abandoned peat production fields pose an important environmental issue in Estonia. They cover 89 km<sup>2</sup> according to the Environmental Register of Estonia. Many of them have considerable peat resources, including 0.05 billion tonnes of poorly humified and 0.25 billion tonnes of well humified peat. If the abandoned areas are not revegetated, they constitute an important source of CO<sub>2</sub> emission (Karofeld 2004). Under such conditions, peat finally mineralizes and ceases to exist as organic sediment.

The investigations carried out by the EGS revealed the variable state of abandoned peat production fields (Orru & Ramst 2008). Some fields are covered with forest, mostly with birches and pines while spruce is less common. Among mire plants Cyperaceae and Gramineae predominate but also different moss species, especially *sphagnum* species are common. Some abandoned areas are overgrown with cotton grass. The growth of cotton

grass is peculiar, being extensive at first, but ceasing later. This is probably due to changes in groundwater level as evaporation increases when trees grow taller.

In addition to using peat in horticulture and as a fuel, peat utilization in balneology has been introduced in Estonia. Respective investigations were carried out by the EGS and the East-Tallinn Central Hospital on patients with Heberden–Bouchard disease. The results show that the strength of hands and flexibility of fingers improved and pain decreased in patients treated with balneological peat (Orru et al. 2008). Balneological peat is rich in bioactive substances, e.g. humic (particularly hymatomelanic) and fulvic acids. The amount of peat suitable for balneological purposes in Estonia is estimated at 1 million tonnes (Orru et al. 2008).

Peat is able to bind hazardous elements, and can thus be used in several environmental technological solutions. In Estonia the content of harmful elements is highest in fens in river valleys feeding from springs (Orru & Orru 2006). As a result of natural processes these substances have been transported into peat by groundwater. Because of anthropogenic pollution like traffic, in some roadside peatlands the content of Pb and Cd was higher in the upper part of the peat layer (Orru & Orru 2006).

## CONCLUSIONS

During the last decades the Estonian peatlands and their peat resources have been thoroughly investigated. Nevertheless, there are several issues that need more detailed research. In recent years the studies have focussed on the processes occurring in the top 50-cm layer of mires and on their vegetation, while less attention has been paid to the genesis of peat and hydrological conditions, i.e. the processes in natural mires and the influence of drainage. The manuscript reports of the inventory contain much material (first of all, the data on the botanical composition of peat) that should be systematically analysed. In the future the use of peat as a natural resource (e.g. in environmental technology solutions, balneology, peat chemistry) should be expanded. Cooperation between geologists, botanists, hydrologists, ecologists, and other environment specialists is of vital importance for successful resolution of the problems related to the complex ecosystem of mires.

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## Eesti turbavarude jätkusuutlik ja keskkonnasäästlik kasutamine

Mall Orru ja Hans Orru

Eesti on rikas turbasoode poolest, need katavad 22,3% territooriumist. Ligi veerand turbasoodest on kaitse all. Turbatootmiseks on kasutusel ~2% ja ~1% võtavad enda alla mahajäetud turbaväljad. Kuna paljud turbasood on kuivendatud, tõstatub keskkonnavalne probleem – soo kui tervikliku ökosüsteemi säilimine. Eesti turbavarude kasutus on reguleeritud jätkusuutliku majandamise printsiipidest johtuvalt. Eesti soode revisjoni käigus (1971–1987) määrati turba hulk ja omadused (sh botaaniline koostis) kõigi Eesti turbasoode lõikes. Käesolev artikkel annab ka ülevaate nimetatud uuringute tulemustest. Lisaks on keskendutud uutele uurimisteedele, mis hõlmavad turba keemilisi omadusi, kahjulike elementide sisaldust, balneoloogilisi karakteristikuid ja mahajäetud turbatootmisalade kasutusvõimalusi, lähtuvalt eri uurimisdistipliinide vaatevinklist.



## PAPER III

Orru, H. & Orru, M. 2006. Sources and distribution of trace elements in Estonian peat. *Global and Planetary Change*, 53, 249–258.



# Sources and distribution of trace elements in Estonian peat

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## Abstract

This paper presents the results of the distribution of trace elements in Estonian mires. Sixty four mires, representative of the different landscape units, were analyzed for the content of 16 trace elements (Cr, Mn, Ni, Cu, Zn, and Pb using AAS; Cd by GF-AAS; Hg by the cold vapour method; and V, Co, As, Sr, Mo, Th, and U by XRF) as well as other peat characteristics (peat type, degree of humification, pH and ash content). The results of the research show that concentrations of trace elements in peat are generally low: V  $3.8 \pm 0.6$ , Cr  $3.1 \pm 0.2$ , Mn  $35.1 \pm 2.7$ , Co  $0.50 \pm 0.05$ , Ni  $3.7 \pm 0.2$ , Cu  $4.4 \pm 0.3$ , Zn  $10.0 \pm 0.7$ , As  $2.4 \pm 0.3$ , Sr  $21.9 \pm 0.9$ , Mo  $1.2 \pm 0.2$ , Cd  $0.12 \pm 0.01$ , Hg  $0.05 \pm 0.01$ , Pb  $3.3 \pm 0.2$ , Th  $0.47 \pm 0.05$ , U  $1.3 \pm 0.2 \mu\text{g g}^{-1}$  and S  $0.25 \pm 0.02\%$ . Statistical analyses on these large database showed that Co has the highest positive correlations with many elements and ash content. As, Ni, Mo, ash content and pH are also significantly correlated. The lowest abundance of most trace elements was recorded in mires fed only by precipitation (ombrotrophic), and the highest in mires fed by groundwater and springs (minerotrophic), which are situated in the flood plains of river valleys. Concentrations usually differ between the superficial, middle and bottom peat layers, but the significance decreases depending on the type of mire in the following order: transitional mires – raised bogs – fens. Differences among mire types are highest for the superficial but not significant for the basal peat layers.

The use of peat with high concentrations of trace elements in agriculture, horticulture, as fuel, for water purification etc., may pose a risk for humans: via the food chain, through inhalation, drinking water etc.

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**Keywords:** peat; peatland; trace elements; genetic type; feeding conditions; Estonia

## 1. Introduction

Peatlands are peat-forming ecosystems. Peat is a mixture of plant remains in different stages of decay consisting in five main groups of organic compounds: proteins, lipids, hydrocarbons, pigments and lignin

(Brownlow, 1996). Due to its composition and structure, peat has a ability to bind trace elements (Coupal and Lalancette, 1976). The mechanisms for metal binding are still to be clarified, as peat's structure is very complicated. Even though the process is hard to be determined, five mechanisms have been proposed for elements retention by peat (Bourg, 1998; Reed, 1998; Brown et al., 2000; Sõukand et al., 2003;): 1) mechanical accumulation of particles larger than pore diameter; 2) biological (plants and microorganisms) mediated binding of heavy metals during their life cycle; 3) physicochemical ion exchange; 4) physical and

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chemical adsorption and also formation of complexes; 5) chemical transfer of readily degradable compounds into less readily degradable compounds, whereas latter accumulate in peat.

The binding mechanisms are largely dependent on pH, concentrations of metal and ligand, competing ions (Bailey et al., 1999), also the radius of the ions to be bound (Rinqvist and Öborn, 2002), peat characteristics (Ong and Swanson, 1966) and the size of the deposited particles (Yang et al., 2002). The affinity of heavy metals to bind to peat usually follows the sequence  $Hg > Cu > Pb > Ni > Zn > Co > Cd > Mn$ , although it may vary depending on peat characteristics (Irving and Williams, 1948; Sharma and Forster, 1993; Ottonello, 1997; Kharkhordin and Atroshchenko, 1998; Aldrich and Feng, 2000; De la Rosa et al., 2003; Tipping et al., 2003).

In addition to the heavy metals, sulphate ions dissolved in surface waters are also subject to adsorption processes (Tipping et al., 2003). There are several other mechanisms that control sulphur retention by peat, but these are still to be investigated (Prechtel et al., 2001).

Trace elements accumulated in peatlands have two main natural sources: 1) atmospheric deposition of soil dusts and aerosols (the only source in ombrotrophic mires); and 2) the incorporation as particulate matter or in solution via runoff and ground waters (by mineral dissolution or desorption of compounds previously accumulated in the environment). Main anthropogenic sources are atmospheric particles, wastewaters, results of changes in environmental conditions such as changes in pH value (Orru and Orru, 2003).

The hazardousness of these elements is a conditional term: their impairing effect appears only beginning from certain concentrations. Most of them are ultimately needed for the proper functioning of plant, animal and also human organisms, though. Higher concentrations may lead to stress, the cessation of the plant development etc. At extremely high concentrations they can induce cancer and distortions of the nervous system (De la Rosa et al., 2003).

Estonia is one of the countries with a higher abundance of peatlands in Northern Europe. At present 9836 mires were inventoried, representing about 1 Mha (22.3% of the Estonian territory), and 2.37 billion tones of peat. During the investigation of Estonian peatlands, high concentration of trace elements was found in some cases (Orru et al., 1992; Orru, 1996). In Kõrvemaa (Estonia), Koff et al. (1998) measured the concentrations of trace elements in short peat cores (70 cm) sectioned every centimetre, and found the highest elements concentrations in the upper 10–30 cm. In

deeper layers the concentrations of all the measured trace elements (As, Cd, Co, Cr, Cu, Ni, Mn, Zn, Pb) decreased. Similar results were obtained by Nieminen et al. (2002) in southwest Finland in a mire close to a pollution source (a Cu–Zn smelter). Detailed studies on the abundance of trace elements have also been reported for other mires in Finland (Virtanen, 1994) and Russia (Krestapova, 1993). For Finland Virtanen (2004) indicated high concentrations of As in some mires. In previous studies we also found relatively high concentrations of some elements in deep peat sections (Orru et al., 1992), which we attributed to contributions by groundwater due to the dissolution of the rock substrate.

The objective of our study was to determine which trace elements are in Estonian peat. The aim of this paper is to discuss the possible sources of the trace elements and describe the determined amount of the trace elements in peat. The paper also gives an overview in which geographical regions the abundance of trace elements in peat is high. Last, we comment the potential hazards that the use of peat with higher concentrations of trace elements might impose on human health or ecological stability.

## 2. Material and methods

### 2.1. Description of the area and sampling

Despite its relatively small extension (45 000 km<sup>2</sup>), many different types of mires (peat thickness >30 cm) are found in Estonia. This is to a great extent due to the numerous landforms of variable composition and shape that are the basis of present landscape. In these landforms the movement of water as well as transported substances are variable, and consequently also the topsoil and vegetation occurring on them differ.

Formation of peat deposits, peat growth rate and current state of mires depend mainly on their feeding regime. The latter changes not only depending on external factors, but also due to the accumulation of peat, since peat accretion may produce a change from the dependence on groundwater (in minerotrophic mires) to rainfall. The latter, in turn, also changes the main sources of the deposited hazardous substances. From the standpoint of development it means the evolution from a fen to a transitional mire and eventually into a raised bog.

The feeding conditions of a mire and consequently the structure and character of the peat layers it contains are also controlled by the position of the mire on the landscape, the geological setting and the character of the Quaternary cover. Therefore the analysis is provided by particular peat's geomorphological setting. In

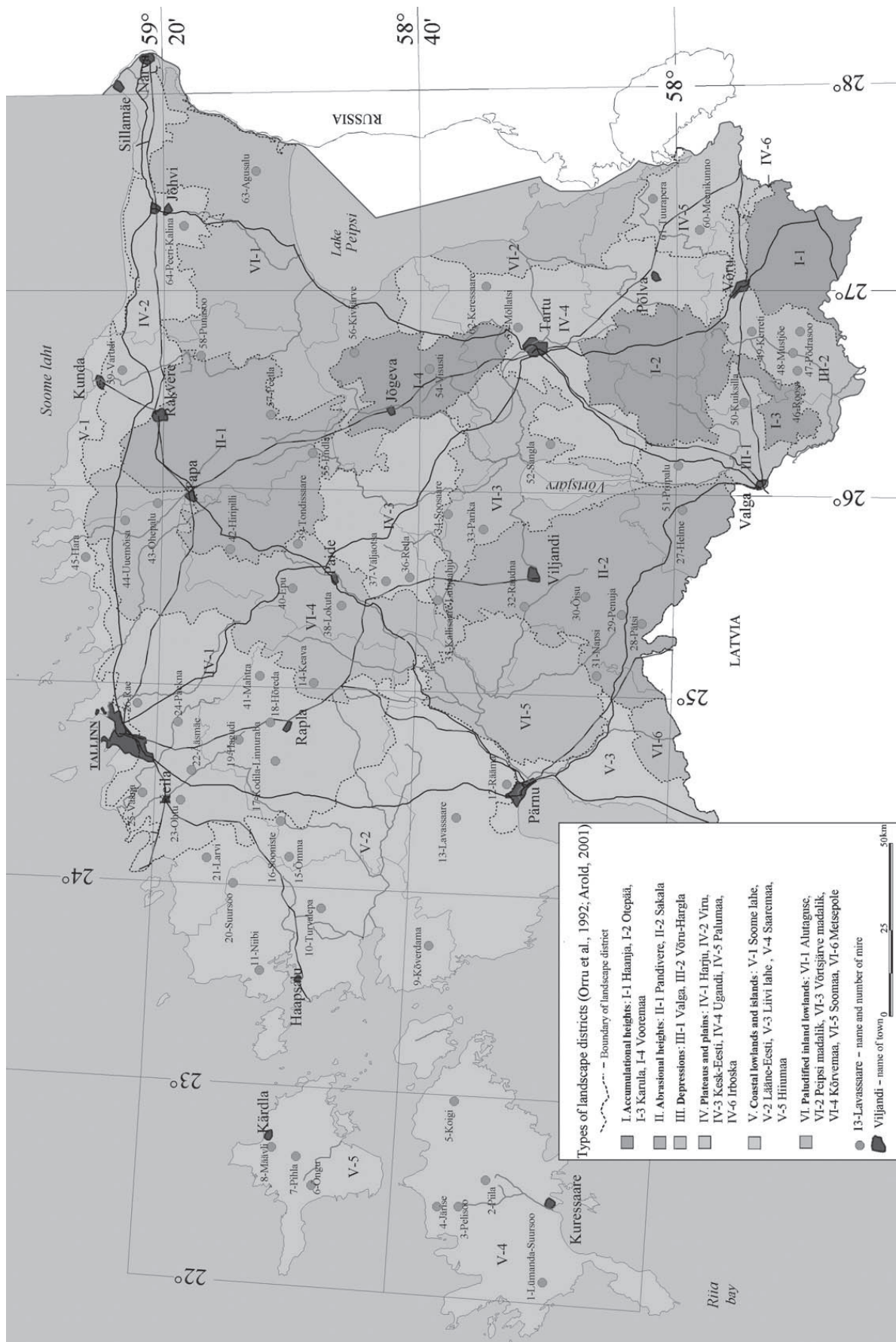


Fig. 1. Location of mires discussed in the paper.

Estonia there are in total 25 different landscape units (accumulational and abrasional elevations, depressions, plateaus and plains, coastal lowlands and inland paludified lowlands) (Fig. 1, Orru et al., 1992; Arold, 2001).

For determination of the trace elements in peat, we selected and sampled 64 representative mires (a total of 684 peat samples). Samples were collected according to the same methodology from the whole peat section. The samples were taken every 0.5 m per one coring, both in natural mires and in peat production areas. They were taken with a hand auger (TBG-66) following the recommendations established for Estonia in “Guidelines for prospecting of peat deposits of the USSR” (Geoltorfrazvedka, 1983).

## 2.2. Analytical methods

Two sets of analyses were done in natural peat: 1) characterization of the peat (ash content, pH, botanical composition and degree of humification); and 2) analyses of trace elements in peat ash.

Ash content was determined after heating the sample at  $450 \pm 10$  °C till constant weight. Results are given as the average of two replicates (when two determinations differed by more than a 2%, a third determination was made and averaged). The lost on ignition represents the proportion of organic matter in the sample. pH was determined in KCl extracts after 18 h, with a peat: solution volumetric ratio of 1:2.5. Again, analyses were done in replicates and if the values differed by more than a 1%, a third determination was done. For the determination of the degree of humification the double-stage centrifuge method was used to separate precipitate of coagulated humus from non-humified components of plants (standard: GOST 10650–72).

The analyses of trace elements were made on peat ash. After ashing the material was homogenised and milled in a porcelain mortar. Five techniques were used to determine the concentrations of the different elements: 1) AAS-flame (AA-1475) for Cr, Mn, Ni, Cu, Zn and Pb; 2) ETA–AAS (AA-475) for Cd; 3) XRF (VRA-30) for V, Co, As, Sr, Mo, Th and U; and 6) gravimetric method for S (description: N°155-X.C.). Before analyses the ashes were digested in a mixed acid solution (one part HCl and three parts  $\text{NO}_3\text{H}$ ). Becker’s standard solutions were used for calibration.

The determination of trace elements by XRF was carried out in sample cups made of an organic film. Background and peak theoretical areas were mathematically fitted. This enabled an immediate taking into account the disturbing factors in determination of the

abundance of trace elements. Standard reference materials were used for calibration (LKSD-4, 40% organic substances, lake sediments; ES-2, 20% organic substances, Dictyonema rocks).

For Hg measurements, the samples were incinerated in microwave digester, in high pressure and temperature. The AAS cold vapour method (Simatsu equipment) was used for measuring. Sulphur content was determined by gravimetric method, heating the sample in  $800 \pm 10$  °C. For S the results are given in percentage while for the rest of the elements concentrations are in  $\mu\text{g g}^{-1}$ .

## 2.3. Statistical methods

Statistical analyses were performed using STATISTICA 6.0 software. In a first step the fitting to the normal distribution was checked with Kolmogorov–Smirnov’, Lilliefors’ and Shapiro–Wilk tests. In further analyses non-parametric methods (independent of the frequency distribution of values, and thus more robust) were used. Relationships between different characteristics were assessed by Spearman rank correlation coefficients and the Duncan test was used for multiple comparisons of average contents. In all cases the significance level was  $p=0.05$ .

Since earlier studies showed that the feeding conditions (whether ombrogenic or minerogenic) and the depth of the sample in the peat column are significant factors to explain the chemical composition of peat, these were also taken into account in our comparisons. The Spearman rank correlation matrices by feeding condition (precipitation, different sources, groundwater, ground- and spring water) and peat layer (surface, middle, bottom) were computed and the statistical effects assessed using Duncan test.

## 3. Results

### 3.1. Elements contents

The analyses of the abundance of trace elements showed that their concentrations in the peat of Estonian mires are extremely variable, differing both by mire type and in the vertical section of peat deposits.

Concentrations in the whole peat section are compared with the maximum concentration obtained for the top layer. The latter is of greatest interest to evaluate anthropogenic pollution as one the possible source of trace elements. Figs. 2 and 3 present the average concentrations of trace elements in peat and the respective maximum concentrations found in the top



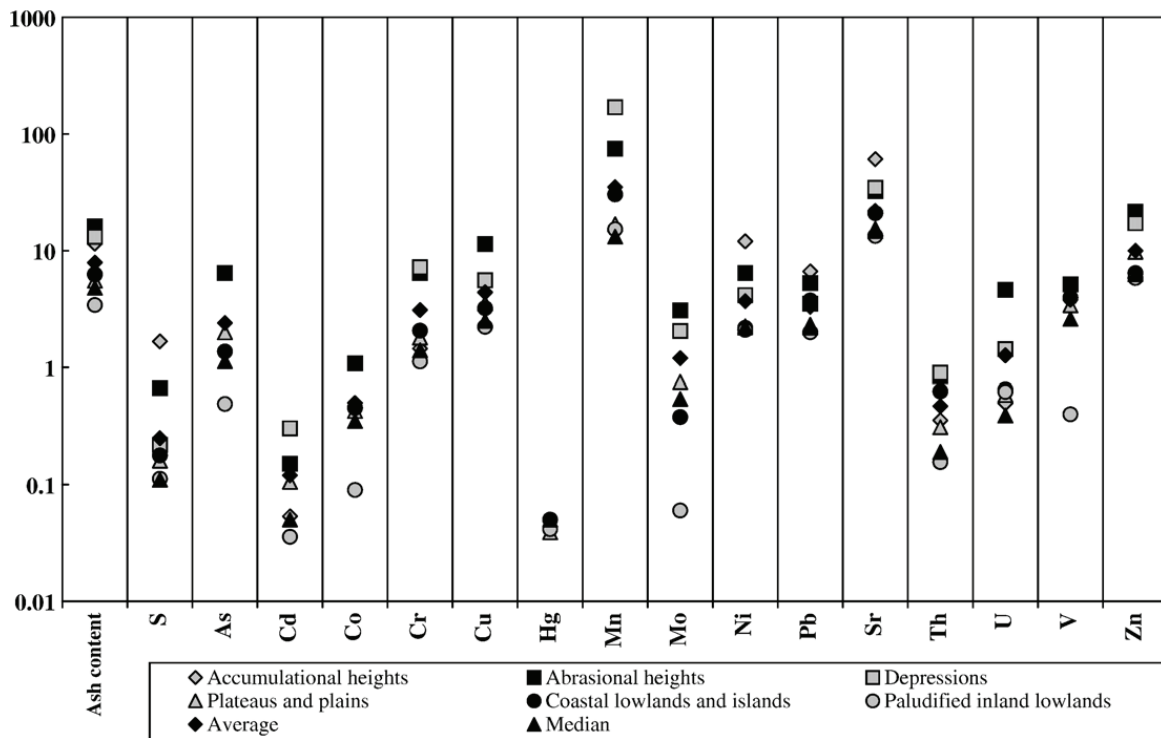


Fig. 2. Average concentrations for the analysed elements in Estonian mires (S in %, the rest of the elements in  $\mu\text{g g}^{-1}$ ).

layer of the mires. Comparison of the maximum concentrations of the top layer with the average concentration for our results shows, that in general the

concentrations of the analysed elements tend to increase with depth. For example, the maximum concentration of S in the top layer is 0.11%, while the average

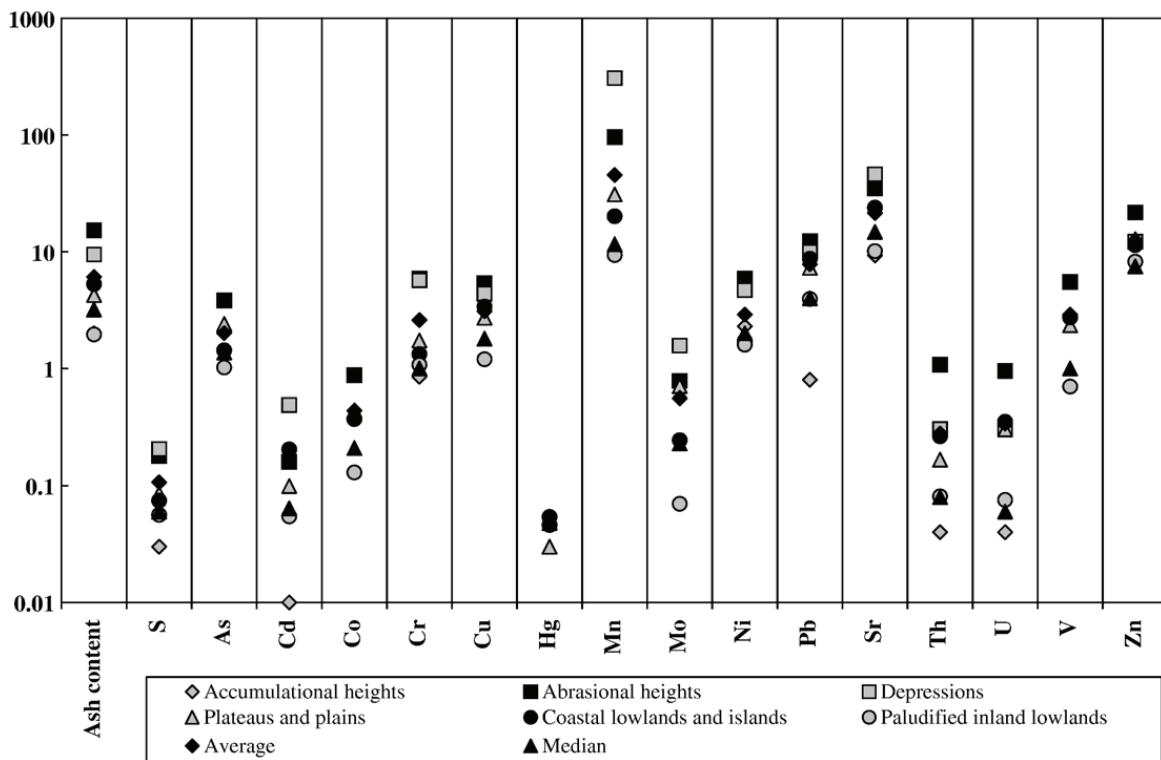


Fig. 3. Average concentrations for the analysed elements in the superficial peat sections (S in %, the rest of the elements in  $\mu\text{g g}^{-1}$ ).

concentration for Estonian mires is 0.25%; the respective concentrations for U are  $0.12 \mu\text{g g}^{-1}$  and  $1.27 \mu\text{g g}^{-1}$  (top layer and average, respectively); for Th  $0.28 \mu\text{g g}^{-1}$  and  $0.47 \mu\text{g g}^{-1}$  and for Ni  $2.9 \mu\text{g g}^{-1}$  and  $3.7 \mu\text{g g}^{-1}$ . The above trend is also similar for Cr, Cu, Ni, Th, U and V.

In many cases the maximum concentrations of hazardous elements occurred in the middle and bottom layers of peat deposits and not in the upper sections; while, on the other hand, quite often the bottom layers are not enriched with the elements. This might be the result of different biological and chemical processes occurring in the course of humification of peat deposits, which need further investigation.

On the contrary, for Cd and Pb (and also in part for Mn, Sr and Zn) higher concentrations usually occur in the top layers, suggesting a relationship to atmospheric pollution by human activities. The concentration of Cd is  $0.16 \mu\text{g g}^{-1}$  in the top layer while the average is  $0.12 \mu\text{g g}^{-1}$ , and for Pb  $7.8 \mu\text{g g}^{-1}$  and  $3.3 \mu\text{g g}^{-1}$  respectively. In previous investigations (Koff et al., 1998) it has also been found that the higher concentrations of these elements occur mostly at a depth of 1–10 cm and decrease towards the base of peat deposit. Also Deiss et al. (2004) and Smith et al. (2005) have suggested that anthropogenic inputs dominate the Pb inventory of the upper peat sections.

Comparison of the concentrations of the elements for mires located in different landscape units with the average concentrations for Estonian mires (arithmetic

mean of all 684 values) shows no clear differences, except for minerotrophic mires fed by springs, which are enriched in most elements compared to the other mire types.

When more than one core was taken for a given mire the results indicate that within mire variations in the concentrations are at least similar to that among mire types. This is likely due to micro-topographical differences in feeding conditions, hydrology and atmospheric deposition.

### 3.2. Statistical analyses

Kolmogorov–Smirnov, Lilliefors and Shapiro–Wilk tests showed that the distributions of all analysed properties/elements (except for Hg concentration, degree of humification in different layers and pH in the bottom layer) are not normally distributed. All showed positive skewness.

Evaluation of the relationship between different properties/elements showed that Co has the highest positive correlations with other trace elements and ash content of peat (Table 1). In most cases, As, Ni, Mo and pH showed high rank correlation coefficients. Medium rank correlation coefficients were found for Cd, Cu, Mn, Sr and Th. Zinc, Pb, S and the degree of humification showed somewhat lower coefficients. Chromium, U, and V, showed both high and low correlation coefficients. On the contrary, Hg showed negative correlation with many analysed properties/elements.

Table 1  
Spearman rank correlation coefficients for analysed indicators

	Ash	pH	S	As	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sr	Zn	Th	U	V
Ash	1.00																	
pH	0.88 <sup>a</sup>	1.00																
S	0.53	0.82	1.00															
As	0.80	0.66		1.00														
Cd	0.59	0.12 <sup>b</sup>	0.33	0.67	1.00													
Co	0.94	0.79	0.78	0.83	0.11	1.00												
Cr	0.54	0.77	0.28	0.79		0.91	1.00											
Cu	0.75	0.70	0.40	0.83	0.35	0.84	0.57	1.00										
Hg	-0.14	-0.85	0.32				0.08	-0.02	1.00									
Mn	0.76	0.76	0.53	0.77	0.44	0.85	0.71	0.72	0.11	1.00								
Mo	0.87	0.85	0.88	0.69	0.33	0.89	0.84	0.82	-0.60	0.77	1.00							
Ni	0.66	0.80	0.44	0.87	0.05	0.92	0.84	0.74	0.08	0.81	0.85	1.00						
Pb	0.49	-0.03	0.27	0.42	0.64	0.20	0.16	0.35	-0.11	0.38	0.04	0.18	1.00					
Sr	0.73	0.86	0.40	0.50	0.50	0.88	0.29	0.63	-0.01	0.70	0.86	0.39	0.25	1.00				
Zn	0.43	0.27	0.17	0.65	0.47	0.40	0.27	0.53	-0.10	0.56	0.37	0.35	0.52	0.34	1.00			
Th	0.86	0.77	0.41	0.82	0.35	0.90	0.55	0.68	-0.22	0.70	0.69	0.66	0.37	0.57	0.36	1.00		
U	0.79	0.81	0.46	0.78	0.31	0.82	0.53	0.70	-0.12	0.65	0.73	0.68	0.40	0.42	0.41	0.81	1.00	
V	0.89	0.71		0.81	0.61	0.92	0.92	0.91	-0.32	0.76	0.80	0.90	0.28	0.79	0.47	0.92	0.80	1.00

<sup>a</sup> 0.88 – bigger than 0.8.

<sup>b</sup> 0.12 not significantly different from 0.

The influence of the peat layer (top, middle, bottom) on the concentration of trace elements for the different types of mires (raised bogs, transitional mires, fens and spring fens) was also analysed (Table 2). No significant differences were found for the concentrations of elements in the peat layers for fens, except for Cd which showed significantly higher concentrations in the top section (2–3 times higher than the other two peat sections). In spring fens only four elements (Co, Cr, Mo and U) showed significantly higher concentrations in the bottom layer. While the other two types of mires (raised bogs and transitional mires) showed significant differences in the concentration of eight and nine elements respectively. In raised bogs Co, Cr, Cu and Sr are enriched in the basal layer, while As (2×), Cd (3×), Pb (3–4×) and Zn (2×) are enriched in the top layer. In transitional mires As, Co, Cr, Cu, Ni, Sr, Th and U are significantly enriched in the bottom layer, but only Pb (2–3×) is enriched in the top layer. Three elements, Hg (few data), Mn and U, showed no significant differences between peat layers for any type of mire; meanwhile Mo, Ni, Th and Zn concentrations were significantly different in only one type of mire. Therefore, the influence of the peat layer decreases in the following order: transitional mires ≥ raised bogs > spring fens > fens.

Fens showed the highest average concentrations for almost all elements in the top and middle peat sections; only for Mn (top section) and U (middle section) that spring fens showed higher concentrations than fens. In

the bottom layer, fens showed the largest concentrations of As, Cd, Co, Mo, Pb and Th; transitional mires for Mn, Sr, Th and V; and spring fens for Co, U and Zn. Raised bogs showed the lowest concentrations for all elements, with very few exceptions (lower concentrations were found for Cd in the top section of transitional mires, Mo in the top section of spring fens and Pb in the top and middle sections of spring fens) (Table 2). Statistical analyses indicated that the type of mire is a significant source of variation for all elements (except Hg) in the top section; for Mo in the middle section; while differences were not significant for the bottom section, mainly due to higher concentrations and variability than in the other sections.

Results clearly indicate that the main source of elements plays a significant role in the concentrations in the peat. The ombrotrophic raised bogs, fed exclusively by precipitation, showed lower concentrations than the minerotrophic mires fed by superficial and/or subterranean waters. Compared to the same peat section in raised bogs, maximum enrichments in the other mire types for the analysed elements were as follows: 19–20× for As (fens, bottom section), Th (transitional mires, bottom), U (spring fens, middle), Zn (spring fens, bottom) and V (transitional mires, bottom); 16–17× for Ni and Cr (fens, middle); 14× for Co (fens, middle; and spring fens, bottom); 7–8× for Cu (fens, middle), Mn (transitional mires, bottom) and Mo (fens, middle); and 3–4× for Cd and Pb (fens, bottom), and Sr (fens,

Table 2

Average concentrations ( $\mu\text{g g}^{-1}$ ) of trace elements in peat layers for different types of mires. Superscript letters indicate the existence of statistical differences (Duncan test,  $p < 0.05$ ); significant differences are marked by different letters, while intermediate groups are coded with two letters (i.e., ab)

Layer	As	Cd	Co	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sr	Th	U	V	Zn
<i>Raised bogs</i>															
Top	0.89 <sup>b</sup>	0.190 <sup>b</sup>	0.09 <sup>a</sup>	0.39 <sup>ab</sup>	1.36 <sup>a</sup>	–	14.16	0.21	0.71	9.62 <sup>b</sup>	11.99 <sup>a</sup>	0.11	0.09	0.51	8.54 <sup>b</sup>
Middle	0.47 <sup>ab</sup>	0.065 <sup>a</sup>	0.07 <sup>a</sup>	0.24 <sup>a</sup>	1.19 <sup>a</sup>	–	9.41	0.15	0.70	2.92 <sup>a</sup>	9.48 <sup>a</sup>	0.11	0.12	0.48	4.58 <sup>a</sup>
Bottom	0.40 <sup>a</sup>	0.070 <sup>a</sup>	0.13 <sup>b</sup>	0.57 <sup>b</sup>	2.86 <sup>b</sup>	–	10.02	0.31	0.83	1.96 <sup>a</sup>	18.03 <sup>b</sup>	0.14	0.12	0.82	4.56 <sup>a</sup>
<i>Transitional mires</i>															
Top	1.25 <sup>a</sup>	0.121	0.34 <sup>a</sup>	1.18 <sup>a</sup>	2.00 <sup>a</sup>	0.05	36.98	0.43	2.99 <sup>a</sup>	13.03 <sup>b</sup>	24.83 <sup>a</sup>	0.93 <sup>a</sup>	1.14	6.22 <sup>a</sup>	17.89
Middle	1.19 <sup>a</sup>	0.085	0.38 <sup>a</sup>	1.43 <sup>a</sup>	2.29 <sup>a</sup>	0.05	43.59	0.96	3.22 <sup>a</sup>	4.17 <sup>a</sup>	27.11 <sup>a</sup>	0.84 <sup>a</sup>	1.01	4.26 <sup>a</sup>	7.57
Bottom	4.20 <sup>b</sup>	0.170	1.34 <sup>b</sup>	6.44 <sup>b</sup>	7.56 <sup>b</sup>	0.04	79.91	0.70	6.04 <sup>b</sup>	5.91 <sup>a</sup>	47.93 <sup>b</sup>	2.60 <sup>b</sup>	1.55	16.37 <sup>b</sup>	17.57
<i>Fens</i>															
Top	4.22	0.493 <sup>b</sup>	0.91	2.60	5.78	0.03	66.83	1.33	8.13	10.62	34.70	1.17	1.63	7.29	25.03
Middle	6.54	0.184 <sup>a</sup>	0.97	4.14	8.43	0.06	38.49	1.20	11.00	3.30	32.38	1.18	1.28	4.70	37.51
Bottom	7.59	0.230 <sup>a</sup>	1.39	6.22	8.63	0.06	54.43	1.73	6.59	7.77	35.56	1.04	0.98	7.38	22.48
<i>Spring fens</i>															
Top	1.87	–	0.49 <sup>a</sup>	1.80 <sup>a</sup>	4.95	–	75.76	0.13 <sup>a</sup>	2.51	4.93	17.85	0.52	1.53	2.41 <sup>a</sup>	8.32
Middle	1.44	–	0.51 <sup>a</sup>	1.89 <sup>a</sup>	3.93	–	45.76	0.83 <sup>ab</sup>	4.65	1.39	28.48	0.47	2.41	2.72 <sup>a</sup>	14.80
Bottom	2.77	–	1.78 <sup>b</sup>	6.28 <sup>b</sup>	7.77	–	61.89	1.36 <sup>b</sup>	5.89	4.13	32.36	2.02	2.01	14.25 <sup>b</sup>	64.84

middle). The concentrations of elements in the middle peat sections of ombrotrophic mires (raised bogs) may thus represent the “natural background” concentrations of Estonian peat, since they exclusively reflect variations in atmospheric inputs of elements.

As for the relationship of concentrations to the main plant component of the peat, the highest values were found in eutrophic *Lignum–Gramineae–Hypnum* peat. Concentration was also high in eutrophic *Carex–Phragmites*, eutrophic *Gramineae* and eutrophic *Hypnum* peats. Peats with other main plant components, particularly oligotrophic *Sphagnum* peats, showed significantly smaller concentrations. This pattern seems to be consistently independent on the peat section (top, middle or bottom).

#### 4. Discussion

The results presented here indicate that concentrations of trace elements in Estonian mires are generally low and therefore atmospheric deposition and terrestrial pathways do not seem to represent a major environmental hazard. The potentially toxic elements are strongly bound to peat organic matter and mires act rather as environmental filters. But if peat with high concentrations of trace elements is used, it may be a source of secondary pollution. Our investigation revealed sporadically high concentrations of U (30–60  $\mu\text{g g}^{-1}$ ), V (30–50  $\mu\text{g g}^{-1}$ ), Mo (20–30  $\mu\text{g g}^{-1}$ ) and Ni (20–30  $\mu\text{g g}^{-1}$ ). For bottom peat sections, Petersell et al. (1997) pointed out the content of minerals containing metals—including polymetallic compounds—in the bedrocks or basal sediment as a possible source for the high concentrations. The mentioned concentrations exceed or a close to the Estonian official limits for topsoils (U 20  $\mu\text{g g}^{-1}$ , V 50  $\mu\text{g g}^{-1}$ , Mo 10  $\mu\text{g g}^{-1}$ , and Ni 50  $\mu\text{g g}^{-1}$ ). When compared to other countries, the average concentration of trace elements in Estonian peat is similar, although smaller and higher values occur in different mires (Krestapova, 1993; Virtanen, 1994; Christanis et al., 1998).

Several investigations show that the chemical composition of peat depends on a number of factors: type of mire (feeding conditions), geomorphological position, geological setting of the region, environmental conditions, anthropogenic impact (atmospheric and soil pollution) (Lappalainen, 1996). Our results suggest that the main factor in Estonian mires seems to be the type of mire, i.e. whether they are fed exclusively by precipitation (ombrotrophic) or also by superficial water and groundwater (minerotrophic). The highest concentrations of trace elements were observed in the middle and

bottom layers of minerotrophic peatlands. Groundwater carries dissolved mineral matter to the mires, and in the acidic mire environment the ionic species are bound to peat organic matter. In many cases, in these layers the ash content is high, thus, a considerable part of the heavy metals can also be bound to inorganic compounds. In these cases the natural sources of heavy metals should be considered as of greater importance than anthropogenic inputs. In our case, concentrations of most elements are similar to those given by Wedepohl (1995) as representative of the continental crust; those for Co, Cr, Mn and Sr are somewhat lower.

The deposition and accumulation of trace elements in peat has probably also been influenced by climatic conditions occurred during the formation of the peat deposits (in the Holocene, the last 10 000 years) (Orru et al., 1992; Christanis et al., 1998; Shotyky et al., 2002). On the other hand, the geomorphological setting of the mire (plateau, river plain, valley, depression) influences the composition of peat and its physicochemical properties mainly through the control of its hydrology, which determines the main source of the elements. On plateaus, raised bogs are common; these have lower ash content and concentrations of trace elements (see for example Fig. 2). On river valleys and depressions, fens are abundant and characterized by higher ash content and concentrations of heavy metals.

The geology of the area and the groundwater flow are also important factors. In southern Estonia peatlands have formed in deep valleys with a large influence of slope springs. This kind of peatland usually shows the highest concentrations of trace elements. We speculate that these elements have been carried from the Devonian sandstones by groundwater. In northern Estonia where the bedrock is represented by Ordovician limestone, the trace elements (especially Cd) have probably been transported by groundwater from the bedrock (a *Dictyonema* argillite). This is supported by the relatively high concentrations of Cr (22  $\mu\text{g g}^{-1}$ ), Mn (1200  $\mu\text{g g}^{-1}$ ), Ni (4.4  $\mu\text{g g}^{-1}$ ), Cu (4.9  $\mu\text{g g}^{-1}$ ) and Sr (340  $\mu\text{g g}^{-1}$ ) of the limestone (Vingisaar et al., 1981).

The geochemical conditions, too, can considerably influence the concentration of hazardous elements in peat. They may lead to the desorption of previously accumulated compounds, resulting in the formation of mobile heavy metal ions, which remain in solution at low pH values (Kharkhordin and Atroshchenko, 1998; Summa and Tateo, 1999; Burba et al., 2001). For example, peat processing may enhance the release of metals to the environment by drainage waters.

The influence of anthropogenic activities is connected to the utilisation of substances containing trace

elements and their release to the environment and subsequent deposition into mires. While peat burning may also be source of pollution (see for example [Mehrag and Killham, 2003](#)). Another part of trace elements of anthropogenic origin may be carried to peat by wastewater or polluted groundwater and therefore it is important to know the hydrogeological conditions, peculiarities of bedrock setting and locations of tectonic faults.

But peat is characterised by the ability to bind heavy metals, and mires can be considered not only as a source of hazardous elements but also as purifiers of the environment (i.e. they accumulate large amounts of pollutants). Therefore, in regions with high anthropogenic pollution wetlands should be preserved namely because of their purifying effect (at present 20% of Estonian mires (200 000 ha) are under protection). Environmental technologies are starting to use the ability of peat to retain trace elements in wastewater treatment using wetlands and peat filters, also as hydrocarbon sorbent and in bioremediation ([Bailey et al., 1999](#)). Clean peat (without low concentrations of trace elements) can also be used for rehabilitation, cosmetics and for producing pharmaceuticals ([Lappalainen, 1996](#)).

## 5. Conclusions

The results of our study show that concentration of trace elements in Estonian peat is low in general. However, in some places considerably high concentrations of trace elements have been recorded. This is mostly the case for mires fed from springs, which are situated on the flood plains of river valleys.

The concentrations of trace elements in individual mires differ with depth (i.e. peat layers) up to hundreds of times. This probably results from differences in environmental conditions related to the genesis of the mire and/or the particular peat layer. The most important factor determining the abundance of the trace elements is the type of mire (by feeding conditions), which is followed by peat type and the depth in the peat deposit. The lowest concentrations of most elements were found in middle sections of raised bogs (ombrotrophic mires). Their average concentrations can be considered as the “natural background” for atmospheric deposition in Estonian peat. The influence of factors such as atmospheric pollution, substratum, bedrock dissolution, flows from groundwater and springs, surface and flooding water from surrounding environment, is less significant in the middle layers of the peat but plays an important role in the superficial and bottom layers.

Hazardousness of trace elements occurs when certain concentrations have been reached in the peat. Trace

elements in peat can be transferred to organisms via the food chain or through drinking water. Peat with high concentration of trace elements should not be used in horticulture neither as a fuel. Nevertheless, trace metals bound to peat organic matter are not readily released and thus mires accumulate many pollutants. In regions with intense anthropogenic pollution wetlands should be preserved as areas purifying the environment.

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## PAPER IV

Orru, M. H. & Systra Y. J. 2009. Geochemical anomalies in the peat deposits of valley and slope peatlands. In *Materialy VIII Mezhdunarodnoi Konferentsii 14.-18.09.2009* (Vorobjev A. E., ed.), pp. 327–330. Moscow–Tallinn.





## **ГЕОХИМИЧЕСКИЕ АНОМАЛИИ В ТОРФЯНЫХ ЗАЛЕЖАХ ДОЛИННЫХ И СКЛОНОВЫХ БОЛОТ ЭСТОНИИ**

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***Ю.Й. Сыстра***

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В климатических условиях, где количество осадков почти в 2 раза превышает испарение, происходит обширное заболачивание территории. В Эстонии около 22,3% площади занято болотами. Несмотря на небольшие размеры страны (45,2 тысяч км<sup>2</sup>), ландшафты характеризуются большим разнообразием. Всего в Эстонии выделяется 6 типов ландшафтов:

- 1) возвышенности нагромождения четвертичных отложений,
- 2) эрозионные возвышенности,
- 3) озерно-речные впадины,
- 4) плато и равнины,
- 5) приморские низменности и морские острова,
- 6) низменности в материковой части.

Болота также отличаются большим разнообразием форм, размеров и условий питания.

Верховые болота питаются в основном осадками, среднегодовое содержание минеральной части которых составляет 23 мг/л (Raukas, Teedumäe, 1997). Переходного типа болота питаются подземными водами и атмосферными осадками, низинные – как текущими подземными и поверхностными водами, так и осадками. Подземные воды значительно сильнее минерализованы, в них сухой остаток составляет в среднем 300-600 мг/л. От источника питания зависит зольность торфа, его химический состав и содержание опасных для здоровья микроэлементов.

В ходе специальных геохимических исследований, проведенных Геологическим центром Эстонии в течение более 20 лет, были изучены и обобщены данные по содержанию опасных микроэлементов в торфе 64 болот из различных ландшафтных типов и частей Эстонии (Ogги, Ogги, 2003).

Было изучено распространение следующих микроэлементов: As, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, S, Sr, Zn, Th, U и V в приповерхностном, среднем и придонном горизонтах торфяного разреза.

В отдельных случаях была установлена аномально высокая концентрация опасных микроэлементов в нижней части торфяного разреза. Ниже дается краткая геохимическая характеристика болот всех основных ландшафтных типов.

На аккумулятивных возвышенностях четвертичных отложений встречаются болота в депрессиях, часто они являются заросшими болотной растительностью озерами. Таких болот изучено всего 2, мощность торфа 2-3 м, зольность в верхней части 1,8-2,2%, в средней – 8,8-15,4% и в придонной части 10,50%. Содержание большинства опасных микроэлементов в золе торфе остается низким уровне, менее 10 мг/кг.

Только в средней и нижней части разреза концентрация Ni в одном случае поднимается до 18,5 и 61,2 мг/кг, Pb – до 6,2 и 36,7 мг/кг и Sr – до 50,5 и 314,2 мг/кг. Источником этих элементов является морена, которая содержит большое количество галек ордовикских и силурийских карбонатных пород.

На эрозионных возвышенностях болота расположены в депрессиях на склонах или в узких разломных долинах и большей частью питаются родниковыми водами.

Толщина торфяного слоя составляет 2-9,5 м.

Характерна высокая зольность торфа, до 31% и более.

Они характеризуются часто весьма высокими содержаниями различных микроэлементов: As до 23,53 мг/кг, Cd до 1,06 мг/кг, Cr до 33,8 мг/кг, Cu до 62,2 мг/кг, Mn до 409,6 мг/кг, Mo до 27,53 мг/кг, Ni до 28,6 мг/кг, Pb до 48,1 мг/кг, Sr до 170,4 мг/кг, Zn до 108,4 мг/кг, U до 47,78 мг/кг.

Некоторые концентрации близки или даже превышают ПДК для жилых районов. Например, для Mo ПДК в почвах равен 20 мг/кг.

Содержание всех микроэлементов, за исключением Pb, увеличивается к подошве торфяного слоя,

Концентрация Pb уменьшается обычно вниз по разрезу, в одном случае она снизилась с 48,1 мг/кг до 7,5 мг/кг при мощности торфа 2,5 м.

Болота в крупных озерно-речных впадинах не имеют таких высоких содержаний опасных микроэлементов, их зольность часто высокая и их отложения представляют смесь из речного ила и торфа.

На равнинных ландшафтах образуются небольшие болота.

Мощность торфа составляет 2,5-6 м, иногда достигает 10 м.

Содержание опасных микроэлементов в золе обычно невысокое, As 1,85-4,32 мг/кг, в одном случае – 11,76 мг/кг, Cd 0,007-3 мг/кг, Co 0,14-3,14 мг/кг, Cr 0,7-16,7 мг/кг, Cu 0,5-26,5 мг/кг, Hg 0,005-0,097 мг/кг, Mn 1,1-127,7 мг/кг, Mo 0,1-6,00 мг/кг, Ni 0,2-7,7 мг/кг, Pb 0,2-46,4 мг/кг, Sr 4,3-79,2 мг/кг, Zn 0,4-117,8 мг/кг, Th 0,03-21 мг/кг, U 0,01-5,41 мг/кг и V 1,8-23,6 мг/кг.

На приморских равнинах болота часто больших размеров и имеют толстый слой торфа, обычно более 10 м.

Типичным представителем такого болота является крупный болотный массив Лавассааре, недалеко г. Пярну. Он образовался из залива Балтийского моря при послеледниковом подъеме территории Эстонии.

Большая часть болота верховая, с преимущественным питанием за счет осадков. Торфяной слой имеет мощность 11 м.

Зольность в верхнем слое 1,0 м составляет всего 3,2%, в среднем 9-метровом слое 6,3% и в придонном слое 1 м – 8,8%. Сверху вниз увеличиваются в целом низкие содержания As, Co, Cr, Cu, Mn, Ni, Sr, U, V, а уменьшаются концентрации Cd, Pb, Zn.

Практически одинакова по разрезу содержание Hg, а концентрация цинка выше всего в поверхностном слое – 19,1 мг/кг и несколько меньше в придонном – 11,4 мг/кг.

В целом для таких болот при мощности торфяного слоя от 1,5 до 12,3 м характерны относительно низкие средние содержания опасных микроэлементов: As 0,69–2,40 мг/кг, Cd 0,028–0,430 мг/кг, Co 0,12–1,25 мг/кг, Cr 0,6–6,9 мг/кг, Cu 1,0–10,5 мг/кг, Hg 0,032–0,065 мг/кг, Mn 3,8–105,2 мг/кг, Mo 0,15–0,79 мг/кг, Ni 0,6–6,6 мг/кг, Pb 1,2–12,1 мг/кг, Sr 3,9–34,1 мг/кг, Zn 1,4–21,1 мг/кг, Th 0,07–3,90 мг/кг, U 0,08–2,35 мг/кг, V 0,5–12,0 мг/кг.

Еще один тип болот представляют внутриматериковые заболоченные равнины, которые распространяются на западном берегу Чудского озера (Алутагузе и устье реки Эмайыги), низменность оз. Выртсъярв, низменности Соомаа, Кырвемаа и Метсеполе.

Для болот этих низменностей характерно исключительно небольшое содержание всех опасных микроэлементов. Типичным представителем такого типа болот можно считать болото Соосааре. Мощность торфа около 7 м, зольность верхней 6 м части от 1,1 до 2,9%, придонной части 0,75 м – 24,3%.

Содержание всех микроэлементов уменьшается внизу вверх: Cd от 0,041 до 0,004 мг/кг, Cr от 5,6 до 1,5 мг/кг, Cu от 5,8 до 1,3 мг/кг, Hg от 0,08 до 0,07 мг/кг, Ni от 7,3 до 1,9 мг/кг, Pb от 3,9 до 0,5 мг/кг, Sr от 37,7 до 1,4 мг/кг, Zn от 13,6 до 4,2 мг/кг, U от 1,26 до 0,02 мг/кг.

В заключение следует отметить, что большинство болот Эстонии в начальном этапе развития имели связь с подземными минерализованными водами. Верховые болота эту связь потеряли и сейчас питаются в основном маломинерализованными осадками.

На склонах и глубоких долинах болота и сейчас получают подпитку из подземных минерализованных вод, которые выносят из более глубоких горизонтов различные микроэлементы, в том числе опасные для здоровья. Торф этих болот перед использованием необходимо проверять на возможное высокое содержание опасных микроэлементов. Нижние горизонты торфа и сейчас могут обогащаться различными микроэлементами, чего необходимо учитывать при эксплуатации таких болот.



## PAPER V

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# Chemical properties of peat in three peatlands with balneological potential in Estonia

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## Abstract

Peat and various peat preparations have been successfully used in the balneology. The particular importance when considering the biological effects of peat has been found to be related to humic substances. In the three study areas with balneological potential, selected according to the previous research and mapping of Estonian peatlands, the content of humic, hymatomelanic, and fulvic acids as well as main characteristics of peat were measured. It appeared that the content of bioactive substances in sampled peat layers was relatively high. The highest concentrations were found in Parika peatland, where the content of humic acids was 39.3%, hymatomelanic acids 19.3% and fulvic acids 1.3%. The main factors influencing the levels of bioactive substances were degree on humification (more humified peat had higher concentrations) and peat type (composition of forest(pine)-cottongrass increased the levels). As lipids had high correlation with hymatomelanic acids and trace elements with fulvic acids, mentioned components could be bound to these humic substances respectively.

**Keywords:** peat, balneology, humic substances, trace elements

# 1. INTRODUCTION

Peatland is a part of landscape where in wet condition and lack of oxygen part of the organic matter will not degrade and accumulates as peat. Peat is though an accumulation of partially decayed vegetation matter with high water content. It is a mixture of the plant parts in different decompose stages. The transformation of peat organic matter by chemical, biochemical and biological decay leads to the formation of a number of chemical substances from what humic, and fulvic acids and their salts, cellulose, lignite, bitumens, peptides, enzymes and fats are the most common (Szajdak et al. 2007).

Peat and various peat preparations have been successfully used in the balneological practice of clinical medicine (Beer et al. 2007). Balneological peat as ecologically clean and natural substance is more human friendly than synthetic substances. Several European countries (Germany, Austria, Czech Republic, Hungary) have long traditions of using the balneological peat. At recent decades, it is also studied and used in Finland (Korhonen 1996).

It is important to consider the region and origin of the peat being used for medicinal purposes. The quality, type and amount of the biologically active substances in peat make certain peat more medically useful (Groven 1999). However, it is well known that the composition of peat in general is very complex and additionally differs depending on the source from the peat. In addition, the quality and composition of the peat is depending on many different factors as the place of origin, the primary types of the plants of origin and a whole spectrum of environmental factors (Beer et al. 2003a). It shows that mineralogical-geological make-up as well as peat chemistry plays very important role.

Beer et al. (2003b) have discussed that there are many indications that also a chemical component may contribute to the clinical success of cutaneous peat treatment because several pharmacological effects have been found which cannot be contributed to the well-established physico-thermal effects. The physical effect influences through temperature and biochemical effect through bioactive substances (Lukanov et al. 2002). Balneology is largely used for treatment of rheumatic diseases that are also common in Estonia (Saks et al. 2001). The biochemical effect of peat is related to the content of humic substances (HS) which participate in the peat healing effect (Klöcking & Helbig 2005). HS are natural products that develop during decomposition of organic matter in humus. HS are the most stable fraction of organic substances in soils (Wollina 2009). They constitute a dark brown non-soluble fraction of peat with an extremely high molecular weight, responsible for the capability to retain water, friability and electrostatic conductivity (Trckova et al. 2005). HS from different sources (from different types of peats and climate zones) have different composition and biological effect, depending on their chemical structure and physico-chemical properties (Hayes 1997; Yamada et al. 2007). In order to understand the major processes and mechanisms that occur in peat, it is obligatory to know the components of HS (Hayes 1998) and to compare their behaviour in aqueous solution in order to understand how their environmental interactions may differ from each other (Young & von Wandruszka 2001). The classical fractionation of HS is based on solubility differences at different pH values. According to that, HS can be divided into four fractions: 1) humic acid (HA) – soluble in water at higher pH values; 2) hymatomelanic acid (HMA) – soluble in ethanol; 3) fulvic acid (FA) – soluble in water under all pH conditions; 4) humin – not soluble in water at any pH value. HS sorb many biological molecules like peptides, sugars, nucleic acid residues, and fats (Hayes 1998; Stevenson 1994; Orlov 1990). It is known that biochemically active humic, fulvic and hymatomelanic acids are successfully used against musculoskeletal, gynaecological and skin diseases (Klöcking & Helbig 2005). HS from peat have several biologic activities such as anti-inflammatory and pro-inflammatory



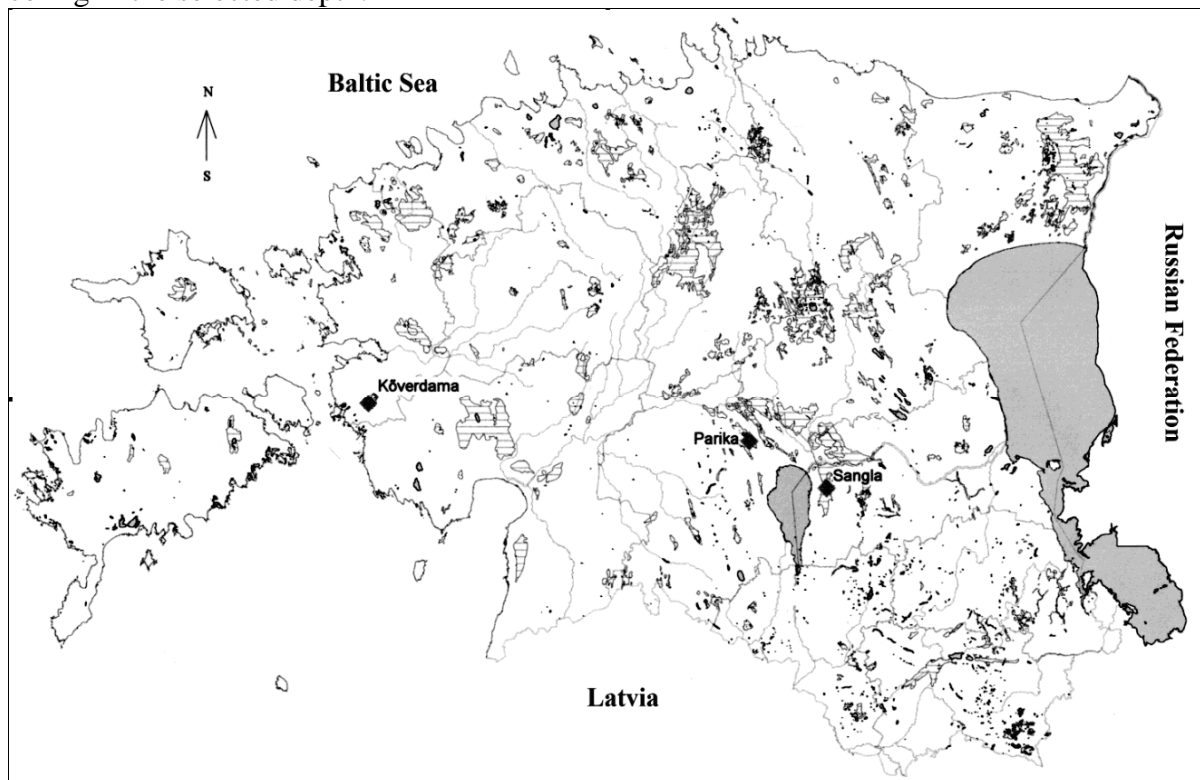
properties (Junek et al. 2009), antiallergic effect (Yamada et al. 2007), antibacterial, antifungal, immunomodulatory and photoprotective actions (Wollina 2009). Fulmic, ulmic and humic acids, all of which have been isolated from peat, have been found to be of particular importance when considering the biological effects of peat (Beer et al. 2000).

According to experience of other countries, the peat suitable for balneology has to be well humified (40–50%) which natural moisture content has to be at least 85% and peat layer under the peat water level (Uosukainen 2002). The content of HS should exceed 20% of dry weight. It should not contain harmful bacteria and heavy metals (Szajdak & Hladon 2009; Orru & Orru 2006). Moreover, balneological peat should complexly consist of HA, HMA and FA, the ash content should be less than 12% and the thickness of proper peat layer at least 0.7 m (Orru et al. 2008).

The aims of the current research were to find out the resources and chemical composition of balneologically suitable peat in Estonia and to identify the geological factors influencing the properties of balneological peat the most.

## 2. MATERIALS AND METHODS

The study areas (Figure 1) were chosen according to the research and mapping of Estonian peatlands made by Geological Survey of Estonia (Orru et al. 1992). Through geological routes the natural conditions, especially vegetation and water regime were studied in the study samples. At first the thickness of proper layer, its placement and the depth of whole peat layer were sounded. For the selection of well-composed peat layer for laboratory analyses, the decomposition degree of peat in horizon was determined *in situ* according to von Post scale (Von Post 1924). The samples were collected with a hand auger after every 0.5 m per one coring in the selected depth.



**Figure 1.** Main peatlands in Estonia and the three study areas (Kõverdama, Parika, Sangla).

Two sets of analyses were done in natural peat: 1) characterization of the peat (ash content, pH, degree of humification and botanical composition); and 2) the yield of HS from natural peat. Ash content was determined after heating the sample at  $450\pm 10$  °C till constant weight. The lost on ignition represents the proportion of organic matter in the sample. pH was determined in KCl extracts after 18 h, with a peat: solution volumetric ratio of 1:2.5. For the determination of the degree of humification the double-stage centrifuge method was used to separate precipitate of coagulated humus from non-humified components of plants. The botanical composition (peat type) was determined with microscope.

The procedure for determination the yield of HA, HMA and FA has been previously described in more detail (Übner et al. 2004). The natural peat (30g) was stirred for 5 h with 100 ml of 0.2 M NaOH and then allowed to stand for 20 h at room temperature. The suspension was centrifuged at 5000 rpm for 30 min. The alkaline extract contained HS. The humin (insoluble part of peat) was separated as precipitate and was washed repeatedly with distilled water to separate soluble HS and dried. The alkaline extract was acidified to pH 2 by addition of 6 M HCl. After 20 h the soluble FA and insoluble HA, and HMA were separated. The precipitate was repeatedly washed with distilled water until  $\text{Cl}^-$  free (control with  $\text{AgNO}_3$ ). The solid residue was repeatedly treated with 96% ethanol to separate the soluble HMA and insoluble HA. Both fractions were dried. The FA solution was cleaned through the Amberlite XAD-7 resin column for desalination. After removal of salts with 0.01 M HCl, the pure FA fraction was recovered by elution with 0.1 M NaOH solution directly onto the strong cation exchanger Amberlite IR-120. The gathered fraction was dried. For the determination of the content of lipids, dry peat was repeatedly treated with mixture of chloroform and ethanol (2:1) to separate the soluble lipid fraction and dried.

For statistical analyses, the Pearson correlation coefficients were calculated.

## 3. RESULTS AND DISCUSSION

### 3.1. Peat resources and main characteristics of peat

The study showed that the depth of the balneologically usable peat layer is studied peatlands 1.1–1.5 m. If it is less than 0.7 m, it is technically and economically difficult to use. Then the layer can be separated in mining and one can be sure that the peat comes from the right depth interval. The total amount of balneological peat resources in studied peatlands was:

- Kõverdama in 94 ha 226,000 tons
- Parika in 73 ha 113,000 tons
- Sangla in 151 ha 466,000 tons.

However, if the three other previously studied peatlands (Larvi, Hõreda, Oese) would be included, the resources of balneological peat would increase up to one million tons (Orru et al. 2008). The country making the most use of peat for therapeutical purposes is Germany where the annual consumption of balneological peat is around 0.4 million  $\text{m}^3$  (~64,000 tonnes) (Lüttig 1984). Taking into account Estonian 1.35 million inhabitants, these resources would be sufficient for Estonian purposes for hundreds of years. However, according to Estonian peatlands mapping (Orru et al. 1992) the suitable resources, where the content of HS is higher than on average, could be even much bigger.

The peat suitable for balneological purposes was mainly well humified (40–50%, von Post 6–8) raised bog peat (Table 1). As for peat types: heath, sphagnum, cottongrass and wood are

represented. All areas in peatlands where the balneological peat can be found, are in natural condition. The water level is 0.3–0.6 m beneath the ground level so the moisture content (85–92%) is bigger than the minimum required value (85%) (Table 1). The ash content was relatively low, varying from 2.8 to 4.8%. In the countries, where peat balneology was available (e.g. Germany, Austria, Finland) the well humified raised bog and fen peat is used. From raised bogs mainly *Sphagnum* (humification H6–H8) and from fens *Carex* peat (humification H8–H10) is used (Naucke, 1981). When the ash content in raised bog peat in Germany and Finland is low that is similar to Estonia, it is much higher in fen peat: 5–12% in Estonia (Oru et al. 1992), ~15% in Germany (Naucke 1981) and 6–12% in Finland (Uosukainen 2002).

**Table 1.** Characteristics of research areas

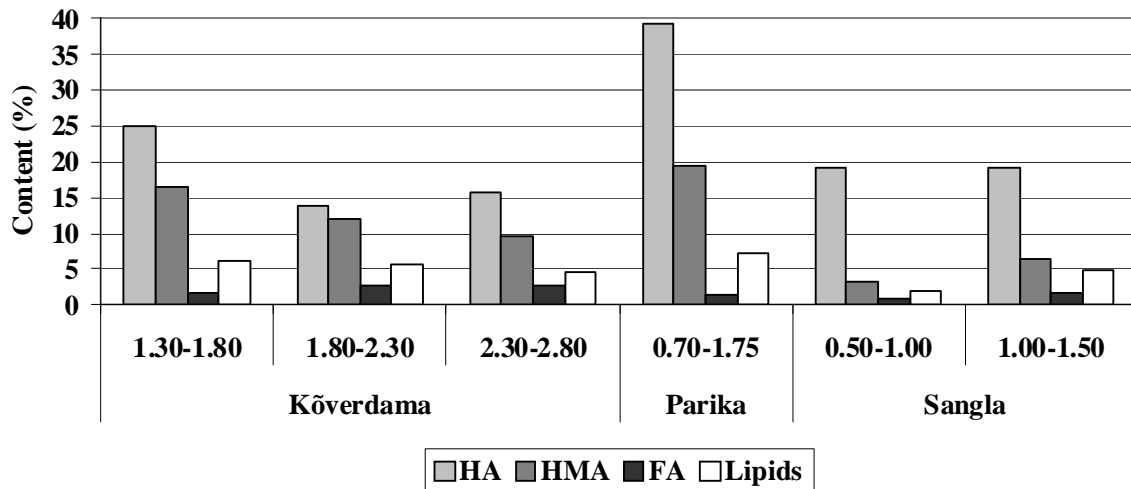
Peatland	Genesis of peat deposit	Mineral subsoil	Vegetation	Nutrition	Depth of peat layer (m)	Peat type	Degree of humification (%; von Post scale)	Ash content (%)	pH	Moisture content (%)
Kõverdama	Paludification	Clay-sand	Pine forest, mosses	Precipitation	1.30–2.80	Heath- <i>Sphagnum</i> , heath cottongrass peat	40–45, H7	4.5	4.55	88
Parika	Lake paludification	Sand	Pine forest	Precipitation	0.70–1.60	Pine- <i>Sphagnum</i> , forest-cottongrass peat	50, H8	2.8	4	87
Sangla	Basin paludification	Gyttja, sand-clay	Pine, birch forest	Precipitation	0.70–2.00	Heath- <i>Sphagnum</i> , heath-cottongrass peat	40–45, H7	4.8	4.8	88

### 3.2. Yield of humic fractions from peat

The analyses showed that in all peat layers HA, HMA and FA can be found (Figure 2). The abundance of humic substances in studied peatlands in Estonia was relatively high. The highest concentration of HS (up to 60%) was found in Parika peatland. This is higher compared to results from Finland, where Uosukainen (2002) got the concentration of HA and HMA from 20–40% and FA from 4–12%. The highest concentrations could be found in well humified (H9) *Sphagnum* peat and less in *Carex* and *Sphagnum-Carex* peat. So both, degree of humification and peat type seem to be important factors affecting concentration of HS in peat. However, Kleb et al. (1999) found that the highest content of HS in peat deposits near Lake Balaton was found in the 0.5–2 m zone and in the range of 43–68%, which is even more than in Parika peatland. Compared to sea and lake sediments (that have historically been used in balneotherapy in Estonia), these levels of HS in peat are higher. Übner et al. (2004) have reported HA 0.15%, HMA 0.08% and FA 0.24% in Haapsalu Bay sediments and HA 2.81%, HMA 0.34%, FA 0.23% in Lake Ermistu sediments.

Content of HS somewhat depended also on the depth of peat layers. Smallest content was in Sangla in the depth of 0.50–1 m (23.5%) and highest in Parika in the depth of 1.25–1.75 m (59.9%). In Sangla the content of HS increased when the depth is increased; however, in Kõverdama peatland that content decreased. In Parika and Sangla peatland the highest content of HS was in the depth of 1–1.8 m. The main explanation for higher content of HS could be first the earlier mentioned degree of humification that increases with depth and the highest value (50%) was found in Parika peatland. Second, it could be affected also by peat type and

age, as Parika is one of the oldest peatlands in Estonia (Orru et al. 1992). During this Orru et al. study (1992) also HA+HMA fraction was analysed in mixed samples from several peatlands, where the concentration was 16% in light humified (H1) *Sphagnum-fuscum* peat, 20% in further humified (H2) peat, 32% in moderately humified (H4) cottongrass-*Sphagnum* peat and 41% in well humified (H7) cottongrass peat.



**Figure 2.** The content of humic (HA), hymatomelanic (HMA), fulvic (FA) acids and lipids in peat dry weight.

The relationship between HA, HMA and FA varied as well. It was 8:6:1 in Kõverdama, 30:15:1 in Parika and 16:4:1 in Sangla. Even more important, the relationship between HA and HMA was subsequently 1.4:1, 2:1 and 3.9:1. Comparing those data with sea and lake sediments (Übner et al. 2004), the differences were not big. Parika peat and sea sediment had almost the same relationship between HA and HMA fractions and lake sediment had the highest value. According to the former research if humic substances occur complexly in peat they are good for human organisms due to their healing properties for arthritis, osteoporosis, rehabilitation problems after operations, degenerative joint-damages, skin problems, stress etc. (Korhonen & Lüttig 1996).

Discussing the different HS components, in FA the amount of carboxyl and phenolic hydroxyl groups is usually higher than for HA (Stevenson 1994). Besides those major functional groups cited above, HMA contains also different subunits from fatty acids, waxes, carbohydrates, terpenes, and nitrogen containing compounds (Glebova 1985). The highest content of lipids was in Parika in the depth of 1.25–1.75 m (7.3%) and smallest content was in Sangla in the depth of 0.50–1 m (1.9%). When the Pearson correlation coefficients were calculated for the content of lipids and HS fractions, the highest correlation had HMA fraction ( $r=0.93$ ). It was lower for HA ( $r=0.57$ ) and lowest for FA ( $r=0.22$ ). This confirms the previous findings by Glebova (1985) that HMA contain different lipids.

### 3.3. Trace elements and HS fractions

As conversed earlier, the chemical composition of peat depends on a number of factors like: feeding conditions of peatland, geomorphologic position, geological setting of region, environmental conditions, and anthropogenic impact. Among the factors, the feeding conditions have shown the main impact, especially for the concentrations of trace elements, as negative factor limiting the usability of balneological peat (Orru & Orru 2008; Szajdak & Hladon 2009). The content of trace elements has been analyzed in these peatlands by Orru & Orru (2006).

In general, the abundance of trace elements in these three peatlands was lower than on average in Estonian peatlands. However, the S content was slightly higher. Moreover, the small existed differences between peatlands could be related to HS. It is known that HS have the ability to react with cations because of strong association of HS with organic and inorganic compounds in soil and water, acting as both storage and transport agents for these species (von Wandruszka 2000). If the HS are acting as transport and storage agents then the content of metals and HS fractions must be correlated. For that purpose, the Pearson correlation coefficients were calculated for each HS fraction (Table 2).

**Table 2.** Correlation coefficients for the content of HS fractions and different metals

	Cd	Pb	U	Th	Sr	Cu	Zn	Mn
HA	-0.50	-0.47	-0.42	<b>-0.76</b>	<b>-0.82</b>	-0.48	-0.47	<b>-0.75</b>
HMA	0.14	-0.15	-0.21	-0.28	-0.26	-0.25	-0.19	<b>-0.83</b>
FA	<b>0.91</b>	0.67	0.61	<b>0.86</b>	0.68	0.67	<b>0.76</b>	0.35

It appeared that FA have good correlations with most of metals, especially with Cd, Th, and Zn. For that reason, higher concentrations of those metals appeared in Kõverdama, where the concentration of FA was the highest. Furthermore, it is known that FA has higher affinity for Pb and Cd (Sekaly et al. 1999). HA fraction gave good negative correlations with Th, Sr, and Mn. Because of that, the concentration of Sr was probably lower in Sangla, where concentration of HA was the highest. HMA fraction, which contains more lipids have good negative correlations with Mn. For that reason in Parika the concentration of HMA fraction was the highest and the concentration on Mn was the lowest.

## CONCLUSIONS

- Balneologically usable peat was found in all three studied peatlands. The biggest resources (0.47 million tons) were in Sangla, but the highest content of humic substances (HS) was found in Parika (resources 0.11 million tons). The genesis of peat deposits was mainly lake paludification, mineral subsoil sand-clay, vegetation pine forest, nutrition precipitation, degree of humification 40–50% (H6–H8) and moisture content 85–90%. Peat type varied, but cottongrass and *Sphagnum* were dominating.
- The main factors influencing the levels of HS were degree on humification and peat type. More humified peat had higher concentrations of HS; however, it was also related to age of peat layers as formation of bioactive substances is time-consuming process. Among the different peat types the forest(pine)-cottongrass seems to increase the levels of HS the most. The lipids in peat could be associated with hylatomelanolic acids because of high correlation coefficients. Whereas several trace elements were well correlated with fulvic acids and some of them negatively correlated with humic acids.

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## **Kolme balneoloogilise potentsiaaliga Eesti turbala turba keemilised omadused**

Balneoloogias on muuhulgas kasutatud edukalt turvast ja mitmeid turbatooteid. Bioloogilise toime tõttu on erilise tähtsusega turbas leiduvad humiinained. Johtuvalt Eesti soode revisjonist ning kaardistamisest, valiti kolm balneoloogilise potentsiaaliga turbaala, kus analüüsiti humiin, hümatomelaan ja fulvohapete sisaldust ning turba üldtehnilisi näitajaid (mineraalainete sisaldus, niiskus, happesus, lagunemisaste ja turbaliik). Selgus, et bioaktiivsete ainete sisaldus kõikides proovitud turbakihtides oli suhteliselt kõrge. Suurimad sisaldused leiti Parika turbaalal, kus humiinhapete sisaldus turba kuivaines oli 39,3%, hümatomelaanhapete sisaldus 19,3% ja fulvohapete sisaldus 1,3%. Peamised faktorid, mis mõjutasid bioaktiivsete ainete sisaldust turbas olid lagunemisaste (kõrgemad kontsentratsioonid oli enam lagunened turbas) ja turbaliik (metsa(männi)-villpea turba leidumine suurendas sisaldusi). Kuna lipiididel oli kõrge korrelatsioon hümatomelaan hapetega ja mikroelementidel fulvohapetega, võivad need komponendid olla vastavalt seotud nimetatud humiinainetega.



## PAPER VI

Orru, M. Re-vegetation of abandoned peat production fields in Estonia and environmental conditions affecting the processes. Submitted to *Mires and Peat*.



# Re-vegetation of abandoned peat production fields in Estonia and environmental conditions affecting the processes

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## SUMMARY

Eighty one abandoned peat production fields with a total area of about 9000 ha exist or investigated in Estonia. Just a very small part of this area has been restored – either afforested or used for growing berries. The re-vegetation of Estonian abandoned peat production fields is mainly the result of natural processes, which are generally very slow due to unfavourable water regime or too thin remaining peat layers. The fields are mostly covered by cottongrass and birches. Often sparse vegetation covers 10–20% of a peat field, but some fields have turned into heaths or grasslands with plant coverage up to 60%. Several moss species new or rare in Estonia have been identified in these areas, e.g. *Polia elongata*, *Ephemerum serratum*, *Campylopus introflexus* and *Bryum oblongum*, resulting from changes in environmental conditions and peat characteristics.

**KEY WORDS:** abandoned peat field, re-vegetation, peat resources, Estonia.

## INTRODUCTION

Peat extraction has long traditions in Estonia. By the end of the 18<sup>th</sup> century most of the forests were depleted (Etverk 1974), which gave rise to more extensive use of peat as fuel by industrial enterprises and households. Around the middle of the 19<sup>th</sup> century, peat started to be used as litter too. For this purpose 14,000 ha of mires were rented out to cooperatives and farmers before World War II (Raudsepp 1946). Peat was extracted in open fields largely by hand, but after World War II the work was gradually mechanised. In the 1950s peat milling was introduced, which has by now become the main extraction technique in peat production. The area of milled peat fields grew rapidly and reached about 25,000 ha in 1971 (Orru & Orru 2008). The peat production amounted to 2–2.5 million tonnes per year. With time, the peat fields gradually became exhausted and by the beginning of the 1990s the area of milled peat fields stabilised at about 15,000 ha. The annual average peat production was then 1–1.2 million tonnes. In recent years the area of peat fields rented out by the state has increased to almost 20,000 ha, but the production volume has not grown (Orru & Orru 2008). The reserves of operating peat milling fields is 24.0 million tonnes as poorly humified and 75.0 million tonnes as well humified peat (Ramst & Orru 2009).

The harvesting of peatlands completely changes the original mire ecosystem. Practical methods for after-use of the disturbed ecosystems are of major importance for both landscape and environment. The re-vegetation of these areas is usually slow and depends on several geological and hydrological factors. The conditions (e.g. climate and peat characteristics) are locally very different and the results from other regions (e.g. Canada) cannot be automatically implemented (Bussi eres *et al.* 2008). The cut-away peatlands are a harsh environment for plants due to unstable water conditions, wind erosion and frost heaving (Huotari *et al.* 2008). Besides, decreased microbial populations (Andersen *et al.* 2006) and low mineral content (Huotari *et al.* 2007) restrict the formation of vegetation. Peat harvesting also removes much of the viable seed bank (Salonen 1987).

The abandoned peatlands may be large sources of carbon loss (Waddington & McNeil 2002, Worrall *et al.* 2003). Peat is also destroyed by wind erosion (Campbell *et al.* 2002). In order to reduce these processes the peatlands should be restored. The main restoration methods suitable for our region are believed to be return to natural peatlands (Vasander *et al.* 2003), afforestation (Pikk & Valk 1996, Aro 2008), cultivation of berries (Starast *et al.* 2009) and reed canary grass (Reinikainen *et al.* 2008), etc. However, re-vegetation and plant cultivation is complicated due to low water levels and wind erosion in these areas (Rocheport 2001).

The aims of the current study were

- to register all abandoned milled peat production fields in Estonia, determine their area and peat resources and to evaluate their present condition;
- to assess the state of vegetation, water level and water regime;
- to determine the composition and general characteristics of peat layers;
- to find out the main factors influencing the re-vegetation processes in abandoned peat production fields.

## METHODS

### Study area

The inventory of Estonian abandoned peat fields was carried out by the Geological Survey of Estonia in 2005–2009 with participation of the author. Altogether 81 abandoned peat fields (Figure 1) have been registered on the basis of digitalised and aerial maps. Prior to fieldwork, the data available on the geological setting, hydrological conditions, properties of the peat deposit, mining period and production volume of the abandoned milled peat fields located in the study areas were examined. Besides, the results of previous investigations (mainly manuscript reports stored at the Geological Survey of Estonia) concerning the current subject were studied.

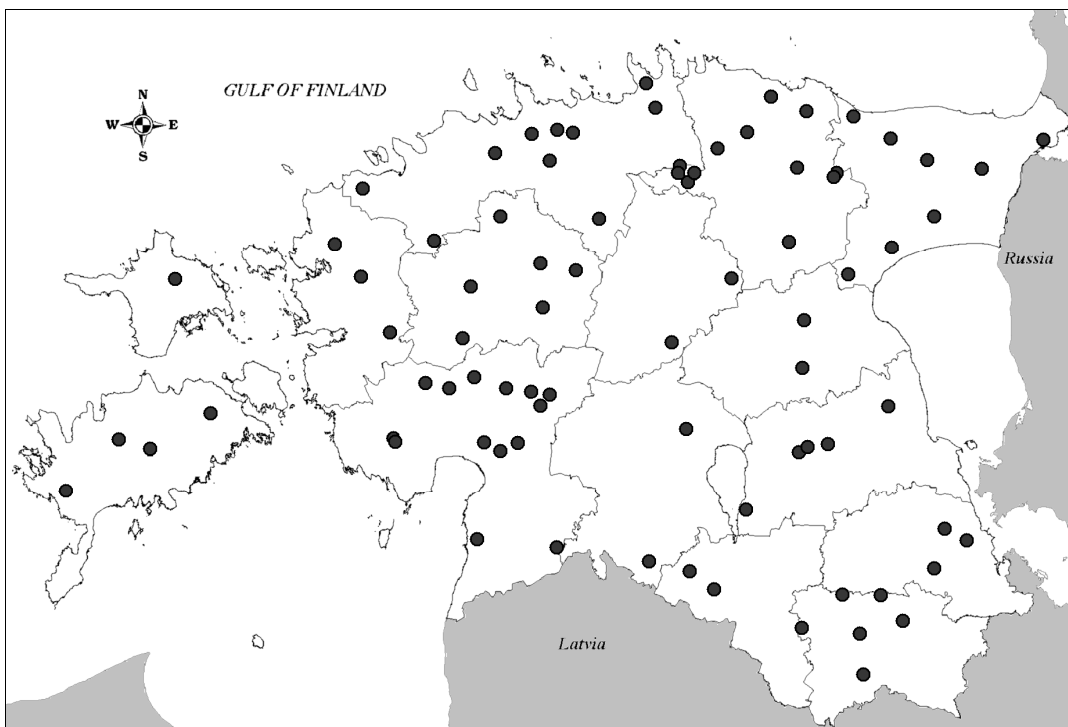


Figure 1. Abandoned peat production fields in Estonia (marked by filled circles).

## Fieldwork, sampling and analysis

In the course of fieldwork, complex investigation of the surveyed milled peat fields was carried out. The boundaries of the fields were specified by using the GPS. The vegetation of different parts of the fields was described (coverage by different layers, species composition) and 320 plant samples were collected for later identification. At single points (on average one point per 10 ha) the thickness of the peat layers was measured by peat sounding, whereas the thickness of poorly as well as well humified peat layers was determined in 890 points. The state of the drainage system and surface water level were also studied. In the peatlands the botanical composition of peat and the decomposition degree of peat (according to von Post) were first determined visually. Later altogether 534 samples were taken for general laboratory analyses of peat (decomposition degree, ash content, acidity, moisture content) at 0.5 m intervals at one point in each homogeneous area. The more exact botanical composition of peat as the content of different species was determined under microscope.

## RESULTS

### Peat deposits in abandoned production fields

The 81 abandoned production fields have the total area of 8,878 ha with peat reserves 14.4 million tonnes (3.4 million tonnes as poorly humified and 11.0 million tonnes well humified peat) (Table 1). The size of the abandoned peat fields varies between 15 and 1,400 ha. However, the majority of them is between 100 and 200 ha. The biggest abandoned peat field lies in Ida-Viru county in Puhatu peatland, where peat was produced for briquette manufacture (currently the factory is out of operation).

**Table 1.** The area and reserves of operating and abandoned peat milling fields

County	Number	Area, ha	Reserves, million tonnes	
			Poorly humified peat	Well humified peat
Harju	10	415	0.36	0.65
Rapla	6	346	0.46	0.87
Lääne	3	82	0.05	0.13
Järva	2	203	0.15	0.63
Jõgeva	2	68	0.01	0.11
Ida-Viru	8	1931	0.49	1.81
Lääne-Viru	12	609	0.24	1.93
Tartu	5	254	0.25	0.66
Viljandi	2	87	0.08	0.23
Pärnu	15	3816	0.32	1.32
Hiiu	1	38	0.04	0.06
Saare	4	286	0.15	0.78
Valga	2	109	0.04	0.35
Võru	6	498	0.66	1.07
Põlva	3	136	0.10	0.38
<b>Total</b>	<b>81</b>	<b>8878</b>	<b>3.40</b>	<b>10.98</b>

The current research showed that the remaining peat deposit in abandoned production fields is in general rather thin both among poorly and well humified peat layers. However, it varies a lot among areas. The depths of the poorly humified peat layer differ from 0.2 to 2.6 m (average 1.7 m) and well humified peat layers from 0.3 to 3.4 m (average 2.1 m). As abandoned production fields are drained areas with very diverse water regimes, the moisture content of peat varies on large extent (74–93%).

In study areas all three kinds of peat layers (eutrophic, mesotrophic, oligotrophic) can be found. The eutrophic peat consists of well humified (von Post 4–6) *Phragmites*, *Lignum-Phragmites*, *Phragmites-Carex*, *Lignum-Carex*, *Lignum-Graminaceae*, *Graminaceae-Hypnum* and *Lignum peat*. The average depth of these peat layers was 1.9–2.1 m. The mesotrophic peat has the most limited distribution. The peat layers with the depth of 0.5–0.6 m (seldom up to 1.0 m) consist little less humified (von Post 3–4) *Phragmites-Sphagnum*, *Sphagnum* and *Lignum-Graminaceae* peat. The ash content of mesotrophic as well as eutrophic peat is on average 5.2–7.4%. However, in bottom layers it is much higher – 12–14%. The acidity of increases in order: eutrophic (pH 4.6–5.5), mesotrophic (3.1–4.1) and oligotrophic (2.8–3.1) peat. The upper part of usually 1.5–1.8 m deep oligotrophic peats layers consist of *Sphagnum fuscum*, and *Sphagnum magellanicum* peat and lower layers *Eriophorum-Sphagnum*, *Pinus-Sphagnum*, and complex peat. This raised bog peat is poorly humified (von Post 2–3) with low ash content (1.1–3.6%).

## Vegetation

As most of peat production field in Estonia were abandoned 20–30 years ago when no legal obligation for mining enterprises to reclaim the areas damaged by mining; only a very small part of the exhausted peat fields has been restored. Thus, re-vegetation of Estonian abandoned peat production fields is mostly the result of natural processes.

In general, the cottongrass (*Eriophorum vaginatum*), but also hair moss (*Polytrichum*) are the pioneer plants colonising the areas where bog peat is preserved (Figure 2). Later on birch, pine and spruce start to grow. The appearance of trees is accompanied by perishing of cottongrass tufts due to evaporation of water via the trees. Peat moss grows only in the trenches of abandoned peatlands with a sufficient amount of water, where the peat moss layer is preserved as well.



Figure 2. Fields with cottongrass (*Eriophorum vaginatum*). Hara bog. Northern Estonia (photo by R. Ramst).

The areas with a thin peat deposit often lack poorly decomposed peat layers, and are thus favourable for the establishment of grasses (*Calamagrostis canescens*, *Calamagrostis epigejos* and *Festuca rubra*, at moister sites *Phragmites communi* and *Molinia caerulea*). The moss layer is usually thicker in the areas with higher topography and near ditches. The most abundant moss species in abandoned peat fields is *Polytrichum strictum*, but also *Polytrichum juniperinum*, *Pohlia nutans*, *Pleurozium schreberi* and *Bryum caespitium* are typical. The most common lichens are *Cladonia deformis*, *C. fimbriata*, *C. chlorophaea* and *C. coniocraea*. Peat mosses are very rare in the fields, but locally rather common at the bottoms of ditches (*Sphagnum cuspidatum*, *S. capillifolium*, *S. majus*). *Warnstorfia fluitans* is the most frequent moss species growing in ditches. In addition to hare's-tail cottongrass, flowering plants are represented by sedges (*Carex rostrata*, *Carex pseudocyperus*), rushes (*Juncus articulatus*, *Juncus bufonius*) (Figure 3), marsh arrowgrass (*Triglochin palustre*), broadleaf cattail (*Typha latifolia*) and reeds.

Interestingly it appeared that former peat production fields sparsely re-vegetated are best suited for the growth of several moss species, as these cannot inhabit areas already occupied by other species. Several new species were detected during the inventory: a second locality of *Polia elongata* in western Estonia; *Ephemerum serratum*, last found in Estonia in the middle of the 19<sup>th</sup> century, in central Estonia; *Campylopus introflexus* and *Bryum oblongum* in South Estonia.



Figure 3. Toad rush (*Juncus bufonius*) in Pruuna bog (photo by R. Ramst).

## DISCUSSION

The results of the inventory showed that the abandoned peat production fields of Estonia differ considerably in terms of the thickness of the peat deposit, hydrological regime and vegetation. Furthermore, the processes are diverse in different types of fields. Subsequently the main factors affecting the re-vegetation in different types of peat production fields, and technologies will be discussed.

## Re-vegetation of peat quarries

More than 50 years ago mostly poorly humified peat was extracted in small quarries, mainly manually with spades, and was used as litter. The quarries were small, on average 400–500 m<sup>2</sup> in area and 0.7 m deep and were scattered all over the country. Special drainage ditches were not made, as the quarries were located mostly in the peripheral parts of mires where natural drainage occurs. A characteristic feature of this particular extraction type is that the chemical composition of water changed relatively little because peat was taken out of the quarry in small blocks with natural moisture content, which were further stored on ground surface for drying. By now such quarries are almost completely overgrown with peat moss (Figure 4). Consequently, when the chemical composition of water in peat is altered as little as possible, natural re-vegetation occurs faster and first of all with valuable peat moss. This is also confirmed by the investigations of Wind-Mulder *et al.* (1996), showing that a peat excavation site where minimal peat was removed has presently chemical conditions somewhat similar to those of the original surface, with low element levels typical of bogs. Moreover, in Finland, after 50 years since peat harvesting mire plants have occupied an area in a paludified dragline, which now resembles a mire ecosystem (Klemetti 2008). In Estonia the quarries where peat was extracted with spades usually made up only 0.15% of the territory of peatlands (Raudsepp 1946).



Figure 4. Abandoned peat quarries overgrown with peat moss (photo by M. Orru).

## Re-vegetation of milled-peat production fields

The area of the former litter peat production fields ranges from 10 to 200 ha and the average thickness of the residual deposit is 1.5–2 m. However, the fields where peat is extracted for making briquettes are even larger (up to 460 ha). The upper part of the deposit usually contains a 0.5–1 m thick layer of poorly decomposed oligotrophic peat. The reserves of Estonian abandoned milled-peat production fields amount to 14 million tonnes for an area covering around 9,000 ha (Table 1). In Finland the respective area is even up to 25,000 ha (Sivan & Yli-Petäys 2008). Considering the economic, technological and environmental aspects, 8 million tonnes (2.5 million tonnes of poorly and



5.5 million tonnes of well decomposed peat) on 2,000 ha would still be suited for mining in Estonia. However, this is a much smaller quantity in comparison with the reserves of 99 million tonnes of the presently operating mines. Before extraction of the possible reserves of abandoned peat fields, geological investigations and environmental impact assessment of mining have to be performed. It may turn out that the actual area suitable for restarting mining activity is smaller.

It is important that these abandoned areas should be restored or the peat utilised, otherwise peat will oxidise (Waddington & McNeil 2002) or be subject to wind erosion (Campbell *et al.* 2002). In an actively eroding peatland carbon loss is significant (Worrall *et al.* 2003, Evans *et al.* 2006) and low water levels and wind erosion further hinder the reappearance of plants (Famous *et al.* 1989, Rochefort 2001).

The current conditions and re-vegetation of different abandoned milled-peat production fields vary considerably. The results of investigations have shown that re-vegetation processes are faster in areas where the layer of poorly humified moss peat is preserved. The abandoned sites are often characterised by a varying depth of peat left over the mineral sub-soil (Bellemare 2009). Furthermore, the rate of re-vegetation can be related to geological setting, as more peat and plant species are found in the areas where peat overlies more nutritious carbonate bedrock (Orru *et al.* 1992).

As mentioned above, the abandoned peat production fields of Estonia are first mostly covered by large clumps of common cottongrass (*Eriophorum angustifolium*). The situation is the same in Finland, where cottongrass is also the pioneer of plant colonisation (Tuittila 2000). This pioneer plant species often affects the abandoned peatland ecosystem (Trinder *et al.* 2008). Later on, with the appearance of birch, spruce and pine, cottongrass tufts start to perish because of changed hydrological conditions (Figure 5). The total amount of water lost through birch transpiration is higher than that lost by evaporation from the peat surface (Fay & Lavoie 2009). As a result, peat dries even more and to mineralises rapidly. Mineralised peat is eroded by wind, roots of trees are exposed and trees decline. Decrease in the vegetation of peatlands is accompanied by degradation of the peat layer. In Finland as well several cutaway peat fields are too subject to intense soil erosion and peat oxidation (Picken 2008). In the worst case the entire bog peat layer has been cut away and only a thin (0.3–0.5 m) layer of well humified fen peat which mineralises easily is preserved. Such areas must be reclaimed because natural plant colonisation does not occur here. The water level has to be restored, either by building dams to prevent outflow or by flooding the surfaces. The character of vegetation depends probably also on the distance between drainage ditches in the peat field (Aro *et al.* 1997, Daigle & Gautreau-Daigle 2001). For instance, in Estonia the forest grows rather well (mainly pine, less commonly spruce) on the margins of some abandoned peatlands having a thicker peat layer (min 1.5 m) and a still functioning drainage system (Figure 6).

In most of the Estonian abandoned peat production fields the water table lies at 0.5–1.0 m from the ground level, in the vicinity of large ditches and roads that are used for peat transportation even deeper. Such conditions are not very favourable for the growth of plants and thus several areas practically lack vegetation even 20 years after the mining was terminated. The optimum condition is a permanently high (0.2–0.5 m below the ground surface) groundwater level, permitting successful re-vegetation of the fields within 10 or even less years. The results of the other investigators show that the water table in abandoned mined peatlands is lower and more variable than in unmined sites (Price 2001, Fay & Lavoie 2009). Left untouched, these sites are often barren for decades after harvesting (Nilsson *et al.* 1990). Still, sparse vegetation covering 10–20% of the area has developed in the majority of those fields.

However, some areas are much better re-vegetated. For example, the Hara abandoned peat field in North Estonia is wholly covered by cottongrass. Some abandoned peat fields have turned into heath-like areas with heather coverage of 40–60%. The average groundwater level was there 0.5 m below

ground surface during the growing season and only a relatively small part of poorly decomposed bog peat has been extracted. Shrubs (heather, bog whortleberry, crowberry) grow in these fields mostly in the vicinity of ditches. Single clumps of peat mosses (*Sphagnum cuspidatum*, *S. balticum*, *S. rubellum*, *S. majus*) are found in depressions where the surface water level is 0.1–0.3 m below the ground level. The growth of peat moss species starts usually in the moistest areas on the banks of ditches.



Figure 5. *Eriophorum vaginatum*, partly diminished with the development of the tree layer (photo by R. Ramst).



Figure 6. Pine trees (*Pinus silvestris*) in the Keressaare peatland, southern Estonia (photo by R. Ramst).

## Restored peat production areas

Restoration of wetlands has been a topical issue during the last years, but only a few attempts have been made in this direction in Estonia. A small part (about 50 ha) of abandoned milled peat fields is currently used for growing blueberries (Starast *et al.* 2009) or cranberries (Figure 7). These fields are in good state. The prerequisite for growing berries is that the layer of poorly humified bog peat is preserved, which serves as good substrate for berries.



Figure 7. Cranberry plantation in Valguta bog, southern Estonia (photo by R. Ramst).

Over 10 years of experience in berry cultivation have shown that berries grow well if the peat pH is 5 (T. Jaadla pers. comm. 2010). The best pH value is 3, which inhibits the growth of weeds. In small areas in northern Estonia (near Tallinn) experiments have been made to use sludge for reforestation of abandoned peatlands. The conifers and deciduous trees that have been planted have grown 4–5 m in five years. Moreover, peat moss has been planted on test plots and conditions have been created for mire restoration (drainage ditches have been closed by dams to keep the water in them). It is recommended to equip the dams with regulators to maintain the optimal water level. A peatland-like ecosystem is formed a few years after rewetting (Vasander & Roderfeld 1998). In 2009 the first integrated mire restoration project of an entire abandoned peatland (240 ha) was implemented in the Niibi peatland in western Estonia.

Our investigations showed that besides water level, the other important factors affecting mire restoration are peat composition, surface microrelief and the character of the mineral subsoil. For example, the vegetation is richer in species when the mineral subsoil is rich in carbonates. It should also be mentioned that cut-over peatlands are acidic, typically rich in organic nitrogen, but poor in mineral nutrients, especially phosphorus and potassium (Wind-Mulder *et al.* 1996). Thus fertilizers are believed to be necessary for forest growth. However, the improvements occur if fertilizers are used up to a certain dosage (Bussières *et al.*, 2008). As positive results achieved in Estonia have shown, the substantial remained peat layer is also important (Pikk & Valk 1996, Noormets *et al.* 2004). Moreover, in selecting the alternatives for after-use of abandoned peat fields it is vital to take into consideration

the chemical and physical properties of the mineral subsoil and various other geological factors (Picken 2008). It has been recommended that a variety of hydrological conditions should be created in restored sites in order to enhance environmental heterogeneity (Verberk *et al.* 2006)

In Finland the abandoned peatlands have been mostly forested (Aro 2008) and to some extent cultivated with reed canary grass (*Phalaris arundinacea*) (Reinikainen *et al.* 2008). According to Päivanen & Sakari (2008), forest grows relatively well, probably due to draining, in those pre-drained and partly abandoned peatlands the area of which is smaller. For instance, mainly pine, less commonly spruce grow rather well on the margins of some abandoned peatlands in Estonia where the layer is thicker (min 1.5 m) and the drainage system still functions. Reed canary grass as a potential bioenergy source (Hyvönen *et al.* 2009) has also been cultivated in Estonia in the Lavassaare abandoned peatland. In New-Zealand the main restoration goal has been rapid establishing of vegetation cover and minimising peat degradation. Schipper *et al.* (2002) have found the raised cultivation treatments to be more effective with plant cover exceeding 88% (e.g. *Leptospermum scoparium*) in 2 years, whereas the other cultivation methods provided significantly less cover, ranging between 1 and 75%. Abandoned peatlands are also suitable for cultivation of herbs like majoran (*Origanum vulgare*), salvia (*Salvia officinalis*), lemon balm (*Melissa officinalis*), dill (*Anethum graveolens*), camomile (*Marticaria recutita*) and sundew (*Drosera rotundifolia*) (Galambosi & Jokela 2008).

## CONCLUSIONS

Nearly 9000 ha of abandoned peat production fields were found in 81 peatlands in Estonia, with resources of 14 million tonnes. Of that amount about 2000 ha, with the resources of 8 million tonnes, would be suited for restarting peat mining. These peat layers could be excavated or peatlands restored to prevent peat oxidation.

The conditions of the abandoned peat production fields vary largely; however, the re-vegetation in general is poor. The pioneer plant is usually cottongrass, but also *Polytrichum*. They are followed by birch, pine and spruce. Yet, due to trees and more intensive evaporation, cottongrass tufts start to perish. The areas with a thin peat deposit often lack poorly decomposed peat layers, which favours the establishment of grasses. Peat moss grows only in the trenches of abandoned peatlands with sufficient amounts of water, where some of the peat moss layer is preserved as well.

The abandoned peat production fields are also a suitable habitat for new or rare species of flora in Estonia. Several mosses, such as *Polia elongata*, *Ephemerum serratum*, *Campylopus introflexus* and *Bryum oblongum*, were found there.

The re-vegetation rate of exhausted peat fields depends first of all on the water regime, being promoted by a permanently high (0.2–0.5 m below the ground surface) groundwater level. However, most of the Estonian abandoned peat extraction fields have a water regime unfavourable for re-vegetation and thus will not develop into functioning mire ecosystems even in many years. Additionally, the depth of the remaining peat layer and peat type are important. The milled-peat production fields with a deeper remaining light humified peat layer are better re-vegetated than the areas with thin well humified peat layers.

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