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TRIIN TRIISBERG

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Department of Botany, Institute of Ecology and Earth Sciences,
Faculty of Science and Technology, University of Tartu, Estonia

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Supervisors: Dr. Edgar Karofeld, University of Tartu, Estonia

Prof. Jaanus Paal, University of Tartu, Estonia

Opponent: Prof. Eeva-Stiina Tuittila, School of Forest Sciences, University of Eastern Finland, Finland

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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following papers, which are referred to in the text by Roman numerals:

I Triisberg, T., Paal, J., Karofeld, E. 2011. Re-vegetation of block-cut and milled peatlands: an Estonian example. *Mires and Peat*, 8, 1–14.

II Triisberg, T., Karofeld, E., Liira, J., Orru, M., Ramst, R., Paal, J. 2013. Microtopography and the Properties of Residual Peat Are Convenient Indicators for Restoration Planning of Abandoned Extracted Peatlands. *Restoration Ecology*, 22, 1, 31–39.

III Triisberg, T., Karofeld, E. & Paal, J. 2013. Factors affecting the re-vegetation of abandoned extracted peatlands in Estonia; a synthesis from field and greenhouse studies. *Estonian Journal of Ecology*, 62, 3, 192–211.

IV Karu, H., Pensa, M., Rõõm, E.-I., Portsmuth, A. & Triisberg, T. 2014. Carbon fluxes in forested bog margins along a human impact gradient: could vegetation structure be used as an indicator of peat carbon emissions? *Wetlands Ecology and Management*, Doi: 10.1007/s11273–014–9339–5.

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1. INTRODUCION

In the European Union, only about 2.8% of the land area is covered with peatlands with peat thickness of more than 30 cm; 2.1% of it is in exploitation at present as peat mining areas (Joosten, 2008). For industrial peat mining mostly the ombrotrophic mires (raised bogs) are used because they have a thick (several meters) homogeneous *Sphagnum* peat layer. In former times, peat was traditionally hand-cut from trenches in bog margins or extracted as block-cut peat, and these activities had a rather limited and local impact on the bog ecosystems while no drainage was applied. Therefore, these areas re-vegetated naturally rather quickly. In the middle of the 20th century the situation changed remarkably with taking into use peat milling and vacuum mining techniques that raised rapidly the number and especially the size of peat extraction areas. This technique requires deep drainage of the mined peatland with ditches splitting it into peat fields of approximately 20 m wide, and the removal of the vegetation. After the end of extraction, the extracted peatlands are sometimes used for agricultural purposes and forestry, but quite often they are abandoned without any restoration or further usage. In Estonia peatlands in different stage and conditions cover ~22 % of territory (Orru, 1992), whereas mires still in natural state cover 5.5% (245 000 ha; Paal & Leibak, 2011). The total area of abandoned extracted peatlands is currently 9371 ha (3.8% of the area of natural mires), but in the coming decades this area will be doubled because of the depletion of resources on 20,281 ha by the ongoing peat extraction (Ramst & Orru, 2009; Paal & Leibak, 2013).

The spontaneous re-vegetation of abandoned extracted peatlands is a slow process (Lavoie *et al*., 2003; **paper I**) and, consequently, these areas need an active restoration or rehabilitation. Abandoned and poorly vegetated extracted peatlands (Figure 1) generate a threat to the local environment (they have high risk of fires, destroy natural water balance, cause habitats fragmentation, spoil landscape esthetics *etc*.). Moreover, they have also some effect on the global scale, being, for instance, notable sources of greenhouse gas emission (Paavilainen & Päivänen, 1995; Laine & Minkkinen, 1996; Salm *et al*., 2009). At the same time, the measurements of greenhouse gas emission are laborious; therefore reliable proxies to estimate carbon fluxes from disturbed peatlands based on water table depth and plant species composition would be valuable. It appeared that in poorly drained peatland sites, including old block-cut areas, carbon emissions were strongly related to water table depth, whereas species composition was less sensitive to changes in hydrological conditions (**paper IV**). In addition to that, in poorly drained forested bogs stand structural parameters could potentially be good indicators of soil carbon emissions (**paper IV**).

In Estonia drained and extracted peatlands are after industry the country's second largest source of CO_2, exceeding the emission from traffic nine times (Ilomets, 2001) and the annual peat mineralization from these areas exceeds the amount of peat excavated in a year (Ilomets, 2003). Therefore, restoration of extracted peatlands is a vital task for environmental restoration, and particularly, for the recovery of peat accumulation processes (Rydin & Jeglum, 2006; Clarke & Rieley, 2010). Considering that the peat extraction areas are situated mainly in bogs which provide valuable service as fresh water reservoirs and carbon sinks (Keddy, 2010), the main target of restoration should be directing the re-vegetation succession toward paludification if the environmental conditions are suitable for that.

Figure 1. Poorly re-vegetated abandoned extracted peatland in Viru Bog, North Estonia, *ca* 25 years after the end of peat extraction.

According to the Estonian legislation (Act on Sustainable Development, Earth's Crust Act, Mining Act *etc.*) all mining areas, including extracted peatlands, should be recultivated after the end of mining activities (Raudsep, 2011). Nevertheless, mostly extracted peatlands were abandoned during or some years after the end of the Soviet period by the state owned companies and nowadays the responsibility for the recultivation of these areas is unclear and the restoration of extracted peatlands on state land is not top priority for the government. For that reason the abandoned extracted areas have mostly been left for spontaneous re-vegetation and only a few of them have currently been restored, mostly for forestry. For this financial period (2014–2020) European Union has allocated resources for restoration of ~2000 ha of extracted peatlands.

In extracted peatlands, bog ecosystem is totally destroyed, including hydrological regime, fauna and vegetation. The exposed peat layers at the surface are thousands of years old and contain no viable propagules (Salonen, 1987). They should arrive to the extracted peatlands from the surrounding areas mostly by wind, but the establishment of seeds and propagules is held back by many ecological filters and critical factors (Salonen, 1987; Campbell *et al*., 2003; Price *et al*., 2003; Beleya, 2004) and only few arriving propagules are able to germinate and form the plant assemblages that can survive for a longer period (Egawa *et al*., 2009; Huopalainen *et al*., 1998). Local species richness is positively related to the species evenness in the seed pool (Myels & Harms, 2009), as well as to their dispersal and immigration potential (Campbell *et al*., 2003), but besides the seed rain from the adjacent plant communities, the recovery of vegetation and ecosystem functioning depends on many environmental factors, for example, on unstable moisture conditions caused by the water table fluctuations: in dry periods the water table can often drop more than one metre below the surface of the residual peat surface which can completely dry out, whereas in spring and autumn the area can be flooded (Price *et al*., 1998). Moreover, in the large open extracted peatlands prone to wind erosion (Campbell *et al*., 2002) and frost heaving (Groeneveld & Rochefort, 2002), the growth of the plant species is inhibited also by a changed peat pore structure with the soil becoming more dense and humified (Price, 1997).

Techniques for the restoration of extracted peatlands have been the subject of numerous scientific studies, and several peatland restoration guides have been worked out (Wheeler & Shaw, 1995; Stoneman & Brooks, 1997; Heikkilä *et al*., 2002; Quinty & Rochefort, 2003; Paal, 2011). Although abandoned extracted peatlands have quite similar general characteristics throughout their distribution area, they also have regional peculiarities depending on the local climatic conditions *etc.* which need to be considered while undertaking restoration measures. Estonia with its variable climatic and hydrological conditions belongs geobotanically to the boreonemoral vegetation zone, the western part of Estonia is considered as the slightly maritime section, while the eastern part is more continental (Moen, 1999). Therefore Estonian mires have similarities and differences with the mires in Europe on one side, and with the mires in western Russia on the other side. For successful restoration a better understanding of the factors determining the natural re-vegetation processes and their regional peculiarities is necessary (Campbell *et al*., 2003; Lavoie *et al*., 2003 *etc.*). The most widely used indicator for restoration planning of peatlands is the water table (Wheeler & Shaw, 1995; Price *et al*., 2003; Graf *et al*., 2008), but its large yearly and seasonal fluctuations complicate adequate estimation and besides, the method is rather costly. The cost-efficient restoration planning should consider all critical processes and drivers, which might affect the natural re-vegetation; for that, some robust, easily measurable and stable in time indicators are required.

The current PhD-theses investigated if the main factors that are known from previous studies as affecting the re-vegetation process also influence the re-vegetation in Estonian conditions; for that, in addition to gathering empirical data, experimental studies were conducted. The important part of the current theses was to clarify how the respective results could be used practically in restoration projects.

The main aim of this PhD-theses was (i) to determine the most important environmental factors affecting the re-vegetation of the abandoned extracted peatlands on the local mire and regional scale. Besides, to determine (ii) if some robust environmental variables, such as the properties and the depth of residual peat can serve as potential indicators for restoration planning and how they could be used to improve the restoration methods in disturbed mire ecosystems. In extracted peatlands and in greenhouse experiment also (iii) to clarify the differences and reasons of the re-vegetation processes in the central and marginal parts of abandoned extracted peatlands and, (iv) to ascertain using a greenhouse experiment how the fertilization and favourable moisture conditions influence the species richness and composition.

The theses consist of four papers: **paper I** compares the natural re-vegetation processes of milled and block-cut peatlands; **paper II** searches for the indicators for restoration planning on plant assemblages level considering the majority of Estonian extracted peatlands; **paper III** compares the re-vegetation processes in extracted peatlands and in peat blocks held in greenhouse conditions and clarifies the effect of moisture and fertilization, and, beside that, compares also the re-vegetation processes in the central and marginal parts of the extracted peatlands; **paper IV** deals with problems how the vegetation structure variables could be used as indicators of carbon emission from extracted peatlands. However, in current theses from **paper IV** only the data from Selisoo peatland block-cut area (Seli plot 1.1 and 1.2) plant cover was used and compared to the spontaneously re-vegetated block-cut peatland in **paper I**.

2. MATERIAL AND METHODS

2.1. Study sites and data

Paper I analyses the re-vegetation of two extracted peatlands that were abandoned about the same time (Figure 2): Viru peatland, where peat was extracted using vacuum mining techniques from 1966 to 1986 (Ramst *et al.*, 2005), whereas in Rabivere peatland block-cut peat extraction lasted until 1950 and thereafter, from 1950 to 1982, in some parts of the peatland milling technique was used (Ramst *et al.*, 2005). On the eastern part of the Rabivere milled peat extraction area 15 ha were fertilized with P_2O_5 in 1985. Viru peatland, as well as the milled part of Rabivere peatland, were mainly plantless, while the block-cut area in Rabivere peatland was almost completely re-vegetated. The data in **paper II** include an inventory of almost all abandoned extracted peatlands in Estonia (64 peatlands, Ramst *et al.*, 2005, 2006, 2007, 2008; Figure 2) carried out by the Geological Survey of Estonia upon the request of the Ministry of the Environment. In that way this is the first national-scale statistical study of the natural re-vegetation of abandoned extracted peatlands in the world. Studied peatlands were abandoned 5–50 (mostly 20–30) years ago and were sparsely re-vegetated with a mean projective cover of 10–20%. **Paper III** field studies were carried out on three extracted peatlands that were abandoned approximately at the same time (1982–1987). The extracted areas were mainly plantless, except ditches and areas bordering with forest. In the current theses from **paper IV** the plots from two sites in Selisoo peatland (Seli 1.1 and Seli 1.2 in **paper IV**) were used, both of them located in a former block-cut area, where manual peat cutting ended ~50 years ago and are currently protected as a Natura 2000 area. Vegetation in Selisoo peatland (Figure 2) consisted almost entirely of bog species.

In Viru peatland (**paper I**) vegetation and litter data was gathered from 185 1x1 m sample quadrats from the following microform/microsite types: (i) flats – peat fields between drainage ditches (excluded ditch margins), (ii) ditches, (iii) ditch margins (0–5 m from the ditch) and (iv) from the edge of the road (0–7 m from the sides of peat fields that were adjacent to roads). In Rabivere peatland (**paper I**) 100 1x1 m sample quadrats were analysed in (i) flats, (ii) ditches and (iii) ditch margins (0–5 m from the ditch) of the milled area and in (v) humps and (vi) depressions on the block-cut area. In each sample quadrat the pH, the electrical conductivity and the depth of the bog water table were measured: pH with a Schott Handylab pH 11 Instrument and electrical conductivity ($\mu S\ cm^{-1}$) with a Microcomputer 900. For a 10×10 m sample square centred around each quadrat, the density and height of trees and their saplings were recorded.

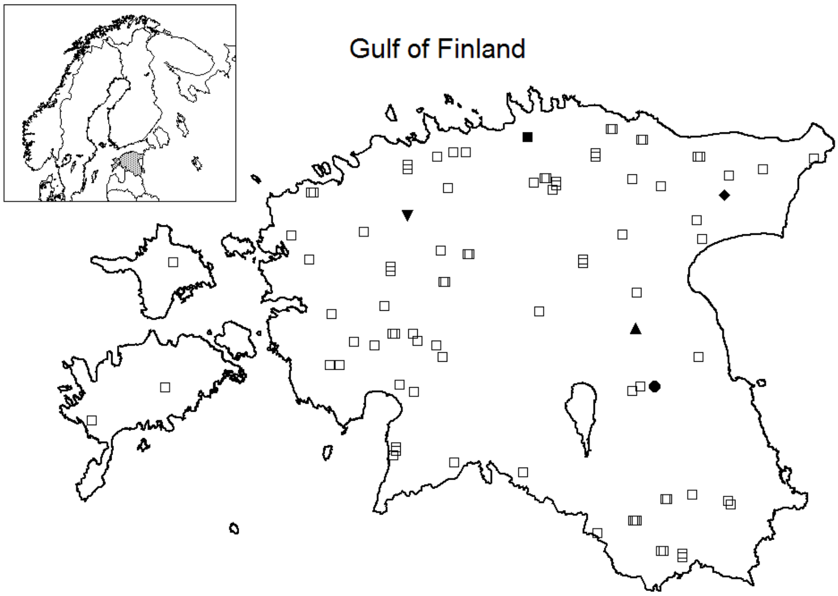

Figure 2. Location of abandoned extracted peatlands in Estonia in studied papers I, II, III, IV. Notations: ▼ – Rabivere peatland, ● – Tähtvere peatland, ■ – Viru peatland, ▲ – Visusti peatland, ◆– Selisoo peatland.

The results of the inventory by Geological Survey of Estonia (Ramst *et al.*, 2005, 2006, 2007, 2008) and the original supplementary data of spontaneous re-vegetation of the extracted peatlands were analysed in **paper II.** The uniform small-area peatlands were inventoried as one study unit, but in the larger-area peatlands, where different peat fields were abandoned at different time or where they had a contrasting outlook due to their treatments, the respective parts were inventoried as separate study areas. The data of those peatlands, which were without an established plant cover and/or areas where peat extraction history was unknown were excluded. In total, survey data from 114 inventory areas was analyzed (Figure 2). During field works by Geological Survey of Estonia, in all inventory areas the presence/absence list of the plant species was compiled separately in three types of microtopographic habitats: flats (peat fields between drainage ditches; excluded ditch margins), ditch margins (0–2 m from the ditch) and ditches. The information about peat characteristics (average depth of the residual peat layer, the thickness of the slightly- and well-decomposed peat, upper-layer peat trophicity level, pH value of the upper-layer peat, degree of decomposition of upper-layer peat) and additional factors such as time since extracted peatland abandonment, the total area of extracted peat fields in the bog and special management operations were considered in the analysis (data from Ramst *et al.*, 2005, 2006, 2007, 2008). The data was supplemented with variables characterizing the landscape around the excavation areas (an active peat mining area, forest *etc.*) and with the distance from the sea, obtained from maps and aerial photos.

Paper III field works were carried out on the marginal and central parts of the extracted peatlands where three randomly placed 1x1 m sample squares (replicants) were described in five randomly chosen localities. In the marginal part the localities represented a gradient from the peatland marginal ditch towards the peatland centre. The first locality was chosen 2–5 m from the marginal ditch. The interval between the next localities was 15–25 m. In the central part of the peatland five sample plots were situated randomly with a distance of 10–15 m as a cluster, while in other localities three 1 x 1 m sample plots were randomly placed. The total number of sample squares was 90. On sample plots the cover percent of every plant species and litter was assessed. In addition, in the bordering forests the plant species list was compiled. In each sample square the degree of peat decomposition was evaluated and the pH and EC of the peat from the depths of 0–10 cm and 10–20 cm from the surface were measured in the laboratory from peat water solution. For measuring the electrical conductivity peat samples were treated with distilled water according to the European Standard of "Determination of electrical conductivity in soil, sewage sludge and biowaste" (www.ecn.nl...). The peat pH was measured using a PE-06HD pH-212 model pH Electrode and the electrical conductivity ($\mu S\ cm^{-1}$) was determined using a Microcomputer 900.

In **paper III**, parallel with the field study a greenhouse experiment was carried out. For that from the marginal and the central parts of the Viru, Tähtvere and Visusti extracted peatlands from the uppermost 10 cm thick peat layer peat blocks were taken from 10 randomly selected points using a saw and mounted into plastic boxes (28 x 42.5 cm). Considering the main wind direction (from W, SW) in Estonia, peat blocks characterizing the peatlands marginal parts were collected at their western edge (~10 m from margin). The peat blocks were held in the greenhouse for 126 days (May to September 2010). Blocks were kept in the greenhouse in natural day light and moderately wet by watering them every few days and sample boxes were covered with a fibric shade cloth to keep the moisture even. The dose of phosphate rock suggested by Sottocornola *et al*. (2007) was used and half of the peat blocks from every sample site was fertilized with complex-fertilizer (granules) equivalent to 25 g/m^2 N:P:K 11–11–21 fertilizer. The species list and number of specimens of each peat block was compiled and the coverage of the mosses was assessed.

In **paper IV** vascular species composition was recorded on 0.4x0.5 m sample squares (n=5) and moss species on 1x1 m squares (n=3).

The nomenclature of vascular plant species follows Leht (2010), of bryophytes Ingerpuu *et al*. (1998), and of lichens Randlane & Saag (1999).

2.2. Data processing

In **paper I** the dataset was grouped according to the peat extraction technique (Treatment) as: (i) the block-cut area on Rabivere peatland, (ii) the fertilized milled area on Rabivere peatland, and (iii) the unfertilized milled area on Viru peatland. The dependence of species richness on environmental variables in **paper I** was found using General Regression Model (GRM) analysis (StatSoft Inc. 2004).

To test the compositional pattern of vegetation (**paper I, III**) Canonical Correspondence Analysis (CCA; Ter Braak & Šmilauer, 2002) was used; before that the values of the study areas distance from the closest forest (**paper III**) were log-transformed. The significance of environmental variables to be included in the CCA model was validated by the conditional effects and Monte Carlo permutation tests. The difference in the mean values of environmental variables in established community types (**paper II**) and in the environmental variables and species cover values according to treatments and microforms (**paper I**) were evaluated using the Univariate ANOVA and the Tukey HSD test (StatSoft Inc. 2004).

The characteristic species for the established data groups (**paper I**), for different peatlands and their study areas in edges, centres and fertilized/ un-fertilized plots (**paper III**) or for each revealed community type (**paper II**) were ascertained according to the Indicator Species Analysis (Dufrêne & Legendre, 1997) implemented in PC-Ord ver. 5.2 (McCune & Mefford, 1999). The significance of each characteristic/indicator species (**paper I**) was evaluated using the Monte Carlo permutation test (McCune & Mefford, 1999). The similarity of species assemblages in sample quadrats grouped by the factors 'Treatment' and 'Microform' (**paper I**) and the distinctness of community types (**paper II**) or species assemblages among peatlands and among their study areas in edges, centres and fertilized/unfertilized plots (**paper III**) was tested using the Multi-Response Permutation Procedures (MRPP; McCune & Mefford, 1999) taking into account the Bonferroni correction for multiple comparisons in pair-wise tests.

The generalized pattern in floristic composition in **paper II** was analysed by the Detrended Correspondence Analysis (DCA; McCune & Mefford, 1999). To define the species community/assemblage types for microtopographic forms Cluster Analysis was applied. For that the chord distance was used as the dissimilarity measure, and the flexible beta method (β=−0.8) as the grouping algorithm (McCune & Mefford, 1999).

3. RESULTS

3.1. Plant species composition

The spontaneous re-vegetation of extracted peatlands varies greatly and depends on the surface topography, the peat properties *etc*. Vegetation in ditches differs from the vegetation in flats and ditch margins (DCA; Fig. 2 in **paper II**) and from the vegetation in other microforms (humps, depressions in **paper I**; CCA, Fig. 2 in **paper I**). For that reason in **paper II** flats and ditch margins were processed separately from ditches. The distinction of the vegetation in flats and ditch margins (**paper II**) was also confirmed by the MRPP test ($p<0.001$). In **paper I** species composition differs significantly between the three treatment areas considered.

It was found (**paper I, II, III**) that the most common species in flats in Estonian extracted peatlands were *Betula* spp., *Pinus sylvestris*, *Eriophorum angustifolium*, *Eriophorum vaginatum*, *Calluna vulgaris*, *Oxycoccus palustris*, *Pleurozium schreberi*, *Polytrichum strictum* and *Cladonia coniocraea*, in ditch margins *Betula* spp., *Calluna vulgaris* and *Empetrum nigrum*. Ditches were most frequently vegetated by *Eriophorum vaginatum*, *Carex rostrata, C. pseudocyperus*, *Salix* spp., *Typha latifolia*, *Sphagnum cuspidatum*, *S. riparium* and *Warnstorfia fluitans*. On depressions and humps on the block-cut area (**paper I, IV**) were growing mostly typical bog species: on depressions *Oxycoccus palustris*, *Sphagnum capillifolium*, *S. fuscum* and *S. magellanicum*, on humps *Ledum palustre*, *Rubus chamaemorus*, *Vaccinium uliginosum*, *Pleurozium schreberi* and *Cladina* spp. On road margins of extracted areas *Eriophorum vaginatum* and *Calluna vulgaris* were abundant.

Adjacent areas of block-cut areas in **paper I** (Rabivere) and **paper IV** (Seli 1.1 and Seli 1.2) were similar: still, undisturbed areas were closer in Selisoo than in Rabivere, bordering with forested and peat extraction areas. Species compositon in Rabivere block-cut and Seli 1.1 and 1.2 areas were quite similar, nevertheless in Rabivere there was much more bog species such as *Rhynchospora alba*, *Sphagnum capillifolium*, *S. fuscum*, *S. cuspidatum etc*. Beside, some mineral soil species were presented, such as *Hylocomium splendens* and *Melampyrum sylvaticum* in Selisoo block-cut area (Table 4 in **paper IV**), and *Cladonia* sp. and *Cladina* sp. in Rabivere block-cut area.

In peat blocks kept in greenhouse (**paper III**) the most common species were *Betula* spp., *Pinus sylvestris*, *Eriophorum vaginatum* and *Polytrichum strictum*, but also several ruderal or forest species that were absent in the peatlands or even in their neighbouring forests were found, e.g. *Chenopodium* spp., *Cirsium* spp., *Epilobium* spp., *Galinsoga cilicata*, *Senecio vulgaris etc*. Some species such as *Bryum* spp. and *Marchantia polymorpha* that were presented in the greenhouse peat blocks were missing in extracted peatlands. Furthermore, many species were found on the forest edges of the extracted peatlands but were missing in the bordering forests: *Carex panicea*, *C. viridula*, *Drosera rotundifolia*, *Oxycoccus palustris*, *Quercus robur*, *Rhynchospora alba*, *Salix* spp., *Dicranella cerviculata* and *Pohlia nutans*.

The species composition of the greenhouse peat blocks collected from the marginal and central parts of the peatlands was rather different (**paper III**), e.g. *Empetrum nigrum* and *Pinus sylvestris* occurred only in peat blocks from the marginal parts of the peatlands, while such species as *Populus tremula*, *Pteridium aquilinum* and *Vaccinium uliginosum* were presented only in peat blocks from the central parts. The species composition was different in the same way in peat blocks in greenhouse and the sample squares in extracted peatlands: many species that were recorded only in peat blocks in the greenhouse but were absent in the extracted peatlands were found: *Epilobium adenocaulon*, *E. montanum*, *Taraxacum* spp., *Bryum* spp., *Leptobryum pyriforme* and *Marchantia polymorpha*. At the same time species like *Andromeda polifolia*, *Calluna vulgaris*, *Ledum palustre*, *Oxycoccus palustris*, *Rhynchospora alba*, *Vaccinium vitis-idaea*, *Dicranella cerviculata*, *Polytrichum strictum* and *Cladonia* spp. were growing in the extracted peatlands, but did not appear in any greenhouse peat blocks. The species composition of fertilized and non-fertilized peat blocks in the greenhouse did not differ significantly (MRPP test, Table 4 in **paper III**).

The vegetation analyses of flats and ditch margins in extracted peatlands were grouped into four clusters which have distinct (MRPP $p<0.001$) species composition (**paper II**). These clusters were defined as community types, and on the ground of the most contrasting indicator species these types were labeled as: (i) the *Phragmites australis–Calamagrostis canescens* type, (ii) the *Eriophorum vaginatum* type, (iii) the *Calluna vulgaris–Polytrichum strictum* type and, (iv) the *Ledum palustre–Sphagnum magellanicum*–lichens type. In ditches four distinctive (MRPP test $p<0.001$) clusters were established: (i) the *Betula–Salix* type, (ii) the *Phragmites australis* type, (iii) the *Sphagnum cuspidatum* type and, (iv) the *Carex rostrata* type. The last type contains also some sphagna, e.g. *Sphagnum balticum*, *S. capillifolium*, *S. fimbriatum*, *S. magellanicum* and *S. squarrosum*. Many fen species were found in the communities of the *Phragmites australis–Calamagrostis canescens* type, while for the *Ledum palustre–Sphagnum magellanicum*–lichens type communities were characteristic species of transitional mires and raised bogs (**paper II**).

3.2. Species richness

By an inventory of almost all abandoned extracted peatlands in Estonia (**paper II**) all in all 111 vascular plant species and 70 cryptogam (moss and lichen) species were registered, among them 28 species occurred with a frequency of at least 5%.

On local peatland scale the highest number of species (32) was recorded in the block-cut area on Rabivere peatland, whereas in the milled areas it was lower but almost similar – 24 and 23 species for Rabivere peatland (fertilized study area) and Viru peatland (unfertilized study area), respectively (**paper I**). Comparing the total number of species of the extracted peatlands and peat blocks kept in greenhouse (**paper III**), the number of species was similar (27 and 25 respectively). The number of species in fertilized and non-fertilized peat blocks in greenhouse did not differ either (19 and 18 species, respectively).

The mean number of plant species per 1x1 m sample quadrat was the highest (9±4) on the block-cut area and noticeably higher on the fertilized area on Rabivere peatland (5±1) than on the unfertilized area in Viru peatland (2±1) (**paper I**). On the scale of microforms, the number of species was the highest in depressions, followed by flat microsites and humps (**paper I**). The total and the mean number of species in all extracted peatlands was higher in their marginal parts than in their central parts (**paper III**), but we did not find the same regularity in peat blocks kept in greenhouse. Furthermore, fertilization did not have a significant increasing effect on plant species number in peat blocks kept in greenhouse.

Species richness was mainly influenced by factors 'Microform' and 'Treatment' (GRM analyses; Table 6 in **paper I**). In flats and ditch margins the species richness was generally increasing in accordance with residual peat layer depth (Table 4 in **paper II**) and with the closeness of the forest area (Fig. 1 in **paper III**). Nevertheless, by classifying the studied areas into four peatland groups (**paper II**) using two criteria: (i) shallow (<2.3 m) and thick (>2.3 m) layer of residual peat and, (ii) young (<23 years) and old (>23 years) abandoned peatlands, it was not possible to discover any effect of time since peatland abandonment on the species richness. The species richness was positively influenced by a thicker residual peat layer (Table 4 in **paper II**).

According to the community types in flats and ditch margins**,** the species richness was the highest in the *Ledum palustre–Sphagnum magellanicum*–lichens type and the lowest in the *Eriophorum vaginatum* type communities (Table 1 in **paper II**). In ditches the species richness appeared to be almost equal in all types (Table 2 in **paper II**).

3.3. Factors influencing the species composition

The main factors determining the vegetation pattern on abandoned extracted peatlands were surface microtopography/microform: the effect of the 'Microform' variable (Figure 3) from total variation was 6.7% (Table 7 in **paper I)** and the peat extraction technique (variable "Treatment", Figure 3) – the effect of the 'Treatment' variables was 2.5% (Table 7 in **paper I)**. Species assemblage of ditches was clearly distinct from assemblages occurring on other microforms.

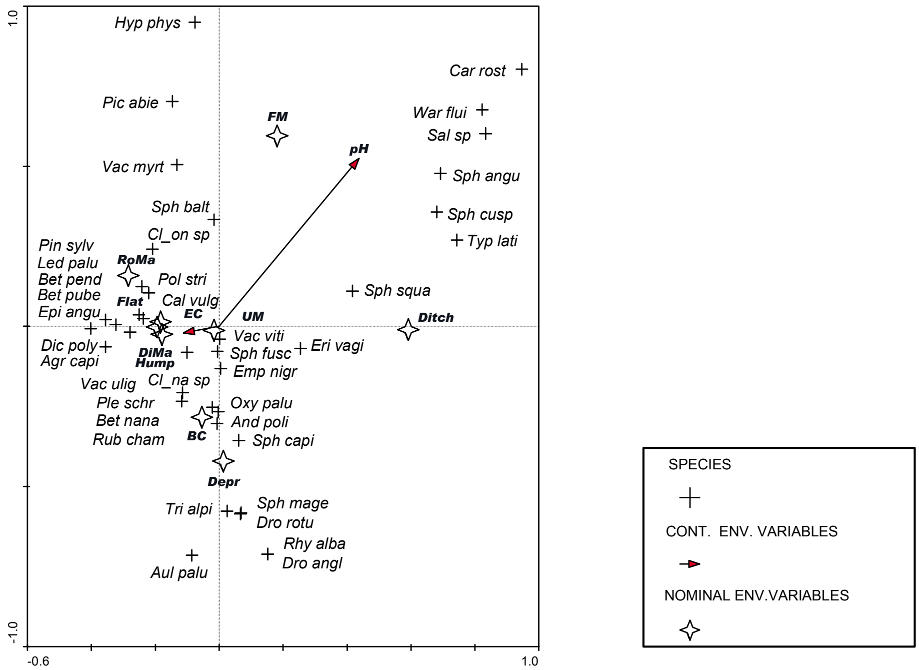

Figure 3. CCA biplot (Axis 1 and Axis 2) of environmental variables and species. Species names are abbreviated to the first three letters of genus and the first four letters of specific epithet. Notations: BC – block-cut area, FM – fertilized milled area, UM – unfertilized milled area; microforms: Flat – flat area, DiMa – ditch margin, Ditch – ditch, RoMa – road margin, Hump – hump, Depr – depression; environmental variables: EC – electrical conductivity of bog water (μS cm^{-1}), pH – pH of bog water.

A considerable part (4.7%) of the total variation in species data was explained by the interaction between the two sets of environmental variables (shared variance; Table 7 in **paper I**). Comparison of the effects of biotic environmental variables and environmental chemistry variables shows that the effect of tree layer and saplings (7.8%) was almost three times larger than the effect of bog water pH and electrical conductivity (2.7%), whereas the fraction of shared variance was in this case very small (1.2%).

Besides microtopography and peat extraction technique, the species composition was affected by bog water pH and residual peat properties. An increase of bog water pH was affecting the species content in the fertilized milled area on Rabivere peatland and in ditches (Figure 3). In flats and ditch margins the variation in vegetation composition was positively correlated with increasing pH, with ash content and the peat trophicity of the upper-layer of residual peat (0–0.5 m), but also with a decrease in the thickness of the slightly-decomposed peat and the total depth of the residual peat layer ($p<0.05$; Table 1 in **paper II** and Figure 4).

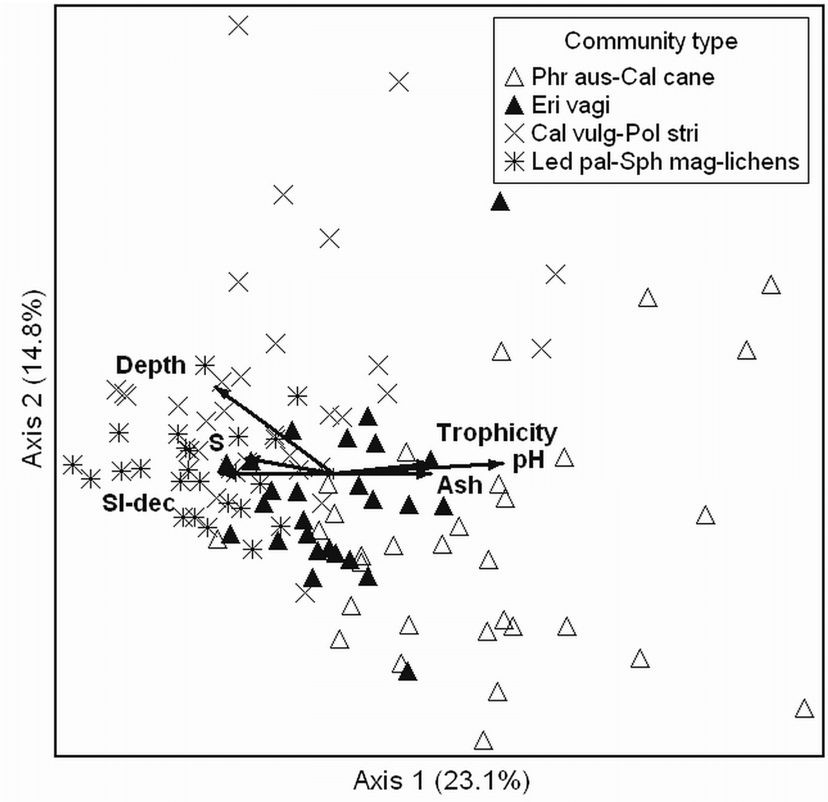

Figure 4. DCA biplot of the environmental factors and vegetation data of flats and ditch margins. Notations: Trophicity, Ash, pH – trophicity level, ash content and pH of the residual peat upper-layer, Depth – depth of the residual peat layer, Sl-dec – thickness of the slightly decomposed peat, S – species richness. Community types: Phr aus-Cal cane – *Phragmites australis–Calamagrostis canescens* type, Eri vagi – *Eriophorum vaginatum* type, Cal vulg-Pol stri – *Calluna vulgaris–Polytrichum strictum* type, Led pal-Sph mag-lichens – *Ledum palustre – Sphagnum magellanicum* – lichens type.

At the same time, only few significant differences of the average estimates in environmental factors between the four community types in flats and ditch margins and four community types in ditches were found. In ditches the vegetation composition was mostly determined by the overall depth of the residual peat and by the thickness of the slightly-decomposed peat layer (Figure 5). A thinner layer of residual peat in flats and ditch margins was associated with the *Phragmites australis–Calamagrostis canescens* community type, whereas the communities of the *Calluna vulgaris–Polytrichum strictum* and the *Ledum palustre–Sphagnum magellanicum*–lichens type in flats and ditch margins and communities of the *Sphagnum cuspidatum* and the *Carex rostrata* in ditches occurred on the thicker layer of slightly-decomposed residual peat (Table 1 and Table 2 in **paper II**). Time since abandonment appeared to be a significant factor, especially in ditches, where it was the strongest factor influencing the vegetation composition. The *Betula–Salix* type in ditches and the *Eriophorum vaginatum* and the *Calluna vulgaris–Polytrichum strictum* types were characteristic for the flats and ditch margins of the most recently abandoned peatlands, while for the development of the *Sphagnum cuspidatum* or *Carex rostrata* type communities in ditches and *Ledum palustre–Sphagnum magellanicum*–lichens type in flats and ditch margins, more time is needed (Table 1 and Table 2 in **paper II**). The impact of other environmental factors, including the water table depth in flats and ditch margins, was rather un-important (Table 1 in **paper II**), caused probably by the scanty and not representable data set for analysis; still, upper-layer moisture has an important role to the re-vegetation as it was shown in the greenhouse experiment (**paper III**). As the importance of water table could not be proved, because water table was measured only once during the field works (**paper II)**, instead of water table the effect of moisture in greenhouse conditions was assessed (**paper III**). In ditches the pH-level of residual peat had also a significant effect (Figure 5).

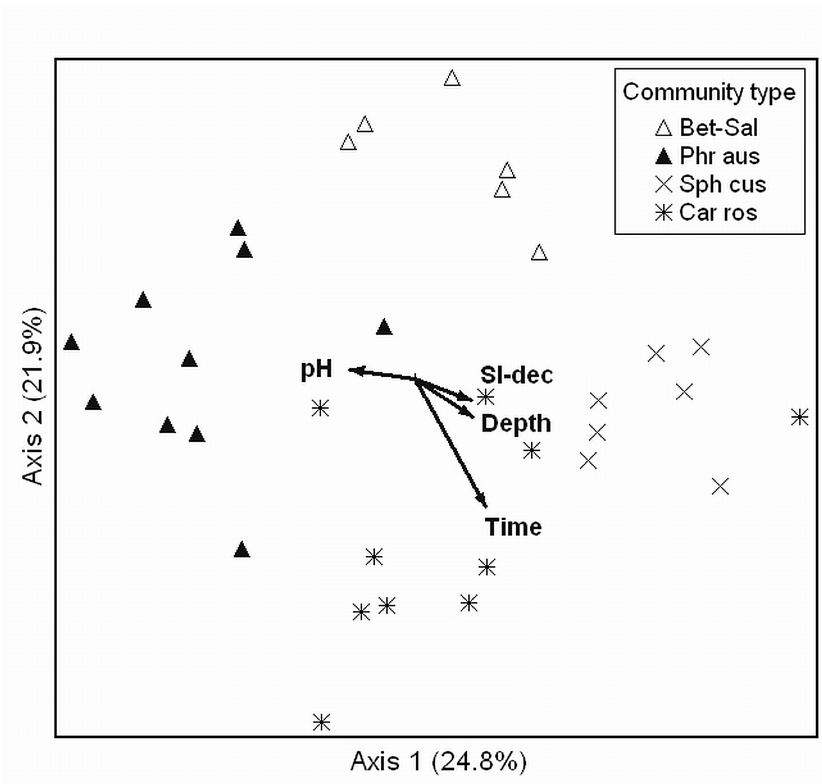

Figure 5. DCA biplot of the environmental factors and vegetation data of ditches. Time – time since peatland abandonment. Community types: Bet-Sal – *Betula–Salix* type, Phr aus – *Phragmites australis* type, Sph cus – *Sphagnum cuspidatum* type, Car ros – *Carex rostrata* type. Other notations as in Figure 4.

In **paper III** it was found that if some pioneer vegetation has already developed on extracted peatlands, its further composition depends largely on the autogenic factors, i.e. on the modification of environment by the plant cover itself (Figure 6): by the litter coverage, the total coverage of vegetation and peat pH in the depth of 10–20 cm. The vegetation composition was also influenced by the properties of the upper peat layer (0–10 cm depth): pH, electrical conductivity and the degree of decomposition. Furthermore, significant were the distance from the nearest forest and the degree of peat decomposition in the depth of 10–20 cm (Figure 6).

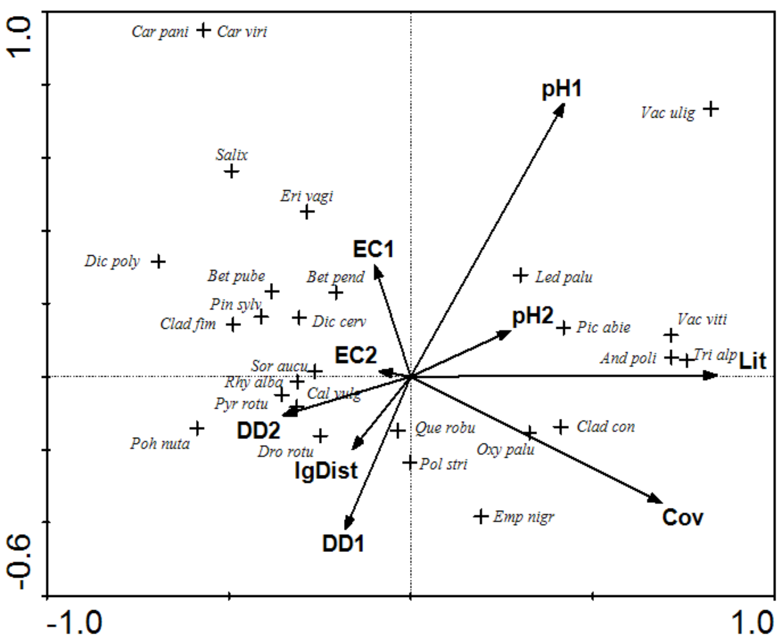

Figure 6. CCA biplot of the environmental factors and field collected vegetation data for abandoned Viru, Tähtvere and Visusti extracted peatlands. Correspondence of the data was 45.8% for the first and 41.0% for the second axis. Notations: Cov – total species coverage on sample squares (%), Lit – total litter coverage on sample squares (%), pH1 and pH2 – pH values of the soil solution in the depths of 0–10 cm and 10–20 cm, correspondingly, EC1 and EC2 – electrical conductivity values (µS cm^{-1}) of the soil solution in the depths of 0–10 cm and 10–20 cm, respectively, DD1 and DD2 – decomposition rates H (von Post scale) of residual peat in the depths of 0–10 cm and 10–20 cm, correspondingly, lgDist – distance from the forest (logarithmed). Species names are abbreviated to the first three letters of genus and the first four letters of specific epithet.

4. DISCUSSION

4.1. The main factors affecting the spontaneous re-vegetation of the abandoned extracted peatlands on the peatland and regional scale

According to the results of the current study and some earlier results (Groeneveld & Rochefort, 2002; Campbell *et al*., 2003), the first species established on extracted peatlands are common pioneer species such as *Betula* spp., *Pinus sylvestris*, *Calluna vulgaris*, *Eriophorum vaginatum etc*. Despite the harsh growth conditions on bare residual peat, the total number of recorded plant species (181) in analysed peatlands was remarkably high (**paper II**). Surprisingly, many species that were recorded in the greenhouse peat blocks, were registered neither on the extracted peatlands nor in the bordering forest areas. Most probably propagules of these species arrived into the extracted peatlands randomly but were able to germinate only in suitable moisture and temperature conditions, mimicked in greenhouse conditions, while on extracted peatlands they remained dormant.

On the local mire scale the main factors influencing the re-vegetation of extracted peatlands were their surface microforms (**paper I**) and former treatment (block-cut or milling) (**paper I, IV**), peat properties (pH, depth of residual peat layer *etc*.) (**paper III**); the total density of established trees and saplings also had some effect (**paper I**). The importance of microtopography has been mentioned also by Rochefort & Campeau (1997) by creating a bigger microhabitats difference for enhancing re-vegetation of extracted peatlands. The positive effect of the tree layer and the saplings has been explained by the better moisture conditions throughout shading, reducing wind erosion and frost heaving (Lachance & Lavoie, 2004). Furthermore, some trees (like birches) are best adapted to the changing water table and can persist in milled areas (Heathwaite, 1995; Lavoie & Saint-Louis, 1999). Once established, birches and other pioneer species create suitable conditions and facilitate the establishment of more demanding species (Boudreau & Rochefort, 1998; Soro *et al*., 1999; Tuittila *et al*., 2000). The litter is substantial for keeping favourable moisture conditions necessary for propagules germination and plant growth (**paper I, III**), moreover, the decomposed organic matter from litter enriches the upper-layer of residual peat with nitrogen (Anggria *et al*., 2012). Still, the litter under the dense tree layer can also impede propagule germination and re-vegetation as it mainly consists of *Pinus sylvestris* needles forming a dense nutrient poor acidic layer (**paper I**).

In addition, it was discovered that in the first stages of re-vegetation the species pool in the neighbouring communities is surely very important, but in the course of succession, when some vegetation has already formed, the autogenic modification of growth conditions becomes more essential (**paper III**). This result is in good accordance with the conclusions brought in Tuittila *et al*. (2000) and Groeneveld & Rochefort (2002, 2005), who have pointed out that the pioneer species *Eriophorum vaginatum*, *Eriophorum angustifolium* and *Polytrichum strictum* reduce frost heaving, prevent residual peat erosion by wind and facilitate the growth of other species (like *Sphagnum* spp.).

The extracted peatlands were sparsely re-vegetated (**paper I, II, III**). In **paper I** it was detected that this refers to the occasional colonization of the plant species, while in the block-cut areas and in the ditches, where the environmental conditions are more stable and favourable, and plants are also able to spread vegetatively, re-vegetation was more successful. In block-cut areas it is tending towards the natural raised bogs or bog forests. Former block-cut areas are more favourable for spontaneous re-vegetation (Poulin *et al*., 2005) due to the smaller area promoting plant invasion from the adjacent intact areas, shallower or absent drainage, and because usually vegetation fragments are left beside the mining trenches after mining. Rabivere peatland block-cut area in **paper I** had higher plant species diversity (almost 30 species) and cover that was supported by microtopographical heterogeneity, which created suitable growth conditions for various plant species. Rabivere (**paper I**) and Selisoo site block-cut area (**paper IV**) were in general re-vegetated quite similarly. The number and cover of *Sphagnum* species in block-cut areas (**paper I, IV**) were indicative of the successful vegetation recovery, as the accumulation of more or less decomposed plant biomass was formed mainly by the *Sphagnum* mosses that is usually an expected result in bog restoration (Rochefort, 2000; Quinty & Rochefort, 2003).

The re-vegetation in ditches in Viru and Rabivere extracted peatlands was faster due to the better moisture conditions and because their bottoms are formed by peat dust blown in from the adjacent peat fields. Moreover, these areas rose and sank synchronously with the fluctuating water table providing stable moisture conditions for plants; these proccesses do not happen on peat fields, where water table also fluctuates greatly, but where moisture conditions are less appropriate to plants germination and survival. The number of plant species in ditches was the lowest among studied microforms, but to some extent this fact follows from their smaller total area, especially as compared to flats (**paper I**). Furthermore, plants in ditches are favoured by water movement carrying more nutrients and oxygen (Campeau *et al*., 2004).

Re-vegetation begins usually in the ditches, where moisture conditions are better, on their banks and in the edges of milled peatlands, especially if they are situated closer to forests and roads; on flat areas this process is much slower. For example, in Viru peatland better re-vegetation of peat fields bordering with a maintenance road (0–7 m from the sides of peat fields adjacent to roads) covered by calcareous gravel was documented (**paper I**). The number of plant species there was relatively low, but their total cover was much greater than in the central parts of peat fields. This can be explained by the outwash of minerals from gravel to peat, as shown by the increased electrical conductivity of bog water, and due to the easier spreading of plants from the road-side. The flat central parts of milled peat fields remain plantless for decades because of their large area, which aggravates the arrival of the propagules, and due to the unfavourable conditions (deep and fluctuating water table depth, long draughts, high peat surface temperature, frost heaving, wind erosion *etc.*) for their germination and survival. Because of unrepresentative data it was impossible to prove the importance of water level, but during the greenhouse experiment the importance of upper-layer peat moisture to the re-vegetation was proved (**paper III**). Still, upper level moisture is beside water table influenced by other factors such as the amount of precipitation, shadow, wind *etc*. At the same time, on a larger total area a larger number of different propagules can be carried by the wind, resulting in the bigger average number of species there. However, in these hostile conditions only some propagules can germinate and only a few plants can grow there for longer periods, resulting in a much lower plant cover. On the studied extracted peat fields the vegetation consisted mainly of the single growing pioneer species or sparse plant assemblages.

On the regional scale (**paper II**) it was found that the abandoned extracted peatlands are habitats for several pioneer species characteristic of mineral soils such as *Calamagrostis epigeios*, *C. neglecta*, *Carex flava*, *Juncus bufonius*, *Pyrola rotundifolia* and *Populus tremula.* This supports the earlier findings that milled peatlands are prone to biological invasions from the large species pool from the neighbourhood (Lavoie & Saint-Louis, 1999; Bérubé & Lavoie, 2000). These non-peatland species cannot be considered as a threat for bog restoration, as usually they do not form dense populations in milled peatlands and they will disappear from the community when natural bog vegetation forms (Salonen, 1990; Poulin *et al*., 2005).

The vegetation analyses in **paper II** established several clusters which had a distinct species composition and were defined as community types (see paragraph 3.1). The typical pioneer species of extracted peatlands were found in all community types in flats and ditch margins all over Estonia, but not in ditches, where they were found only in the *Betula–Salix* community type on thin residual peat. The re-vegetation processes on flats and ditch margins on the regional scale (**paper II**) are predicted mostly by the depth and properties of the residual peat which determines the development of the different community types. Beside that, increasing peat depth influences positively the species richness; the situation could probably be different when the residual peat is so thin that the roots of the plants can reach the mineral soil. In ditches the re-vegetation is influenced by peat trophicity: the community types that have formed in ditches are ordered along the gradient from eutrophic to oligotrophic. The time since abandonment has also some effect on ditch vegetation as in the course of decades of non-management ditches will be filled by sediments or collapsed.

4.2. Can some robust environmental characteristics serve as potential indicators for restoration planning?

According to the analysed and supplemented data of inventory of almost all abandoned milled peatlands in Estonia (**paper II**), it was found that a thin upper-layer of slightly decomposed peat or a thick well decomposed peat layer supports the vegetation development toward fens, while a thick layer of slightly decomposed peat promotes the development of vegetation typical to bogs. The communities of the *Phragmites australis* and the *Carex rostrata* community type in ditches, and also the *Phragmites australis–Calamagrostis canescens* communities on flats and ditch margins represent succession towards meso-eutrophic communities, called *Magnocarici–Phragmetetalia* (Succow & Joosten, 2001) or *Phragmites–Carex* fen (Ilomets, 1997). The *Betula–Salix* type communities in ditches with thin residual peat will probably develop into a strip of meso-oligotrophic woodland, where the pioneering birch will later be at least partly replaced by pine and spruce (Ilomets, 1997). The *Eriophorum vaginatum* communities on flats resemble the typical communities in natural transitional mires. Communities of the *Calluna vulgaris–Polytrichum strictum* type and the *Ledum palustre–Sphagnum magellanicum*–lichens type correspond to the path resulting in communities similar to oligotrophic bog vegetation (Paal & Leibak, 2011). These successional pathways are not specific to Estonian conditions only, but also to other regions (e.g. Kovalinkova & Prach, 2010). It was discovered that the depth and some properties (peat decomposition rate, pH) of residual peat are informative indicators for the potential development of vegetation on extracted peatlands and should be considered in the restoration planning.

The present-day restoration practices of extracted peatland areas concentrate mostly on raising the water table by closing ditches, because expectedly the high water table will ensure a permanently sufficient moisture level and direct the secondary succession towards mire communities (Wheeler & Shaw, 1995; Price *et al*., 2003). The damming of ditches is a widely practiced method to support re-vegetation, nevertheless these results vary largely (Bretschneider, 2012). Because of scanty data it was not possible to study the role of water table depth on the field, but the greenhouse experiment revealed the importance of peat layer moisture for germination and growth of plants. The effect of damming depends much on the depth of the ditches, on whether it reaches the well or slightly decomposed peat layer, and wherer it reaches the peatland mineral bottom or not. It is suggested that the restoration projects should also consider the depth and decomposition degree of residual peat: the parts of milled peatlands with thin and well decomposed residual peat should be restored in a way that enhances their development towards fens, and in sites with thick and less decomposed residual peat layer restoration should promote their development towards bogs. On the basis of **paper II** a robust threshold of residual peat layer thickness for choosing the appropriate target community for restoration can be suggested. Areas with less than 2.3 m of residual peat layer should be restored towards fen and areas over 2.3 m of residual peat layer toward raised bog communities. This general threshold is usually correlated with other essential peat properties (e.g. pH, ash content, trophicity status): the residual peat in areas with >2.3 m of abandoned peatlands consists in the upper layer mainly of slightly decomposed peat and in the areas with depth <2.3 m usually of well decomposed peat. Nevertheless, besides those robust indicators predicting the natural re-vegetation of abandoned peatlands, the restoration projects should be planned case by case, considering also the specific conditions of restored area *etc*.

According to the results of these theses, it is suggested that in areas where the vegetation resembling fen or transitional mire communities has spontaneously already formed, the process of natural re-vegetation should be supported by creating/holding appropriate moisture conditions and introducing fragments of fen plants *etc*. In areas where the depth and other properties of residual peat, as well as the already formed vegetation indicate that restoration towards bog communities is possible, the microtopographic variability should be supported. Increasing microhabitats variability, as shown in **paper I** and found by Rochefort & Campeau (1997) supports the species richness and enhances the re-vegetation.

The ditches in extracted peatlands have a contradictory role. Still working ditches are continuously draining the peatland and the ditches bordering the peat mining areas parallel with the roads are serving as a barrier for plants further vegetative spreading towards flats, inhibiting in that way the dispersial of non-peatland plants from road-sides into peat fields. At the same time, parallel ditches in peat mining area serve as spreading-corridors for peatlands species established in ditches. To promote the spreading of bog-species (including *Sphagnum* mosses) from ditches toward flats, it is advisable to create mounds and shallow furrows perpendicularly with ditches to support the establishment of bog species in microhabitat shelters, and to dam both ends of ditches ensuring in that way better moisture conditions for plants growth. The re-vegetation process can also be effectively accelerated by introducing vascular plant and moss propagules – rhizomes, plant fragments, or seeds and spores (Quinty & Rochefort, 2003) or transplanting undisturbed vegetation blocks from the areas prepared for mining. We suggest that the selection of a donor site for plant material should be chosen according to the depth of the residual peat and the planned choice of the successional direction (i.e. target community).

4.3. The differences of re-vegetation processes in the central and marginal parts of abandoned extracted peatlands and in greenhouse experiment

Paper III study reveals a strong decreasing gradient in the number of plant species from the marginal parts of extracted peatlands (that are close to the vegetated areas like forests) towards the central parts within the first *ca* 20 m. In the greenhouse peat blocks, on the contrary, the number of emerged species was higher in peat blocks collected from the central parts of extracted peatlands. This shows that the distance from the neighbouring species pool is not decisive for propagules arrival to the extracted peatland, i.e. the propagules are present everywhere and probably the success of their germination and growth depends on different, often on small scale environmental conditions in the marginal areas and the central parts of peatlands. Marginal areas of extracted peatlands may receive more propagules but are also more affected by drainage, whereas central parts may get more long distance arrivals but are more affected by wind erosion.

The species composition in the marginal and central parts of extracted peatlands (**paper III**) was similar, but in the peat blocks collected from the respective areas and kept in greenhouse it was different. The species composition in the central and marginal parts of the extracted peatlands and also the composition of species germinated in the greenhouse peat blocks were often rather different or coincided only partly. It was found that propagules were distributed unevenly on peatland surface and, therefore, the species number recorded in the sites of the extracted peatlands on a larger total area was much higher than that represented in the greenhouse peat blocks having only a limited surface.

4.4. The influence of the one-time fertilization and favourable moisture conditions on the re-vegetation of extracted peatlands and peat blocks in greenhouse experiment

Using the results from Rabivere peatland it can be concluded that the one-time fertilization *ca* 25 years ago did not have a significant long-term influence on the total number of species (**paper I**), but it increased the plant cover and the mean number of species *per* quadrat supporting the formation of the first plant assemblages, while in the unfertilized extracted area the vegetation coverage was more fragmented and random. Fertilization had a positive effect on the density of trees and saplings (**paper I**), whereas the number of species in fertilized and non-fertilized peat blocks did not differ significantly (**paper III**).

In abandoned extracted peatlands and also in peat blocks kept in greenhouse poor germination ability of plants was noticed: it was illustrated by the low total and mean number of plant species in both areas (**paper III**). The species composition in peat blocks kept in greenhouse in better moisture and temperature conditions (blocks were watered in every few days and were covered with a fibric shade cloth to keep the moisture even) differed from the species composition from abandoned extracted peatlands: in the peat fields mostly typical bog species were presented, while in the greenhouse mainly forest or ruderal species appeared. The occurrence of the latter species in the peat blocks in greenhouse could be explained by better moisture conditions and by the fact that the propagules of ruderal species are more germination capable than other species, especially in better moisture conditions. It is also possible that typical bog species need more time to germinate and stabilize their growth, whereas in this study (**paper III**) their germination was limited by the short duration of the experiment. This difference of species in extracted peatlands and greenhouse peat blocks confirms that the propagules of forest or ruderal plant species are able to arrive to the extracted peatlands, but the unfavourable environmental conditions there do not enable their germination and growth (Belyea, 2004). It was also found (**paper III**) that though many species are able to spread from long distances, their growth will occur only in localities where moisture conditions and nutrient availability enhance propagules germination. It was confirmed by some apophytic species like *Chenopodium* spp., *Cirsium* spp. and *Epilobium* spp. (Kukk, 1999) that emerged in the peat blocks in greenhouse, but were not recorded in the nearby forest.

It was interesting that the number of plant individuals in the greenhouse peat blocks was higher for the non-fertilized peat blocks and fertilization also did not affect considerably the total number of species. There were not so many indicative species for the greenhouse peat blocks with fertilization treatment, only one indicative species (*Marchantia polymorpha*) appeared to be significant. That could explain the vegetation variation in different areas and treatments. The growth of *Marchantia polymorpha* increases naturally in wet conditions with moderate acidity and it demands high light conditions (Ellenberg *et al*., 1992; Ingerpuu *et al*., 1998). The low number of indicator species for the peat block samples could derive from the random propagules content in the field conditions and from the chance for species with different autecological features to germinate due to the favourable conditions in greenhouse.

Though it is somewhat irrelevant to compare the results of fertilization experiments carried out by fertilizers containing active substances in different proportions, certain rough comparisons are still possible. For instance, Ferland & Rochefort (1997) have noticed that phosphorus, included also into the complex-fertilizer used in our experiment, favours the recolonization of extracted peatlands by mosses and vascular plants; Sottocornola *et al*. (2007) have mentioned that the fertilization with granular phosphate rock increased the coverage of some species. According to **paper III**, it was surprising that a complex-fertilizer did not have any remarkable effect on the number on species: it was in several cases higher in non-fertilized peat blocks. Though Salonen & Laaksonen (1994) have shown that light watering does not have a major effect on plant colonization on extracted peatlands, on the basis of the theses it can be averred that re-vegetation of extracted peatlands is inhibited mainly by the unsuitable moisture conditions (and low water table) and not so much by the nutrient availability: in the optimal moisture conditions kept in greenhouse several species that were not present in natural areas germinated successfully. It was also seen that water table depth in poorly drained sites influenced strongly peat carbon emissions.

5. CONCLUSIONS

The spontaneous re-vegetation of abandoned extracted peatlands lasts for decades and is often rather stochastic process. The results of field studies and a inventory of extracted peatlands demonstrate that on the local peatland scale the main factors influencing the re-vegetation of extracted peatlands are their surface microforms (**paper I**), former treatment (block-cut or milling) (**paper I, IV**) and peat properties (**paper III**), moisture level of the upper-layer peat (**paper III**), the total density of established trees and saplings has also some further effect (**paper I**). The sparse re-vegetation of milled peatlands refers to the stochastic colonization of the plant species, while on the block-cut areas and in the ditches, where the environmental conditions are more favourable and stable, and plants spread by the propagules and vegetatively as well, the re-vegetation is more successful leading towards the plant cover typical in the natural raised bogs or bog forests (**paper I, IV**).

The statistical evaluation results of the inventory of extracted peatlands covering first in the world the entire country (**paper II**) showed that among studied factors the microtopography is the main factor distinguishing the composition of the first plant communities. The re-vegetation processes on flats and ditch margins on regional scale (**paper II**) is predicted mainly by the depth and properties of the residual peat, while in ditches the re-vegetation is influenced by peat trophicity: the community types in ditches represent a gradient from eutrophic to oligotrophic habitats. The results showed that the depth of the residual peat layer of 2.3 m appears to be the robust threshold for choosing the appropriate target community for restoration: areas with residual peat depth lower than 2.3 m should be restored predominately towards fen or transitional mire, whereas the areas with residual peat depth over 2.3 m toward raised bog communities. This threshold combines also the information about other peat properties (e.g. pH, ash content, trophicity status), as the residual peat in areas with >2.3 m of abandoned peatlands consists mainly of slightly decomposed *Sphagnum* peat in upper-layer and areas with residual peat depth <2.3 m consist mainly of well decomposed peat (**paper II**).

Based on the field and greenhouse study results it was found that the plant species pool exists everywhere on abandoned extracted peatlands, but the germination of species is a random process determined mainly by suitable moisture conditions (**paper III**). The distance from the neighbouring species pool is not decisive for propagules arrival to the extracted peatland: the propagules are present everywhere on extracted peatlands and the success of their germination and growth depends on different environmental conditions in the marginal areas and the central parts of peatlands (**paper III**). The improvement of the moisture conditions (like in the greenhouse conditions) enables germination of many species (including some ruderal species), that have randomly arrived. Still, those species do not form a viable seedbank for the extracted peatlands being able to germinate only in favorable conditions created, e.g. in greenhouse.

A single time application of fertilizer (P_2O_5) did not have a long-term effect on the total number of plant species on extracted peatlands, but increased the plant cover and the mean number of species *per* quadrat (**paper I**). Neither did the complex fertilizer (N:P:K 11–11–21) have an overall influence on the number of species in greenhouse experiment as the number of species in fertilized and non-fertilized peat blocks did not differ significantly. It indicates that the re-vegetation of extracted peatlands is more affected by moisture conditions than by the lack of nutrients or propagules arrival (**paper III**).

To restore the abandoned extracted peatlands it is suggested that in areas where the vegetation resembling fen or transitional mire communities has spontaneously already appeared, their natural re-vegetation process should be supported with regulating or holding the water table on the appropriate level and spreading the plant fragments from suitable donor area. In areas where restoration towards bog communities is possible, the microhabitat variability could be additionally supported by creating mounds and shallow furrows positioned perpendicular with ditches: in that way the plants can spread along them to the flats. The re-vegetation process can be accelerated by introducing plant and moss propagules (Quinty & Rochefort, 2003) or transplanting undisturbed vegetation blocks from the areas under the preparation for peat mining and thereafter creating suitable moisture conditions. The selection of donor sites for plant material should be performed according to the depth of the residual peat, existing plant assemblages on extracted peatland and by a target community for restoration.

SUMMARY IN ESTONIAN

Jääksoode taastaimestumist mõjutavad faktorid Eestis

Eesti on üheks maailma enamsoostunud piirkonnaks, kus erinevas seisundis turba-alad katavad ~22% territooriumist (Orru, 1992). Samas on soid siin erinevatel eesmärkidel ulatuslikult kuivendatud ning mitme sajandi jooksul on turvast ka kaevandatud. Seetõttu katavad looduslähedases seisundis sood praegu vaid *ca* 5.5% Eesti territooriumist. Kui varem kaevandati turvast peamiselt soode servades käsitsi tükkturbana, mis mõjutas soode seisundit suhteliselt vähe, siis hoopis märgatavamaks muutus kaevandamise mõju alates 20. sajandi keskpaigast, kui kasutusele võeti frees- ja vakuumtehnoloogia. Kaevandamine nende meetoditega toimub suure pindalaga sügavalt kuivendatud nn. tootmisväljakutel, mis pärast turbavarude ammendamist jäetakse enamasti lihtsalt maha ning neist kujunevad ulatuslikud jääksood. Käesoleval ajal on jääksoode pindala Eestis 9371 ha, kuid nende pindala suureneb lähikümnendil üle kahe korra praegu kasutusesoleva ~20 000 ha turbatootmisalade ammendumise tõttu.

Jääksoode spontaanne taastaimestumine toimub väga aeglaselt, sest soo kaevandamiseks ettevalmistamise käigus ala kuivendatakse, eemaldatakse pinnalt kogu taimkate ning koos pindmiste turbkihtidega ka kõik idanemisvõimelised diaspoorid. Jääksoo pinnal paljanduvates mitme tuhande aasta vanustes turbakihtides on aga taimede diaspoorid hävinud või need ei ole enam idanemisvõimelised; idaneda suudavad jääksoodes ainult mõnede taimeliikide tuulega saabunud levised, mis on võimelised idanema, kasvama elujõulisteks taimedeks ning moodustama püsivaid taimekooslusi. Jääksoode taastaimestumist takistavad peamiselt mitmed ebasoodsad keskkonnategurid, sh ebastabiilsed niiskustingimused, tuuleerosioon ning külmakerge.

Turba mineraliseerumise tõttu on jääksood olulised kasvuhoonegaaside allikad. Eestis on kuivendatud sood ja jääksood põlevkivielektrijaamade järel teiseks suuremaks CO_2 allikaks, ületades ligikaudu üheksa korda liikluses eralduvat süsihappegaasi kogust. Sel viisil lendub aastas kuivendatud soodest ja jääksoodest süsinikuna rohkem turvast, kui seda kaevandatakse ning seetõttu on jääksoode korrastamine keskkonnakaitseliselt oluline probleem. Vastavalt seadustele tuleb kõik kaevandatud alad kaevandamise lõppedes rekultiveerida, kuid suurem osa Eesti mahajäetud turbakaevandusaladest hüljati Nõukogude perioodil või vahetult pärast selle lõppu ning nende korrastamine ei ole siiani Eestis kahjuks prioriteetne olnud. Seetõttu on käesolevaks ajaks korrastatud ainult mõned üksikud jääksoo osad. Alanud Euroopa Liidu finantsperioodiks (2014–2020) on aga Eestile eraldatud rahalisi vahendeid vähemalt 2000 ha jääksoode korrastamiseks. Kuna turba kaevandamine toimub peamiselt rabades, kus turbalasundi moodustab vähelagunenud sfagnumturvas, ent samas on rabad süsiniku sidujana, magevee reservuaarina, mitmete taime- ja loomaliikide peamise elupaigana ja muudel põhjustel väga väärtuslikud ökosüsteemid, tuleks jääksoode korrastamisel püüda nende taastaimestumist suunata taassoostumise, sh rabade kujunemise suunas.

Jääksoode korrastamise juhendeid on välja töötatud mitmetes riikides (Wheeler & Shaw 1995; Stoneman & Brooks 1997; Heikkilä *et al*., 2002; Quinty & Rochefort, 2003; Paal, 2011). Kuigi parasvöötme erinevate piirkondade freesväljad on üldjoontes sarnased, esineb neil ka lokaalsest kliimast jms. tulenevaid regionaalseid iseärasusi, mida tuleks jääksoode korrastamisel, sh soode taastamisel arvestada. Seni on korrastamiskavad keskendunud peamiselt jääksoode turbalasundis veetaseme tõstmisele, kuid tavaliselt on sellele omane ulatuslik sesoonne ja aastatevaheline kõikumine, mis raskendab veetaseme adekvaatset mõõtmist. Seetõttu on korrastamise planeerimise lihtsustamiseks oluline leida üldistavaid ja lihtsalt hinnatavad ning ajas stabiilseid indikaatoreid.

Käesoleva väitekirja peamisteks eesmärkideks oli: (i) selgitada välja olulisemad keskkonnafaktorid, mis mõjutavad jääksoode taastaimestumist lokaalsel ning regionaalsel tasemel, (ii) testida, kas keskkonnafaktorid, nagu jääkturba omadused (pH, troofsus jne.) ja paksus on rakendatavad kui potentsiaalsed indikaatorid jääksoode korrastamise planeerimisel ja kuidas neid oleks võimalik praktiliselt kasutada, (iii) selgitada välja erinevused ja neid põhjustavad peamised tegurid jääksoo kesk- ja ääreosade taimestumises nii mahajäetud turbatootmisaladel kui ka kasvuhooneeksperimendi põhjal ning (iv) teha eksperimentaalsete katsetega kasvuhoones kindlaks, kuidas mõjutab jääksoo taimede liigirikkust ning koosseisu paremate niiskustingimuste loomine ja väetamine.

Doktoritöö põhineb neljal teadusartiklil. Esimeses artiklis käsitleti jääksoode spontaanse taastaimestumise protsessi Viru- ja Rabivere raba frees- ja Rabivere raba tükkturba-aladel ning uuriti, kuidas mõjutab taastaimestumist Rabivere freesväljade väetamine. Viru raba jääksoos registreeriti taimede liigiline koosseis ja taimestiku katvus 185-l 1x1 m suurusega ruudul, mis paigutati erinevatele mikrovormidele (jääkvälja tasane keskosa, kraav, kraaviserv ja teeserv). Rabivere raba jääksoos analüüsiti taimkatet 100-l 1x1 m suurusega ruudul, mis paiknesid freesväljadel jääkvälja tasasel keskosal, kraaviservas ja kraavis ning tükk-turbaaladel lohkudes ning mätastel. Igal analüüsiruudul mõõdeti soovee pH taset, elektrijuhtivust ning veetaseme sügavust ning iga analüüsiruudu ümber hinnati 10x10 m ruudul puurinde ja järelkasvu tihedust ja kõrgust.

Teises artiklis lähtuti kogu Eesti ulatuses toimunud mahajäetud turbatootmisalade inventeerimise andmetest (uurimus viidi läbi Eesti Geoloogiakeskus poolt Keskkonnaministeeriumi tellimusel) ning analüüsiti, millised indikaatorid võiksid regionaalsel tasemel olla olulised jääksoode edukaks korrastamiseks. Kasutati 64 jääksoo andmeid üle Eesti. Igas jääksoos uuriti taimkatet kolmel mikrovormil: jääksoo tasasel keskosal, kraaviservas ja kraavis. Suuremad jääksood, mis olid maha jäetud erineval ajal või millel oli ebatavaline kuju, analüüsiti eraldi aladena; kokku analüüsiti andmeid 114-lt alalt. Inventuuri andmetest kasutati iga ala taimeliikide loendit erinevatel mikrovormidel ning andmeid turba omaduste (keskmine jääkturba sügavus, vähe- ja hästilagunenud turbakihi paksus, pealmise turbakihi troofsus, pH ja lagunemisaste), ala mahajätmise aja, erinevate töötluste ning jääkvälja pindala kohta. Kaartide ning aerofotode põhjal täiendati andmeid naabruses paikneva taimkatte tüübiga (aktiivne turbatootmisala, mets jne.). Tegu on teadaolevalt maailmas esmakordselt kogu riigi jääksoid hõlmava andmestiku analüüsiga.

Kolmandas artiklis võrreldi kolme mahajäetud jääksoo ning neist võetud ja mitme kuu vältel kasvuhoones hoitud turbaproovide taastaimestumise erinevust, samuti jääksoode ääre- ja keskosade taimestumise erinevust ning selgitati sobivate niiskustingimuste ja väetamise mõju taastaimestumisele. Uuring viidi läbi enam-vähem samaaegselt mahajäetud Viru, Tähtvere ja Visusti raba jääksoodel. Igal alal uuriti taimkatet piki jääksoo servast selle keskosa suunas kulgevat transekti, kasutades viies 15–25 m tagant korduvas analüüsipunktis juhuslikult paigutatud kolme 1x1 m suurusega analüüsiruutu. Jääkvälja keskosas paigutati analüüsiruudud kolmes korduses 10–15 m intervalliga viide punkti. Analüüsiruutude koguarv ühes rabas oli 90. Igal analüüsiruudul registreeriti taimede liigiline koosseis ja turba lagunemisaste, mõõdeti turba vesilahuse pH ning elektrijuhtivus sügavustel 0–10 cm ja 10–20 cm. Lisaks koostati jääksood ümbritseva metsa taimeliikide nimekiri. Jääksoo serva- ja keskosast võeti turba jääklasundist 28x42,5x10 cm suuruse plokina turbaproove, mida hoiti leviste tärkamiseks kasvuhoones taimede kasvuks soodsates tingimustes, kusjuures pooled proovidest väetati kompleksväetisega. Igal kasvuhoones hoitud turbaproovil määrati taimede liigiline koosseis, hinnati sammalde katvust ning loendati taimeisendite arv.

Neljandast artiklist kasutati käesoleva töö eesmärkide täitmiseks eelkõige spontaanselt taastaimestunud Selisoo tükkturba-ala analüüsiruutude taimkatte andmeid. Neid võrreldi esimeses artiklis käsitletud Rabivere tükkturba-ala taimkatte andmetega selgitamaks niisuguste jääksoode taastaimestumise üldisi seaduspärasusi ning hindamaks milline mõju on piirnevate looduslike alade taimestikul ning teistel teguritel jääksoode taimestiku kujunemisele.

Väitekirja tulemustest selgus, et lokaalsel skaalal olid väliuuringute andmestiku alusel jääksoode taastaimestumist mõjutavateks peamisteks teguriteks mikrovorm (**artikkel I**), kaevandamise viis (frees- või tükk-turbameetodil kaevandamine) (**artikkel I, IV**) ning turba omadused (turba niiskus, pH jne.) (**artikkel III**). Mõningast efekti omas ka alal kasvama hakanud puude ning nende järelkasvu tihedus (**artikkel I**). Freesväljade hõre taastaimestumine viitab nendel taimede juhuslikule kolonisatsioonile, samal ajal kui tükk-turbaaladel ning freesväljade kraavides, kus keskkonnatingimused on soodsamad ning stabiilsemad, on taimede seemnete ning ka taimede vegetatiivne levik soodustatud ja taastaimestumine edukam (**artikkel I, IV**). Tükk-turbaalal oli taastuv taimestik sarnane looduslikele rabadele või rabametsadele (**artikkel I, IV**). Mikrotopograafia mõjutas taastaimestumist ka regionaalsel tasemel, olles peamine faktor, mis eristas esimesi moodustunud taimekooslusi (**artikkel II**). Taastaimestumise protsess jääkvälja keskel ja kraaviservades oli regionaalsel skaalal mõjutatud peamiselt turba paksusest ja jääkturba omadustest (troofsus, pH jne.), samal ajal kui kraavides sõltus taastaimestumine peamiselt turba troofsusest. Jääksoo korrastamiseks sobiva suuna valimisel osutus oluliseks piiriks turba jääklasundi paksus: alad, mille turbakihi paksus on alla 2,3 m sobivad taastamiseks eeskätt madal- või siirdesookooslusteks ning alad turbakihi paksusega üle 2,3 m rabakooslusteks. Paksema turbakihiga aladel on suurem tõenäosus, et ülemine turbakiht koosneb vähelagunenud rabaturbast, samal ajal kui õhema turbakihiga aladel on enamasti esindatud hästilagunenud turbakiht ning siirde- või madalsooturvas (**artikkel II**). Osutatud lävend seondub ka jääkturba peamiste omadustega (pH, tuhasisaldus, troofsus jne.).

Käesoleva töö puhul ilmnes, et veetaseme mõju taastaimestumisele on pigem mitteoluline, kuid niisugune järeldus võib tuleneda andmestiku ebaühtlusest ning veetaseme korduvmõõtmiste puudumisest. Turba jääklasundi veetase sõltub oluliselt ilmastikust (millal olid viimati suuremad sajuhood, põud jne.) ja sesoonsusest ning seetõttu on raske saada adekvaatseid mõõtmisandmeid. Veetasemest olulisem on pealmise turbakihi niiskusesisaldus, mis omab olulist rolli taimede idanemahakkamisele ning kasvamisele.

Liigirikkus oli jääksoodel kõrgem selle äärealadel, st looduslikult taimestunud koosluste naabruses ning liikide arv väheneb jääksoo keskosa suunas. Kuid samadest piirkondadest võetud ning kasvuhoones hoitud turbaproovides oli liigirikkus, vastupidi, suurem jääksoo keskosast kogutud proovides (**artikkel III**). Turbaproovide madalam liigirikkus jääksooga võrreldes võis siin aga tuleneda kasvuhoones hoitud proovide suhteliselt väikesest pindalast. Samas võimaldasid turbaproovide paremad niiskustingimused kasvama hakata ka mitmetel (sh ruderaalsetel) liikidel, mida jääksoos ei leidunud (**artikkel III**). Samuti selgus, et ühekordne väetamine Rabivere jääksoos ~25 aastat tagasi taimeliikide koguarvule pikaajalist mõju ei avaldanud, kuid suurendas taimeliikide keskmist arvu ning katvust mõnedes analüüsiruutudes (**artikkel I**). Kasvuhoones hoitud turbaproovide väetamine üldist liigirikkust ei mõjutanud, mis viitab sellele, et jääksoode aeglane taastaimestumine on tingitud pigem ebasoodsatest niiskustingimustest kui toitainete vähesusest (**artikkel III**).

Töö tulemuste põhjal saab soovitada mahajäetud jääksoode taastaimestumise kiirendamiseks aladel, kus taastaimestumine madal- või siirdesoo suunas on juba alanud ja vastavad kooslused on juba moodustunud, toetada seda protsessi veetaseme reguleerimisega ja/või hoidmisega sobival kõrgusel. Aladel, kus on võimalik taastada rabakooslust, on soovitatav suurendada mikrovormide mitmekesisust, soodustades seeläbi taastaimestumist ning suurendades liigirikkust. Selleks saab soovitada jääkväljadele kuivenduskraavidega risti paiknevate piklike lohkude rajamist, kujundades sel viisil vallidest ning nende vahele jäävatest madalatest lohkudest koosneva mikrotopograafia, toetades seeläbi taimeliikide levikut kuivenduskraavidest kaevandusväljakute keskosa suunas. Taastaimestumise protsessi jääksoodes saab kiirendada ka (turba)sammalde ning muu taimematerjali introdutseerimise teel või tuues taimestikuga turbapätse aladelt, kus tehakse ettevalmistusi kaevandamiseks. Doonorala valikul tuleks lähtuda sellest koosluse tüübist, mille taastamine on eesmärgiks võetud.

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REFERENCES

Anggria, L., Kasno, A. & Rochayati, S. 2012. Effect of organic matter on nitrogen mineralization in flooded and dry soil. *ARPN Journal of Agricultural and Biological Science*, 7(8), 586–590.

Beleya, L. 2004. Beyond Ecological Filters: Feedback Networks in the Assembly and Restoration of Community Structure. In *Assembly Rules and Restoration Ecology: Bridging the Gap between Theory and Practice* (Temperton, V.M., Hobbes, R.J., Nuttle, T. & Halle, S., editors), pp 115–131. Society for Ecological Restoration International.

Bérubé, C. & Lavoie, M.-E. 2000. The natural revegetation of a vacuum-mined peatland: Eight years of monitoring. *The Canadian Field-Naturalist*, 114, 279–286.

Boudreau, S. & Rochefort, L. 1998. Restoration of post-mined peatlands: Effect of vascular pioneer species on *Sphagnum* establishment. In *Proceedings of the International Peat Conference Peatland Restoration and Reclamation, Duluth, Minnesota, July 14–18, 1998* (Malterer, T., Johnson, K. & Stewart, J., editors), pp 39–43. International Peat Society, Jyväskylä, Finland.

Bretschneider, A. 2012. Die Bedeutung von Birken im Hochmoor. *TELMA*, 44, 137–146.

Campbell, D.R., Lavoie, C. & Rochefort, L. 2002. Wind erosion and surface stability in abandoned milled peatlands. *Canadian Journal of Soil Science*, 82, 85–95.

Campbell, D.R. & Rochefort, L. 2003. Germination and seedling growth of bog plants in relation to the recolonization of milled peatlands. *Plant Ecology*, 169, 71–84.

Campbell, D.R., Rochefort, L. & Lavoie, C. 2003. Determining the immigration potential of plants colonizing disturbed environments: the case of milled peatlands in Quebec. *Journal of Applied Ecology*, 40, 78–91.

Campeau, S., Rochefort, L. & Price, J.S. 2004. On the use of shallow basins to restore cutover peatlands: Plant establishment. *Restoration Ecology*, 12(4), 471–482.

Clarke, D. & Rieley, J. (editors). 2010. *Strategy for responsible Peatland Management*. International Peat Society, Finland.

Determination of electrical conductivity in soil, sewage sludge and biowaste. CEN/TF. 2005–10–04. TC WI: 2003 (E).
http://www.ecn.nl/docs/society/horizontal/Hor_desk_15-2_EC-revised-Annex1.pdf (visited 21.12.2012).

Dufrêne, M. & Legrendre, P. 1997. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs*, 67, 345–366.

Egawa, C., Koyama, A. & Tsuyuzaki, S. 2009. Relationships between the developments of seedbank, standing vegetation and litter in a post-mined peatland. *Plant Ecology*, 203, 217–228.

Ellenberg, H., Weber, H.E., Düll, R., Wirth, W.W. & Pauliβen, D. 1992. Zeigewerte von Pflanzen in Mitteleuropa. *Scripta Geobotanica*, 18, 258 pp. Veralg Erich Goltze KC, Göttingen.

Ferland, C. & Rochefort, L. 1997. Restoration techniques for Sphagnum-dominated peatlands. *Canadian Journal of Botany*, 75, 1110–1118.

Graf, M.D., L. Rochefort & Poulin, M. 2008. Spontaneous revegetation of cutaway peatlands of North America. *Wetlands*, 28(1), 28–39.

Groeneveld, E.V.G. & Rochefort, L. 2002. Nursing plants in peatland restoration: on their potential use to alleviate frost heaving problems. *Suo*. *Mires and Peat*, 53(3–4), 73–85.

Groeneveld, E.V.G. & Rochefort, L. 2005. *Polytrichum strictum* as a Solution to Frost Heaving in Disturbed Ecosystems: A Case Study with Milled Peatlands. *Restoration Ecology*, 13(1), 74–82.
Heathwaite, A.L. 1995. The impact of disturbance on mire hydrology. In *Hydrology and Hydrochemistry of British Wetlands* (Hughes, J.M.R. & Heathwaite, A.L., editors), pp 401–417. Wiley, Chichester.
Heikkilä, H., Lindholm, T. & Jakkola, S. 2002. Soiden ennallistamisopas (A guide for the restoration of peatland habitats). *Metsähallituksen luonnonsuojelulkaisuja*, Sarja B 66, 124 pp (in Finnish).
Huopalainen, M., Tuittila, E-S., Laine, J. & Vasander, H. 1998. Seed and spore bank in a cut-away peatland twenty years after abandonment. *International Peat Journal*, 8, 42–51.
Ilomets, M. 1997. Genesis and development of mires. In *Geology and Mineral Resources of Estonia* (Raukas, A. & Teedumäe, A., editors), pp 293–298. Estonian Academy Publishers, Tallinn.
Ilomets, M. 2001. Mis saab jääksoodest? *Eesti Loodus*, 6, 218–221 (in Estonian).
Ilomets, M. 2003. Mille arvel kaevandame turvast? *Eesti Loodus*, 2/3, 20–24 (in Estonian).
Ingerpuu, N., Kalda, A., Kannukene, L., Krall, H., Leis, M. & Vellak, K. 1998. *Eesti sammalde määraja.* Eesti Loodusfoto, Tartu (in Estonian).
Joosten, H. 2008. The IMCG Global Peatland Database on the Web http://www.imcg.net/gpd/gpd.htm. (Assessed 26 February 2011).
Keddy. P. A. 2010. Services and functions. In Wetland Ecology: Principles and Conservation (Keddy, P.A., editor), pp 301–329. University Press, Cambridge.
Kovalinkova, P. & Prach, K. 2010. Spontaneous succession of vegetation in mined peatlands: a multi-site study. *Preslia*, 82, 423–435.
Kukk, T. 1999. *Eesti taimestik.* Teaduste Akadeemia kirjastus, Tartu-Tallinn (in Estonian).
Lachance, D. & Lavoie, C. 2004. Vegetation of *Sphagnum* bogs in highly disturbed landscapes: relative influence of abiotic and anthropogenic factors. *Applied Vegetation Science*, 7, 183–192.
Laine, J. & Minkkinen, K. 1996. Forest drainage and the greenhouse effect. In *Peatlands in Finland* (Vasander, H., editor), pp 159–164. Finnish Peatland Society, Helsinki.
Lavoie, C. & Saint-Louis, A. 1999. The spread of gray birch (*Betula populifolia* Marsh.) in eastern Quebec: Landscape and historical considerations. *Canadian Journal of Botany*, 77, 857–868.
Lavoie, C., Grosvernier, M., Girard, M. & Marcoux, K. 2003. Spontaneous revegetation of mined peatlands: An useful restoration tool? *Wetlands Ecology and Management*, 11, 97–197.
Leht, M. (editor) 2010. *Eesti taimede määraja*. Eesti Loodusfoto, Tartu (in Estonian).
McCune, B. & Mefford, M.J. 1999. *PC–ORD. Multivariate analysis of ecological data, version 4.* MjM Software Design, Gleneden Beach, Oregon, USA
Moen, A. 1999. *National atlas of Norway. Vegetation.* Norwegian Mapping Authority, Høenfoss, 200 pp.
Myels, J.A. & Harms, K.E. 2009. Seed arrival, ecological filters, and plant species richness: a meta analysis. *Ecology Letters*, 12, 1250–1260.
Orru, M. 1992. *Eesti turbavarud* (Estonian Peat Resources). Eesti Geoloogiakeskus, Tallinn (in Estonian).

Paal, J. (editor) 2011. *Jääksood, nende kasutamine ja korrastamine*. Keskkonnainvesteeringute Keskus & Eesti Turbaliit, Tartu: VALI trükikoda (in Estonian).
Paal, J. & Leibak, E. 2011. *Estonian mires: inventory of habitats*. Publication of the Project "Estonian Mires Inventory completion for maintaining biodiversity". Regio, Tartu.
Paal, J. & Leibak, E. 2013. *Eesti soode seisund ja kaitstus*. Publication of the Project "Estonian Mires Inventory completion for maintaining biodiversity". Regio, Tartu (in Estonian).
Paavilainen, E. & Päivänen, J. 1995. Utilization of peatlands. In *Peatland Forestry* (Vasander, H., editor), pp 15–30. Springer, Germany.
Poulin, M., Rochefort, L., Quinty, F. & Lavoie, C. 2005. Spontaneous revegetation of mined peatlands eastern Canada. *Canadian Journal of Botany*, 83, 539–557.
Price, J. 1997. Soil moisture, water tension, and water table relationships in a managed cutover bog. *Journal of Hydrology*, 202, 21–32.
Price, J.S., Rochefort, L. & Quinty, F. 1998. Energy and moisture considerations on cutover peatlands: surface microtopography, mulch cover and *Sphagnum* regeneration. *Ecological Engineering*, 10, 293–312.
Price, J.S., Heathwaite, A.L. & Baird, A.J. 2003. Hydrological processes in abandoned and restored peatlands: An overview of management approaches. *Wetlands Ecology and Management*, 11, 65–83.
Quinty, F. & Rochefort, L. 2003. *Peatland Restoration Guide*. Second edition. Canadian Sphagnum Peat Moss Accociation, New Brunswick Department of Natural Resources and Energy.
Ramst, R., Orru, M. & Halliste, L. 2005. *Eesti mahajäetud turbatootmisalade revisjon. 1. etapp: Harju, Rapla ja Lääne maakond*. Eesti Geoloogiakeskus, Tallinn (in Estonian).
Ramst, R., Orru, M., Salo, V. & Halliste, L. 2006. *Eesti mahajäetud turbatootmisalade revisjon. 2. etapp: Ida-Viru, Lääne-Viru, Jõgeva, Järva ja Tartu maakond*. Eesti Geoloogiakeskus, Tallinn (in Estonian).
Ramst, R., Orru, M., Salo, V. & Halliste, L. 2007. *Eesti mahajäetud turbatootmisalade revisjon. 3. etapp: Viljandi, Pärnu, Saare, Hiiu maakond*. Eesti Geoloogiakeskus, Tallinn (in Estonian).
Ramst, R., Salo, V. & Halliste, L. 2008. *Eesti mahajäetud turbatootmisalade revisjon. 4. etapp: Valga, Võru ja Põlva maakond*. Eesti Geoloogiakeskus, Tallinn (in Estonian).
Ramst, R. & Orru, M. 2009. Eesti mahajäetud turbatootmisalade taastaimestumine. *Eesti Põlevloodusvarad ja -jäätmed*, 1, 6–7 (in Estonian).
Randlane, T. & Saag, A. (editors) 1999. Second checklist of lichenized, lichenicolous and allied fungi of Estonia. *Folia Cryptog. Estonica*, 25, 1–132.
Raudsep, R. 2011. Turbakaevandamist reguleerivad õigusaktid. In *Jääksood, nende kasutamine ja korrastamine* (Paal, J., editor), pp 33–38. Keskkonnainvesteeringute Keskus & Eesti Turbaliit, Tartu: VALI trükikoda (in Estonian).
Rochefort, L. & Campeau, S. 1997. Rehabilitation Work on Post-Harvested Bogs in South Eastern Canada. In *Conserving Peatlands* (Parkyn, L., Stoneman, R.E. & Ingram, H.A.P., editors), 287–294. Cab International, Wallingford, U.K.
Rochefort, L. 2000. *Sphagnum* – a keystone in habitat restoration. *The Bryologist*, 103, 503–508.
Rydin, H. & Jeglum, J. 2006. *The Biology of Peatlands*. Oxford University Press.

Salm, J-O., Kimmel, K., Uri, V. & Mander, Ü. 2009. Global warming potential of drained and undrained peatlands in Estonia: a synthesis. *Wetlands*, 29(4), 1081–1092.

Salonen, V. 1987. Relationship between the seed rain and the establishment of vegetation in two areas abandoned after peat harvesting. *Holarctic Ecology*, 10, 171–174.

Salonen, V. 1990. Early plant succession in two abandoned cut-over peatland areas. *Holarctic Ecology*, 13, 217–223.

Salonen, V. & Laaksonen, M. 1994. Effects of fertilization, liming, watering and tillage on plant colonization of bare peat surfaces. *Annales Botanici Fennici*, 31, 29–36.

Soro, A., Sundberg, S. & Rydin, H. 1999. Species diversity, niche metrics and species associations in harvested and undisturbed bogs. *Journal of Vegetation Science*, 10, 549–560.

Sottocornola, M., Boudreau, S. & Rochefort, L. 2007. Peat bog restoration: Effect of phosphorus on plant re-establishment. *Ecological Engineering*, 31, 29–40.

StatSoft Inc. 2004: STATISTICA (data analysis software system), version 7. Online at: www.statsoft.com.

Stoneman, R. & Brooks, S. 1997. *Conserving Bogs. The Management Handbook.* The Stationery Office Ltd, Edinburgh, 286 pp.

Succow, M. & Joosten, H. 2001. *Landschaftsökologische Moorkunde*. E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u. Obermiller), Stuttgart.

Ter Braak, C.J.F. & Šmilauer, P. 2002. *CANOCO Reference Manual and CanoDraw for Windows User's Guide*. Biometris, Wageningen and České Budějovice.

Triisberg, T. 2006. *Jääksoode looduslik taastaimestumine Viru raba näitel*. BSc thesis. Tallinn University (in Estonian, summary in English).

Tuittila, E.-S., Rita, H., Vasander, H. &. Laine, J. 2000. Vegetation patterns around *Eriophorum vaginatum* L. tussocks in a cut-away peatland in southern Finland. *Canadian Journal of Botany*, 78, 47–58.

Wheeler, B.D. & Shaw, S.C. 1995. *Restoration Of Damaged Peatlands*. John Wiley & Sons Ltd, London, 567 pp.

PUBLICATIONS

Artiklite lingid:

Artikkel I
http://mires-and-peat.net/pages/volumes/map08/map0805.php

Artikkel II
http://onlinelibrary.wiley.com/doi/10.1111/rec.12030/abstract

Artikkel III
http://www.kirj.ee/22902/?tpl=1061&c_tpl=1064

Artikkel IV
http://link.springer.com/article/10.1007/s11273-014-9339-5

CURRICULUM VITAE

Name: Triin Triisberg
Date of Birth: 03.06.1985
Nationality: Estonian
E-mail: triin.triisberg@gmail.com

Education:

2008–...	University of Tartu, Botany and Ecology, PhD-studies
2006–2008	Tallinn University, Landscape Ecology, MSc, *cum laude*
2003–2006	Tallinn University, Landscape Ecology, BSc
1992–2003	Tallinna Liivalaia Gymnasium, secondary education, *silver medal*

Languages: Estonian (native language), English, German.

Professional employment:

07.2013–...	Estonian Museum of Natural History, project manager of the collections digitalizion project of Estonian Museum of Natural History;
07.2008–07.2013	Engineering Bureau STEIGER, Department of Geology, Geological Surveys of Peatlands, Peatlands Restoration;
02.2009–12.2011	University of Tartu, Institute of Ecology and Earth Sciences, technician
09–11.2007	University of Tartu, Institute of Botany and Ecology, ETF grant project no. 6755, fieldwork manager;
06–09.2006	Tallinn University, Institute of Ecology, fieldwork manager.

Research interests:
The main environmental parameters influencing the re-vegetation of extracted peatlands; peatlands recultivation.

Publications:

Karu, H., Pensa, M., Rõõm, E.-I., Portsmuth, A. & Triisberg, T. 2014. Carbon fluxes in forested bog margins along a human impact gradient: could vegetation structure be used as an indicator of peat carbon emissions? *Wetlands Ecology and Management*, Doi: 10.1007/s11273-014-9339-5.

Triisberg, T., Karofeld, E. & Paal, J. 2013. Factors affecting the re-vegetation of abandoned extracted peatlands in Estonia; a synthesis from field and greenhouse studies. *Estonian Journal of Ecology*, 62, 3, 192–211.

Triisberg, T., Karofeld, E., Liira, J., Orru, M., Ramst, R., Paal, J. 2013. Microtopography and the Properties of Residual Peat Are Convenient Indicators for Restoration Planning of Abandoned Extracted Peatlands. *Restoration Ecology*, 22, 1, 31–39.

Triisberg, T., Paal, J., Karofeld, E. 2011. Re-vegetation of block-cut and milled peatlands: an Estonian example. *Mires and Peat*, 8, 1–14.

Paal, J., Leiner, E., Paal, T., Triisberg, T. 2011. Frees-jääksoode taastaimestumine. Paal, J. (ed.). *Jääksood, nende kasutamine ja korrastamine*, lk 54–63, Tartu: VALI trükikoda.

Paal, J., Lode, E., Triisberg, T. 2011. Jääksoo ja turba jääklasund. Paal, J. (ed.). *Jääksood, nende kasutamine ja korrastamine*, pp 41–45, Tartu: VALI trükikoda.

Triisberg, T. 2010. Jääksoode looduslik taastaimestumine ja seda mõjutavad peamised keskkonnategurid Rabivere raba näitel *TalveAkadeemia konverentsi kogumik* (on CD).

Triisberg, T., Paal, J., Karofeld, E. 2010. After-use of cutaway peatlands – can favouring spontaneous re-vegetation be an alternative? *PEATLANDS International*, 1, 20–23.

Triisberg, T. 2007. Jääksoode looduslik taastaimestumine Viru raba näitel. Kogumikus: *Kevade* (Terasmaa, J. & Printsmann, A., eds.), EGS publikatsioonid nr VIII, Tallinna Ülikooli kirjastus.

Triisberg, T. 2007. Jääksoode looduslik taastaimestumine Viru raba näitel. *TalveAkadeemia konverentsi kogumik* (on CD).

The most important oral conference presentations:

- “Cut-over peatlands, needs for their restoration and experience”. “Baltic Peat Producers Forum”, Jürmala, Latvia, 2008.
- “After use of harvested peatlands – can favouring of the spontaneous re-vegetation be an alternative?”. IPS Convention “Peat Technology and the After-Use of Cut-Over Peatlands”, Jyväskylä, Soome, 2010.
- “The main factors influencing re-vegetation of cut-over peatlands in Estonia” the conference of Geoeco doctoral school “Next generation insights into geosciences and ecology”, Tartu, Estonia, 2011.
- “The main factors influencing re-vegetation of cut-over peatlands in Estonia”. Conference “International Symposium on Responsible Peatland Management and Growing Media Production”, Quebec, Kanada, 2011.
- “Regularities and driving factors of spontaneous re-vegetation of extracted milled peatlands in Estonia”. The 14th International Peat Congress “Peatlands in Balance”, Stockholm, Sweden, 2012.

Scholarships:

2004 Ministry of the Environment scholarship;
2005 Tallinn University scholarship;
2007 Estonian-Revelia Academic Fund, Harald Raudsepa scholarship;
2007 Estonian National Committee in the United States scholarchip;
2008 Estonian World Council scholarchip;
2010 Doctoral school of Earth Sciences and Ecology scholarship for participation in the scientific conference;

2010 Archimedes foundation, Kristjan Jaak scholarship for participation in the scientific conference in 2010;

2010 Archimedes foundation, Kristjan Jaak scholarship for participation in the scientific conference in 2011;

2011 Doctoral school of Earth Sciences and Ecology scholarship for participation in the scientific conference;

2012 Archimedes foundation, Kristjan Jaak scholarship for participation in the scientific conference.

Professional development

2010 "Course in Forest Field Station" – University of Helsinki, Hyytiälä, Finland.

2011 "Workshop: Sphagnum Farming Workshop in Shippagan" –, Shippagan, Canada.

2012 Courses: "Introducion in Quaternary Palynology" and "Peatlands revitalization" – Ernst-Moritz-Arndt-University Greifswald, Greifswald, Germany.

2012 Peatland course for Student ("Pre Congress Tour for Students") – Gysinge, Sweden.

Social activities

Participation in "International Mire Conservation Group", "International Peat Society", "Estonian Wetlands Society", "Estonian Seminatural Community Conservation Association", "European Youth-geographer Association", "Estonian Geography Association's Youthclub".

Hobbies

Music and composing, singing in a choir, dancing (folk dances).

ELULOOKIRJELDUS

Nimi:	Triin Triisberg
Sünniaeg:	03.06.1985
Kodakondsus:	Eesti
E-post:	triin.triisberg@gmail.com

Haridus:

2008–...	Tartu Ülikool, botaanika ja ökoloogia doktoriõpe
2006–2008	Tallinna Ülikool, MSc geoökoloogia erialal, *cum laude*
2003–2006	Tallinna Ülikool, BSc geoökoloogia erialal
1992–2003	Tallinna Liivalaia Gümnaasium, keskharidus, *hõbemedal*

Keelteoskus: eesti keel (emakeel), inglise keel, saksa keel.

Töökogemus:

07.2013–...	Eesti Loodusmuuseum, Eesti Loodusmuuseumi kogude digiteerimise projektijuht;
07.2008–07.2013	Inseneribüroo STEIGER, geoloogia osakond, soode geoloogilised uuringud, soode rekultiveerimine;
02.2009–12.2011	Tartu Ülikooli Ökoloogia ja Maateaduste Instituut, tehnik;
09–11.2007	Tartu Ülikooli Botaanika ja Ökoloogia Instituudi botaanika osakond, ETF grandiprojekti nr. 6755 väliuuringutes osalemine;
06–09.2006	Tallinna Ülikooli Ökoloogia Instituut, väliuuringutes osalemine.

Peamised uurimisvaldkonnad:
Jääksoode taastaimestumise seaduspärasused; soode rekultiveerimine.

Publikatsioonide loetelu:

Karu, H., Pensa, M., Rõõm, E.-I., Portsmuth, A. & Triisberg, T. 2014. Carbon fluxes in forested bog margins along a human impact gradient: could vegetation structure be used as an indicator of peat carbon emissions? *Wetlands Ecology and Management*, Doi: 10.1007/s11273-014-9339-5.

Triisberg, T., Karofeld, E. & Paal, J. 2013. Factors affecting the re-vegetation of abandoned extracted peatlands in Estonia; a synthesis from field and greenhouse studies. *Estonian Journal of Ecology*, 62, 3, 192–211.

Triisberg, T., Karofeld, E., Liira, J., Orru, M., Ramst, R., Paal, J. 2013. Microtopography and the Properties of Residual Peat Are Convenient Indicators for Restoration Planning of Abandoned Extracted Peatlands. *Restoration Ecology*, 22, 1, 31–39.

Triisberg, T., Paal, J., Karofeld, E. 2011. Re-vegetation of block-cut and milled peatlands: an Estonian example. *Mires and Peat*, 8, 1–14.

Paal, J., Leiner, E., Paal, T., Triisberg, T. 2011. Frees-jääksoode taastaimestumine. Paal, J. (toim). *Jääksood, nende kasutamine ja korrastamine*, lk 54–63, Tartu: VALI trükikoda.

Paal, J., Lode, E., Triisberg, T. 2011. Jääksoo ja turba jääklasund. Paal, J. (toim). *Jääksood, nende kasutamine ja korrastamine*, lk 41–45, Tartu: VALI trükikoda.

Triisberg, T. 2010. Jääksoode looduslik taastaimestumine ja seda mõjutavad peamised keskkonnategurid Rabivere raba näitel *TalveAkadeemia konverentsi kogumik* (CD-l).

Triisberg, T., Paal, J., Karofeld, E. 2010. After-use of cutaway peatlands – can favouring spontaneous re-vegetation be an alternative? *PEATLANDS International*, 1, 20–23.

Triisberg, T. 2007. Jääksoode looduslik taastaimestumine Viru raba näitel. Kogumikus: *Kevade* (Terasmaa, J. & Printsmann, A. toim), EGSi publikatsioonid nr VIII, Tallinna Ülikooli kirjastus.

Triisberg, T. 2007. Jääksoode looduslik taastaimestumine Viru raba näitel. *TalveAkadeemia konverentsi kogumik* (CD-l).

Olulisemad suulised konverentsiettekanded:

– „Cut-over peatlands, needs for their restoration and experience". „Balti turbatootjate foorum", Jürmala, Läti, 2008.
– „After use of harvested peatlands – can favouring of the spontaneous re-vegetation be an alternative?". IPS konverents „Peat Technology and the After-Use of Cut-Over Peatlands", Jyväskylä, Soome, 2010.
– „The main factors influencing re-vegetation of cut-over peatlands in Estonia". Geoeco doktorikooli konverents „Next generation insights into geosciences and ecology", Tartu, Eesti, 2011.
– „The main factors influencing re-vegetation of cut-over peatlands in Estonia". Konverents „International Symposium on Responsible Peatland Management and Growing Media Production", Quebec, Kanada, 2011.
– „Regularities and driving factors of spontaneous re-vegetation of extracted milled peatlands in Estonia". The 14th International Peat Congress „Peatlands in Balance", Stockholm, Rootsi, 2012.

Saadud stipendiumid:

2004 Eesti Keskkonnaministeeriumi stipendium;
2005 Tallinna Ülikooli stipendium;
2007 Estonian-Revelia Academic Fund'i Harald Raudsepa stipendium;
2007 Eesti Rahvuskomitee Ühendriikides stipendium;
2008 Ülemaailmse Eesti Kesknõukogu stipendium;
2010 Maateaduste ja Ökoloogia doktorikooli toetus teaduskonverentsil osalemiseks;
2010 Sihtasutus Archimedes, Kristjan Jaagu stipendium teaduskonverentsil osalemiseks (2010. aastal);

2010 Sihtasutus Archimedes, Kristjan Jaagu stipendium teaduskonverentsil osalemiseks (2011. aastal);
2011 Maateaduste ja Ökoloogia doktorikooli stipendium teaduskonverentsil osalemiseks.
2012 Sihtasutus Archimedes, Kristjan Jaagu stipendium teaduskonverentsil osalemiseks.

Erialane enesetäiendus
2010 „Course in Forest Field Station" – Helsinki Ülikool, Hyytiälä, Soome.
2011 „Workshop: Sphagnum Farming Workshop in Shippagan" – Shippagan, Kanada.
2012 Kursused: „Introducion in Quaternary Palynology" ja „Peatlands revitalization" – Ernst-Moritz-Arndt-University Greifswald, Greifswald, Saksamaa.
2012 Soode teemaline kursus üliõpilastele („Pre Congress Tour for Students") – Gysinge, Rootsi.

Ühiskondlik tegevus
Liige järgmistes erialaorganisatsioonides: „International Mire Conservation Group", „International Peat Society", „Eesti Märgalade Ühing", „Pärandkoosluste Kaitse Ühing", „Euroopa Noorgeograafide Assotsiatsioon", „Eesti Geograafia Seltsi Noorteklubi".

Huvialad
Muusika ja komponeerimine, koorilaul, tantsimine (rahvalikud tantsud).

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56. **Ana Rebane.** Mammalian ribosomal protein S3a genes and intron-encoded small nucleolar RNAs U73 and U82. Tartu, 1999, 85 p.
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65. **Silvia Sepp.** Morphological and genetical variation of *Alchemilla L.* in Estonia. Tartu, 2000. 124 p.
66. **Jaan Liira.** On the determinants of structure and diversity in herbaceous plant communities. Tartu, 2000. 96 p.
67. **Priit Zingel.** The role of planktonic ciliates in lake ecosystems. Tartu 2001. 111 p.
68. **Tiit Teder.** Direct and indirect effects in Host-parasitoid interactions: ecological and evolutionary consequences. Tartu 2001. 122 p.
69. **Hannes Kollist.** Leaf apoplastic ascorbate as ozone scavenger and its transport across the plasma membrane. Tartu 2001. 80 p.
70. **Reet Marits.** Role of two-component regulator system PehR-PehS and extracellular protease PrtW in virulence of *Erwinia Carotovora* subsp. *Carotovora*. Tartu 2001. 112 p.
71. **Vallo Tilgar.** Effect of calcium supplementation on reproductive performance of the pied flycatcher *Ficedula hypoleuca* and the great tit *Parus major,* breeding in Nothern temperate forests. Tartu, 2002. 126 p.
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