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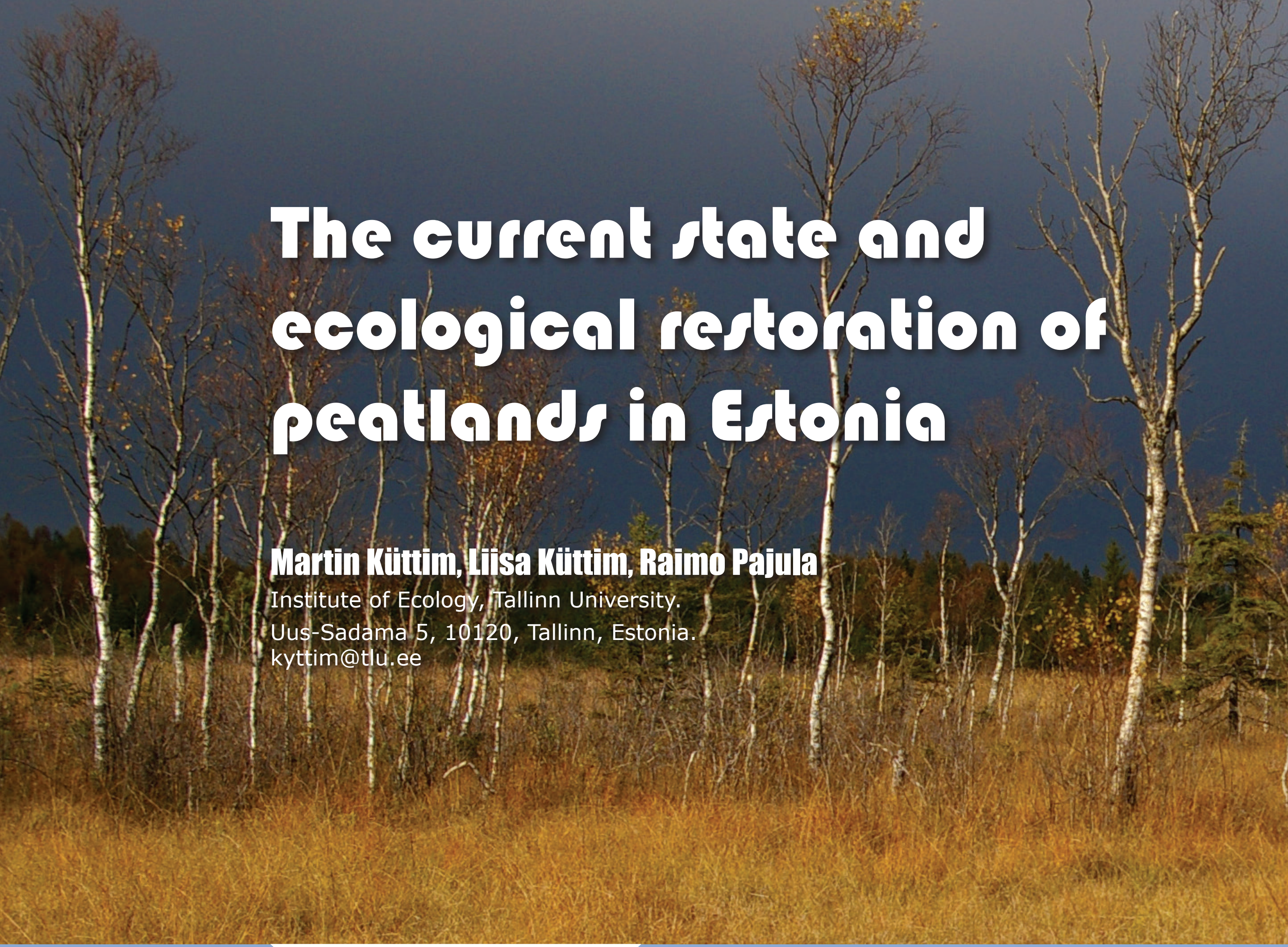

The current state and ecological restoration of peatlands in Estonia

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Abstract

Peatlands are globally important ecosystems for their habitats, carbon sink and freshwater reservoir functions. Estonia is among the most peatland-rich countries worldwide with ca 20% (9,150 km^2) of its land area covered with peat soils. Majority of these peatlands, however, are altered by the drainage for the agriculture, forestry and peat extraction that has led to a degradation of peatland ecosystems, and declined their functioning. The rapid loss of peatland habitats, subsidence of peat soils and carbon emissions after water level drawdown have highlighted the need for the ecological restoration of drained peatlands. Although the first restoration attempts in the early 2000s in Estonia covered only minor areas, the current increase of restoration projects in quantity and quality has been promising, and the aim to restore 10,000 ha of degraded sites in Estonia for 2020 is likely to be implemented.

Key words

Peatlands, mires, bogs, fens, Estonia, ecological restoration, drainage, *Sphagnum*, peat, cut-away peatlands, wetlands, greenhouse gases.

Calcareous tufa-forming species-rich fens are among the rarest and the most threatened wetland types worldwide. Paraspõllu fen in Northern Estonia. (Photo: Martin Küttim).

Introduction

Peatlands are an inherent element in the Estonian landscape. In addition to their high areal cover, their role in the history and the controversial meaning to people have made them symbolic. While peatlands have been seen as an „abscesses of the landscape" due to their wetness and infertility in the past, their value is acknowledged today for buffering the water fluctuations, relieving the effects of climate change, providing habitats for the wildlife, and offering the aesthetic value and recreational possibilities for people. Consequently, the peatlands that once were drained for forestry and agriculture with hard work are now restored back as close as possible to their natural state with an equal effort. In this paper, we will provide an overview about the current state of peatlands in Estonia, and the results of recent restoration activities.

Peatlands of Estonia

Peatlands cover only 3% of the terrestrial landscapes of the World, but contain one third of global soil carbon stocks and 10% of fresh water (Rydin & Jeglum 2013). They are fascinating ecosystems, where waterlogged and anaerobic conditions have favoured the accumulation of organic matter from only partly decomposed plant remnants. Peatlands form where the precipitation exceeds the evaporation, and where the water does not infiltrate to the underlying soil deposits. The pristine peatlands – mires – are ecosystems, where accumulation of organic matter – peat – continues, and the characteristic vegetation exists. Generally, mires start to develop from the minerotrophic conditions – the fen stage – but become less and less mineral rich, as the growing peat layer isolates plant roots from the mineral rich ground water, and make them fed only by nutrient-poor precipitation. The mire has reached to the bog stage (photos 1 & 2).

Photo 1. The vegetation of open bogs is dominated by grasses and Sphagnum mosses. Marimetsa bog in Western Estonia. (Photo: Martin Küttim) (p. 148).

Photo 2. One of the last remaining parts of Pääsküla bog at the edge of the City of Tallinn, where the bog vegetation has remained. The majority from the original 947 ha of the bog has been drained for forestry and peat extraction. (Photo: Martin Küttim) (p. 149).

The formation of mires in Estonia started after the last Ice-age about 10,000 years ago in the preboreal climatic period (Valk 1988). The vast majority of the peatlands, however, started to form 3000–7000 years ago (Ilomets et al. 2007). In relation to its area, Estonia is the second-most peatland-rich country in the World with about 20.2% of its territory (9,150 km^2) covered with peat soils (Paal & Leibak 2011) that are distributed over the territory of Estonia (figure 1). However, the pristine mires with continuing peat formation account only for the quarter of this area. The majority of Estonian peatlands have been drained for forestry, agriculture and peat extraction, and even the pristine sites are often influenced by the drainage. Consequently, the area of mires has declined to only half of its extent in the early 20th century (Laasimer 1965; Paal & Leibak 2011). Currently, the pristine fens occupy not more than 42,300 ha, undamaged transitional mires cover ca 40,000 ha and bogs ca 151,200 ha – all together 5.3 % of the Estonian territory (Paal & Leibak 2011). About 229,000 ha of Estonian mires are under protection (Paal & Leibak 2011).

Fig. 1. The distribution of mires in Estonia: paludified forests, open and wooded mires (p. 149).

Peat is among the most important natural resources in Estonia that is currently extracted here from 200 km^2, about 1 million tons each year (Kohv & Salm 2012). With that amount, Estonia is the 3rd or 4th largest exporter of peat in the World. The overall peat stocks of Estonian peatlands are approximately 2.37 billion tons (Ilomets 2005), but they vary in their rate of decay and botanical composition. The deepest recorded thickness of peat deposits is 18 m, the average thickness is 3 to 4 m (Orru, 1995). The mean annual peat formation varies regionally, between peatland types and even within the same peatland (Paal & Leibak 2011). Although the overall peat formation of Estonian peatlands is 0.92-1.42 million tons per year (Ilomets 2005), peat is generally considered to be a fossil fuel rather than a renewable resource. Nowadays, as peat is a major substrate for the modern horticulture, the vast quantities of peat extracted in Estonia are exported to the Western Europe and elsewhere. In addition to a growth substrate, peat has been an important resource for energy (e.g. peat briquettes and milled peat), and an underlying substrate for the livestock (Paal, J. 2011).

The ecological importance of mires and their numerous relevant functions are generally well acknowledged. Firstly, mires have a great hydrological importance. They preserve and purify the water, and mitigate the consequences of flooding and drought periods. Secondly, mires can relieve the climate change by accumulating atmospheric carbon through the peat formation. Thirdly, peatlands provide habitats for various species (Joosten & Clarke 2002). The drainage of mires will alter all these functions, but the local need for the additional land for agriculture and forestry, and an international necessity for peat as a fuel and for horticultural substrate have made the water level drawdown inevitable (Paal, J. 2011). The drainage network in Estonian peatlands is dense, thousands of kilometres in total (Ring et al. 2017). The water level drawdown by the drainage systems has the most visible effect on mire functioning (photo 3). Firstly, as the water level lowers, the range of the aerated layer of the topmost peat will increase. That will enhance the decomposition processes, and increase the carbon emissions to the atmosphere. The peat layer will consequently subside. Secondly, water level drawdown will alter the plant communities. Plant communities inherent to mires, which are dominated by e.g. peat mosses and sedges, will be replaced by other plant communities common in drier habitats (Rydin & Jeglum 2013). Moreover, the invasion of tree stands takes often place (Sarkkola et al. 2010). The altered habitats are not suitable for the mire fauna as well. Thirdly, the altered water regime does not buffer the water fluctuation any more, leaving the rivers starting from the mires dry during the drought periods. These water bodies can also be polluted with organic sediment, biogens, and the fish catch is likely to decline (Worral & Burt 2007).

Photo 3. A ditch draining the cut-away peatland. (Photo: Raimo Pajula) (p. 150).

Ecological restoration of peatlands: aims and practices

The activities of ecological restoration are designed to convert the degraded or destroyed ecosystems back to as natural state as possible (Similä et al. 2014). In Northern Europe, the restoration activities are applied on several types of peatlands: firstly the cut-away peatlands, where the vegetation is absent or scarce; secondly the mire margins, which have forested due to drainage; and finally bogs, fens and transitional mires that suffer from drainage as well. In most types of degraded peatlands, the natural recovery is generally extremely slow. Hence, the restoration measures are to be applied to reform the plant communities inherent to mires (Joosten 1992).

The crucial task for the ecological restoration of any type of peatland is to rise the water level close to the ground surface, so that it would favour the growth and development of mire plant communities, restore the peat accumulation, and concurrently turn the peatland from carbon source back to carbon sink (Kohv & Salm 2012). For that, the ditches will be dammed or even filled. Dams made of peat, wood or artificial material enable to regulate the water level in the peat to a height, where it enhances the restoration processes in the peatland, but do not flood e.g. the neighbouring forests and fields (Similä et al. 2014). Moreover, sometimes the clear-cutting of tree stands is also necessary for the restoration. Usually this has to be carried out in the sites that were originally open mires according to old maps and aerial photographs, but have forested due to drainage (Masing 2018).

After the end of active peat extraction, cut-away peatlands are left. They have a little or even no vegetation, so that the restoration of these sites can be extremely challenging. The self-recovery of the mire vegetation at these sites is hindered by a major fluctuation of water level and ground temperatures, low pH and CO_2 levels (Grootjans et al. 2009). Since these sites are large and with low cover of vegetation, they are prone to be affected by frost heaving, which reduces the re-vegetation potential as well (Rochefort & Lode 2006). Thus, the cut-away peatlands are among the first priority to restore, as the bare peat layer with no vegetation and low water table is highly inflammable, remarkable source of CO_2 emission, and inappropriate as habitats, but in case of successful restoration cut-away peatlands can carry the same values as pristine mires (Kohv & Salm 2012; Masing 2018). For that, cut-away peatlands need careful human intervention.

The growth of *Sphagnum* mosses – a dominant element in the vegetation of bogs – is a major contributor to the peat formation and carbon accumulation in bogs (photo 4). Thus, establishing a *Sphagnum* cover and enhancing its growth is a crucial task during the restoration of cut-away peatlands. The expansion of *Sphagnum* cover is more rapid and successful, if the *Sphagnum* fragments are transferred from a donor area ("Canadian method"). *Sphagnum* growth in length and biomass depends on various factors, such as temperature, precipitation, shading, water level, nutrient concentrations etc (Krebs et al. 2016). Climatic parameters cannot be usually altered by restoration activities, but eg. balancing the water level near the surface and nutrient additions could enhance *Sphagnum* growth and distribution in the restoration sites. If these activities are successful, the *Sphagnum* growth in length and biomass at the restoration site could even exceed the growth values at the pristine sites, but it can vary between the *Sphagnum* species and years (Krijer 2017). Nevertheless, restoring the carbon sequestration function of a peatland can still take 50 years or more (Samaritani et al. 2011). Also, despite the relatively high *Sphagnum* cover, these areas are more sensitive to inter-annual changes in the water level compared to the neighbouring pristine sites (Wilson et al. 2016).

Photo 4. Sphagnum mosses are an inherent genera of ombrotrophic peatlands – bogs – and the main contributors to the formation of peat. (Photo: Martin Küttim) (p. 153).

Ecological restoration of peatlands in Estonia

The majority of Estonian peatlands have been drained and thus do not function as pristine mires any more. Peatlands have been drained already from 17th century in Estonia (Paal, J. 2011). Intensive agricultural drainage of fens started at the end of 19th century. In 1960-80s the annual forestry drainage at peatlands was 15,000-20,000 ha (Valk 1988). 150,000 ha of peatlands were drained in Estonia between 1969 and 1975 alone. Now, according to the governmental development plan for the nature protection, the state aims to restore at least 10,000 ha of them for 2020 (Masing 2018). The major activities at the restoration sites are conducted by the State Forestry Agency (RMK), and advised and monitored by the universities (Tallinn University, University of Tartu) and NGO-s (Estonian Fund for Nature). For 2018, at 2497 ha of peatlands the restoration activities have already been completed (figure 2), and another 4773 ha is currently being restored (Masing 2018). Therefore, the schedule for the restoration activities is extremely intense, and already some experience exist.

Fig. 2. The shares of peatland types restored in Estonia 2011-2018 (Masing 2018) (p. 154).

The majority of already rewetted sites in Estonia are the margins of ombrotrophic and mixotrophic peatlands – bogs and transitional mires – because these are potentially more prone to restore only after damming the ditches and raising up the water level than other damaged peatland types (Similä et al. 2014). The water in bogs originates only from the precipitation, and thus its vegetation is less sensitive to the composition of water chemistry. Such practices were carried out for the first time in 2004–2005 at Luitemaa nature reserve, where dams were built on drainage ditches in Tolkuse bog (Kaitstavate... 2015). The first major restoration project took place in Soomaa National Park, where the south-east part of Kuresoo bog (80 ha), where the natural water regime was affected by drainage, was restored in 2008-2013. The main restoration activity was to close up the drainage system by damming (additional dams were created in 2015). Experimentally, deforestation was carried out (Kaitstavate... 2015). The research prior to the rewetting and deforestation was thorough and the restoration was successful, but with only few water level loggers, the post-restoration monitoring has been minor. The major restoration activities will continue in Soomaa National Park, where 1290.5 ha are currently being restored and 231.8 ha already completed (Masing 2018). The other major restoration sites of bog margins concentrate on Endla mire complex, Muraka bog, and mires in Luitemaa and Alam-Pedja nature reserve.

Restoring minerotrophic peatlands – fens – is a more complex issue and needs thorough research prior to damming, because the vegetation of fens depends on the availability of mineral-rich groundwater (Rydin & Jeglum 2013; Similä et al. 2014). Experience for that in Estonia is still scarce, but the construction of the first pilot site in Paraspõllu spring fen (photos 5 & 6) began in 2007 by the Institute of Ecology at Tallinn University to develop and test different methodologies to restore the inherent vegetation in fens. Our studies showed that the recovery of species-rich communities typical to fens are mainly depending on the role of the mineral content of water available to plants and to the extent of the fluctuations in water levels over the years. Currently, the first degraded fens in western Estonia have been rewetted: Viidumäe (35 ha) and Kukka (24.2 ha) spring fens (Kaitstavate... 2015).

Photo 5. Calcareous tufa-forming species-rich fens are among the rarest and the most threatened wetland types worldwide. Paraspõllu fen in Northern Estonia. (Photo: Martin Küttim) (p. 155).

Photo 6. Fertilisation and mowing experiment in Paraspõllu fen in Northern Estonia in order to find the methodology for restoring the natural Carex-dominated fen community. (Photo: Raimo Pajula) (p. 155).

The most difficult task – but perhaps the most important – is to rewet and revegetate the cut-away peatlands (photos 7a & 7b). Although the Estonian laws oblige the miners to re-cultivate the area after peat extraction, the vast areas of cut-away peatlands were abandoned at the end of the Soviet era in Estonia, and need to be re-cultivated by the state now – almost 10 000 ha in total (Kohv & Salm 2012). There, in addition to wetting, the diaspores of *Sphagnum* mosses need to be sown in order to enhance the development of vegetation inherent to mires (Kohv & Salm 2012; Similä et al. 2014). The first experience with reforming the plant communities in abandoned peat extraction sites took place in Nigula Nature Reserve, where cranberries were established (274 ha) to the exhausted peat extraction site in 1967-1984. The aim of the work was berry production but this created conditions for the returning of the bog ecosystem as well. Today, the area is covered with plants typical to bogs (Paal, T. 2011). As for the restoration of bog margins, the planned rewetting of a cut-away peatland was also conducted for the first time in Luitemaa nature reserve in 2004–2005, where *Sphagnum* sowing was tested in Maasikaraba cutaway peatland (Kaitstavate... 2015). The Institute of Ecology at Tallinn University established the first test areas to find a suitable methodology for restoring the abandoned peat extraction fields in Viru bog in Lahemaa Natural Park in 2005 (photos 8a & 8b). The restoration activities were implemented there 2011-2013. Currently, three cut-away peatlands have been rewetted in northern Estonia, 187 ha in total: Hara, Viru and Rannu cut-away peatlands (Masing 2018). In all three sites, the ditches were dammed andthe trees removed, but *Sphagnum* mosses were sown only in Viru (Kaitstavate… 2015).

Photos 7a and 7b. Hara restoration area at the former cut-away peatland in Northern Estonia, where the restoration activities took place 2011–2013. Sphagnum mosses and tussock cottongrass (Eriophorum vaginatum) are returning to the peatland. The lower flooded areas are favourable habitats for wetland birds. (Photoes: Martin Küttim & Raimo Pajula) (p.156).

Photo 8a and 8b. Viru restoration area at the former cut-away peatland, next

to a natural bog in Northern Estonia. The restoration activities took place there 2011–2013. Even though seasonally flooded, the area still dries out during the summer. (Photoes: Martin Küttim & Raimo Pajula) (p. 157).

Restoration experiments by the Institute of Ecology at Tallinn University

Institute of Ecology at Tallinn University have relatively long traditions in studying the functioning of mire ecosystems, especially bogs, calcareous fens and spring mires. In 1990s formed so called "peatland group" lead since then by Mati Ilomets. Research concentrated in 1990s on the hydrology and ecosystem functioning of bogs, and also on the ecology of *Sphagnum*. In 2000s we started studies about the impact of drainage on the mire water regime and plant communities to clarify the extent and strength of the drainage impact to various mire types. At the same time studies of the ecology of the calcareous fens started. Studies of fens were concentrated to the relations between plant communities (species composition), water regime, and soil and water chemistry.

Additionally, the peatland group of Institute of Ecology has conducted numerous applied studies including compiling peatland use strategies, inventories and monitoring of mires, monitoring and state reporting of condition of Natura habitat types, inventories of abandoned peat extraction areas, management plans for mire reserves etc.

Studies of cut-away peatlands started in the early 2000s. The experiments of recolonization *Sphagnum* mosses on the cut-away peatlands started in 2005 on three sites with various hydrological conditions and residual peat characteristics: Viru bog, Seli bog, and Ohtu bog. The "Canadian method" was applied on the test plots - *Sphagnum* fragments were sown on the bare peat. Various *Sphagnum* species and species mixtures, also mulching (covering by straw) technologies and fertilization were tested to find the most successful restoration technology for the Estonian conditions. Results indicated that the succession of the restoration (*Sphagnum* carpet formation) is highly site-specific, and depending on numerous environmental parameters, including weather conditions on the following years that can be critical for the restoration success.

During the last decade, we have also studied the restoration techniques for calcareous fens and spring mires, a highly disturbed mire types in Estonia. The main test area has been Paraspõllu mire with calcareous fen and spring fen communities. Restoration of mineral rich fens and spring mires demand specific knowledge about chemical processes and nutrient cycles in relation to water regime. The rise of water table at strongly drained areas can release nutrients (especially phosphorus) to the water bodies, and can cause unfavourable changes also in the plant communities. Drained fens are often dominated by purple moor-grass (*Molinia caerulea*) that by forming high tussocks occupies the space, and outcompetes natural fen species. To restore natural *Carex*-dominated fen communities, we tested cutting off the purple moor-grass tussocks. Together with the rise of the water table, the results were promising, and the signs of the ecosystem recovery were observable already in few years.

Conclusions and future perspectives

In 2011-2018 the state, universities and NGO-s have jointly finished the restoration activities on 2330 ha, and on 5000 ha the work currently continues (Masing 2018). During that time, the knowledge and experiences gained will enable to start the work on bigger and more complicated sites. The ongoing restoration projects will continue, as well as the work on the new sites is about to start. 89 degraded peatlands in total are listed to be restored in 2016-2023, all together more than 22,000 ha (Kaitstavate... 2015).

The majority of the finances for the restoration activities come from the EU structural funds. For example, a major contribution to restoring the degraded peatlands in Estonia will be given by two extensive Life projects. The first one, "Life Peat Restore", is a joint project between Estonia, Latvia, Lithuania, Poland and Germany, where Tallinn University is a partner, and that in Estonia aims to restore 3343 ha of drained peatlands in Läänemaa Suursoo mire (photos 9 & 10). The vast area contains several types of peatlands, such as degraded calcareous fens, active raised bogs, bog forests, western taiga and deciduous swamp woods. The peat accumulation has halted in majority of these. The overall length of the ditches in the restoration site is 45 km. To raise the water level close to the surface, tens of kilometers of ditches will be filled with peat and more than hundred wooden and peat dams will be constructed. The project lasts 2016–2021.

Photo 9. The restoration area in Läänemaa Suursoo mire, where the restoration activities will take place in 2019. The plots for the monitoring of vegetation can be seen from the photograph. (Photo: Raimo Pajula) (p. 158).

Photo 10. Frost in the Läänemaa Suursoo mire. (Photo: Raimo Pajula) (p. 159).

The other Life project, "Conservation and Restoration of Mire Habitats", aims to restore six peatlands in central and NE-Estonia (about 5800 ha in total), and is jointly conducted by the Estonian Fund for Nature, University of Tartu and Archaeovision NGO. Within this project, 240 km of ditches will be dammed or filled. The project areas include 50 ha of cut-away peatlands in nature conservation areas, and 3450 ha of Natura 2000 priority habitats, including active raised bogs, bog woodlands, deciduous swamp woods and western taiga. The project lasts 2015-2020.

The future restoration projects concentrate on the peatland sites with high importance and current negative impact on the environment (including greenhouse gases), but also to sites with high restoration potential and cost efficiency. In addition, more attention will be given to fens, especially to spring fens, which are more complicated to restore than bog margins, but due to the small area of the pristine sites are not enough to ensure the habitats for the inherent spring fen species in Estonia (Kaitstavate... 2015).

The restoration activities enhance the recovery of the peatland ecosystems after drainage, but also improve our knowledge about them. Knowledge-based restoration projects are generally successful, and from the nature conservation perspective, the investment is worth its value.

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